BIM FOR BRIDGES AND STRUCTURES

TPF-5(372)

BIM for Bridges and Structures Final Report

Summary of Study Outcomes

March 2024

Version 2.1 – Final Report

This report was prepared for with the participation of the Iowa Department of Transportation and the United States Department of Transportation, Federal Highway Administration as a deliverable of the project TPF-5(372): “Building Information Modeling (BIM) for Bridges and Structures.”

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16. Abstract
In 2017, the AASHTO Committee on Bridges and Structures (COBS), Technical Committee T-19 on Software and Technology organized the pooled fund study TPF-5(372) BIM for Bridges and Structures. The pooled fund objective was to develop a standard way of exchanging 3D models and other digital data using an open, non-proprietary format. The TPF-5(372) study was a multi-year and multifaceted project with various areas of focus. The main technical focus was developing an open data standard for software developers to incorporate into their software products that are utilized by the US bridge industry. This final report organizes the formal deliverables of the study as "direct outcomes" and summarizes the product, its purpose, significance, and outcomes. The report also discusses the indirect outcomes of the study, summarizing the connection to the study, the significance, and the outcome. The appendix includes the document-based products of the study. Finally, this report discusses the next steps that should follow the TPF-5(372) study. These next steps would continue the work undertaken in this study and govern and steward its products.

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The authors of this final report especially recognize the participants from the pooled fund partners, consisting of the state departments of transportation of Alabama, California, Delaware, Florida, Georgia, Iowa, Illinois, Indiana, Kansas, Michigan, Minnesota, Mississippi, North Carolina, Nebraska, New Jersey, New York, Ohio, Oklahoma, Pennsylvania, Texas, Utah, Vermont, Washington, Wisconsin and the Federal Highway Administration.

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Executive Summary

In 2017, the AASHTO Committee on Bridges and Structures (COBS), Technical Committee T-19 on Software and Technology organized the pooled fund study, now known as TPF-5(372) BIM for Bridges and Structures. The pooled fund objective was to develop a standard way of exchanging 3D models and other digital data using an open, non-proprietary format.

The TPF-5(372) study was a multi-year and multifaceted project with various areas of focus. These included research, stakeholder engagement and education, and economic analysis. However, the main technical focus was developing an open data standard for software developers to incorporate into their software products that are utilized by the US bridge industry.

This final report organizes the formal deliverables of the study as “direct outcomes” and summarizes the product, its purpose, significance, and outcomes. The report also discusses the indirect outcomes of the study, summarizing the connection to the study, the significance, and the outcome. The appendix includes the document-based products of the study.

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List of Acronyms

AASHTO	American Association of State Highway and Transportation Officials
ABDD	AASHTO Bridge Data Dictionary
AbRV	Alignment-based Reference View
AGC	Associated General Contractors of America
ARTBA	American Road and Transportation Builders Association
BIM	Building Information Modeling
bSDD	buildingSMART Data Dictionary
bSI	buildingSMART International
bSUSA	buildingSMART United States
COBS	Committee on Bridges and Structures
FHWA	Federal Highway Administration
J-STAN	Joint Subcommittee on Data Standardization
JTCEES	Joint Technical Committee on Electronic Engineering Standards
IDM	Information Delivery Manual
IDS	Information Delivery Specification
IFC	Industry Foundation Classes
MVD	Model View Definition
NSBA	National Steel Bridge Alliance
TPF	Transportation Pooled Fund
US	United States
UTS	Unit Test Suite
XML	eXtensible Markup Language

Glossary of Terms

Building Information Modeling (BIM): According to the National BIM Standard-US Version 3, BIM is a term which represents three separate but linked functions. (1) *Building Information Modeling* is a business process for generating and leveraging building data to design, construct and operate a facility during its lifecycle. (2) *Building Information Model* is the digital representation of physical and functional characteristics of a facility. (3) *Building Information Management* is the organization and control of the business process by utilizing the information in the digital prototype to affect the sharing of information over the entire lifecycle of an asset.

buildingSMART Data Dictionary (bSDD): A specific Data Dictionary based on EN ISO 12006-3:2016 that is maintained by buildingSMART International. ISO 12006-3:2016 specifies a language-independent information model which can be used for the development of dictionaries used to store or provide information about construction works. It enables classification systems, information models, object models and process models to be referenced from within a common framework.

Data Exchange: Exchange of data between sources, often involving the transformation of the structure from one schema to another. A data exchange differs from an information exchange because information gives meaning to the data that is being exchanged.

Document Exchange: Documents and other information that give meaning and context of how to use the data communicated in a data exchange. Information includes all supplemental documents and procedures that give data context and meaning. Generally, these are communicated in PDF files or paper documents and may consist of design drawings, specifications, reference documents and other information.

Industry Foundation Classes (IFC): An international standard (ISO 16739-1:2018) for data sharing in the construction and facility management industries. It is both an open data specification and an open data format to describe, exchange and share information.

Information Delivery Manual (IDM): A human-readable document that captures the business process and gives detailed specifications of the information that a user fulfilling a particular role would need to provide at a particular point within the lifecycle of a built asset. The methodology and format for IDMs is published as ISO 29481-1:2016.

Information Delivery Specification (IDS): A machine-readable document that defines how objects, classifications, properties, and even values and units need to be delivered and exchanged. The IDS is used to define Level of Information Need and verify that a model meets the requirements.

Information Exchange: The set of information passed between two sources, which include data along with documents and other information that give meaning and context of how to use the data.

Model View Definition (MVD): A subset of the IFC schema that is needed to satisfy many use cases within a technical domain. For example, the Alignment-based Reference View.

Process Map: The visual representation of a process model in a graphical workflow diagram. Modeling notation, such as Business Process Model and Notation, is used to represent the various objects in the process model.

Use Case: A specific event of a broader defined process, in which there is only one way of completing a specific goal.

Chapter 1 – Study Overview

This chapter provides general overview information describing the TPF-5(372) BIM for Bridges and Structures study.

Background

Previous studies and pilot BIM delivery projects have concluded that the US bridge industry lacks a unified file format for exchanging 3D models and other digital data. Designers, contractors, fabricators, and owners all use different software platforms, which are not typically interoperable. Currently, it is not easy to transfer digital information between different stakeholders. The solution to this is establishing a standard that will allow stakeholders to share, view and store data files in an open, non-proprietary format across all platforms and phases, from planning to design to operations and maintenance.

In 2017, the AASHTO Committee on Bridges and Structures (COBS), Technical Committee T-19, decided to tackle this issue. The result was the creation of the pooled fund study TPF-5(372) *BIM for Bridges and Structures*. The pooled fund objective was to develop a standard way of exchanging 3D models and other digital data using an open[1], non-proprietary format. This is a necessary first step to set the stage for a successful model-based approach to designing and constructing bridge projects.

Industry Foundation Classes

Industry Foundation Classes (IFC) is the open, non-proprietary data schema selected by the pooled fund members as a basis for developing the aforementioned software standard. IFC has existed since the 1990s; however, it only began to support linear infrastructure (such as roads and bridges) with the release of IFC 4.1 (which provided support for alignment-based layout) in 2014 followed by IFC 4.2 (which provided initial support for bridges, highways, rail, and ports) in March of 2019. The IFC versions 4.1 and 4.2 have been withdrawn. The linear referencing and infrastructure extensions introduced in 4.1 and 4.2 respectively have been revised since their introduction and incorporated into IFC 4.3. Over the course of the TPF-5(372) project, the IFC 4.3 standard has evolved through four release candidates and two technical addenda and IFC 4.3 ADD2 is the only ISO certified version[2].

IFC is developed by buildingSMART International (bSI) and published as an International Organization for Standardization (ISO) standard. bSI operates various technical committees and national chapters to represent the vast international stakeholders in the development of the interdisciplinary standard. At the time of this report, IFC 4.3 – which includes support for four infrastructure domains including bridges – was approved and in the process of being published as ISO/FDIS 16739-1:2024.

[1] "Open format" means that the file format can be incorporated by any software vendor; it does not mean that the content of a file is accessible to all parties.
[2] Complete history of the evolution of IFC versions is available at https://technical.buildingsmart.org/standards/ifc/ifc-schema-specifications/

Study Objectives

The TPF-5(372) study was a multi-year and multifaceted project with various areas of focus. These included research, stakeholder engagement and education, and economic analysis. However, the main technical focus was developing a software standard for software developers to incorporate into their software products that are utilized by the bridge industry and that could become required deliverables by state DOTs. The tasks associated with this research can be classified into five categories, as described below.

Investigation and Exploration

These tasks used research strategies to establish the context for the data standard. This included identifying comparative data standard implementation efforts, collecting terminology, creating a glossary of terms, and exploring the return on investment for implementing BIM.

IFC Development

These tasks focused on developing an IFC-based interoperable standard solution for US bridges. The activities were defining process and use case definitions, publishing an Information Delivery Manual as an AASHTO guide specification, developing technical solutions in parallel with the international development of the IFC 4.3 standard, and developing software implementation resources.

Communications

These tasks focused on creating industry cohesion around the need for and adoption of an IFC-based standard for bridges. The activities included developing an updated roadmap, liaising with bSI to coordinate national efforts with the international framework, outreach to US bridge industry stakeholder (e.g., National Steel Bridge Alliance, AASHTO committees), providing recommendations on the governance of the standard being developed, and developing a software vendor engagement group to manage expectations and promote and provide support for implementation.

Education and Engagement

These tasks focused on educating and engaging industry on the outcomes of the work. Activities included creating a stakeholder engagement plan, developing a website, external technical coordination with targeted stakeholders, and select educational products.

Economic Analysis

These tasks focused on research into the return on investment (ROI) of implementing BIM for Bridges and Structures and any available tools that can be used by State DOTs to quantify the ROI of their planned investments.

Chapter 2 – Study Outcomes

The study had many outcomes that were planned deliverables, as well as other outcomes that were directly or indirectly influenced by the successful completion of the Study. This chapter introduces both direct and indirect outcomes and states the purpose and significance of each.

Direct Outcomes

This section describes the direct outcomes of the study, which were specific deliverables provided by the consultant team.

AASHTO-buildingSMART Engagement Memo

Type: Memo Completion: Q2-2019, update Q1-2020

This memo, found in Appendix 1, describes the status of work to develop a relationship between COBS T-19 and bSI. bSI is an international organization based in Europe and operates on a fee-based membership model. Members are eligible to provide consultation and vote on the standards developed by bSI and published through the International Organization for Standardization (ISO).

Purpose

A working relationship between COBS T-19 and bSI was an important component of standards development for both AASHTO and bSI in regard to the use of bSI standards (e.g. IFC) for the infrastructure domain. AASHTO made a significant investment in developing a national IFC-based standard and needs to have representation within bSI.

Significance

There are legal and procedural challenges for AASHTO funding a significant membership fee in an international organization. However, a relationship is important to maintain the US national standard. The memo explored initial efforts to work around direct membership via participation in the US Chapter of bSI, but the US chapter was not participating fully in international development efforts, particularly related to infrastructure.

Outcomes

The second memo, found in Appendix 2, provided updates on the status, including a change in how the US Chapter of bSI operated, the publication of AASHTO Administrative Resolution AR-1-19, which formally adopted IFC and established the Joint Subcommittee on Data Standardization (J-STAN), and authorized AASHTO to pursue a formal relationship with bSI.

BIMforBridgesUS.com Website

Type: Website Completion: Q3-2019, updated periodically

A stand-alone website that is maintained by the TFP-5(372) contractor.

Purpose

The website was established to communicate externally with the industry at-large regarding the study and its outcomes.

Significance

The website provides a landing page with basic information regarding the TPF-5(372) study and open standards, as well as a copy of the current version of the roadmap infographic. There are three additional pages, one with a calendar of events and one with an organized collection of resources of interest to the wider community, including select work products of TPF-5(372).

Outcomes

The website is available at https://bimforbridgesus.com/.

Terminology Database Memo

Type: Memorandum Completion: Q4-2019

This memo, found in Appendix 3, provided an introduction to the terminology database and the process of creating a Glossary of Terms. An example Glossary of Terms was also provided.

Purpose

The intent of the terminology database was to be the main repository of all the terminology gathered throughout the TPF-5(372) project. The memo communicated the process, purpose, and progress in collecting terminology.

Significance

The database collected terms, synonyms, and definitions from existing sources and captured the citation. This enabled the development of a glossary of terms that reflected the most suitable existing definition rather than developing new definitions. The memo provided a glossary of terms for use in many documents developed as part of the project and as a reference for the technical representatives of the pooled fund study.

Outcomes

During Task 1, the database was established and populated with an initial collection of approximately 400 terms. This terminology was expanded several times—to 2000 terms at the time the memo was produced—and subsequently used in other tasks. Once the glossary of BIM terms was developed and the bridge-related terms moved into the information requirement that forms part of the IDM and then the Data Dictionary, the database became obsolete and was archived.

Software Vendor Engagement Plan

Type: Report Completion: Q4-2019

This plan, found in Appendix 4, established the components and timetable to enable effective engagement with the software community in the US infrastructure market. The Software Advisory Group was established as the primary interface between software vendors, the consultant team, and pooled fund members.

Purpose

The overall purpose of the engagement was to support vendors to create software solutions to facilitate the development, implementation, and adoption of new BIM-based workflows and standards for

AASHTO members in the design, procurement, construction, and operations of bridges and associated structures.

Significance
The consultant team used the advisory group to pass project information along to vendors interested in participating in the project, as well as acting as a communications conduit between the pooled fund members, the consultant team, and the vendors. As the project progressed over its 5-year span, the support needs for vendors implementing the new workflows and standards was coordinated from within the advisory group.

Outcomes
The plan provided a reference to all project participants during the life of the project, guiding expectations and outcomes from all parties in clear terms. The plan's execution was successful and will serve as the template for software vendor engagement in the TPF-5(523) BIM for Bridges and Structures – Phase II study.

Software Vendor One-on-One Meetings and Results Memo

Type: Memo Completion: Q4-2020

The memo, found in Appendix 5, summarizes the outcomes of one-on-one meetings held with software vendors participating in the software advisory group. Nine out of the twenty-two software vendors involved in the advisory group at that time participated in a one-on-one meeting.

Purpose
The purpose of these meetings was to foster an open, frank, and semi-confidential dialog to help the consultant team assess the status of vendors moving forward.

Significance
The one-on-one meetings were a way to validate the Software Vendor Engagement Plan and assess the feasibility of the overall project goals. It was also an opportunity to assess how committed vendors were to implement IFC, identify issues that the consultant could help resolve, and identify support needs.

Outcomes
In general, those software vendors that participated in the one-on-one discussions indicated that the Software Vendor Engagement Plan, project goals, and timeline were feasible. There was a generally positive attitude from the vendors as they were encouraged by the continued open communications and documentation from the project team. However, considering the low number of vendors who chose to participate in the discussions, the consultant identified the need to engage in more direct outreach and communication with those vendors that did not participate.

Investigation and Exploration Report: Common Data Standard Efforts

Type: Report Completion: Q1-2020

The report, found in Appendix 6, provides an overview of related data standardization efforts. It considered general industry standards such as IFC, transportation-specific standards, such as FHWA's

Model Inventory of Roadway Elements, and bridge-specific standards such as AASHTO's *Manual for Bridge Element Inspection*.

Purpose

The report documents the outcome of research to find comparative implementation efforts of common data standards and describes the approach taken to capture terminology and make recommendations for the project activities.

Significance

The report documented comparable industry efforts that require a shared vocabulary and definition of terms.

Outcomes

The report on comparable industry efforts illustrated where IFC fit within the standards landscape and emphasized the need for developing an IFC-based standard for bridges. The terminology collection was used for a memo, glossaries of terms for several documents, and as the foundation of some of the work that went into defining the information requirement in the Information Delivery Manual (IDM).

IFC Development Gap Analysis Report: Analysis of Current IFC 4.2 Efforts

Type: Report Completion: Q2-2020

This gap analysis report, found in Appendix 7, analyzes the differences between the previous Model View Definition (MVD) work done in the FHWA-sponsored project to develop an IFC 4.1-based MVD for bridges, *IFC Bridge Design to Construction Information Exchange (US) MVD,* and the parallel developments at bSI.

Purpose

The main rationale of the gap analysis was to identify whether all functionality that had been defined within the previous US MVD had been transferred to the international work, or whether there are gaps that still need to be addressed.

Significance

In general, the gap analysis identified that almost all definitions that were included in the previous US MVD had been added in parallel to the international IFC definitions, leading to the release of IFC4.1 in 2017. There were only a few minor differences that are elaborated in detail in this report. This framed the approach to the work to develop IFC-based solutions for a US national standard.

Outcomes

The IFC development work carried out as part of the TPF-5(372) study remained in close alignment with international development work. Representatives from the study provided feedback to bSI that was addressed in the work to develop IFC 4.3. Bearings is one example of content incorporated into IFC 4.3 as a result of a gap identified by this report.

Bridge Lifecycle Process Map Validation Report

Type: Report Completion: Q2-2020

This report, found in Appendix 8, documents the outcome of the analysis and validation of the bridge life cycle process map developed by two FHWA-sponsored research projects and most recently published as part of HIF-16-011 “Bridge Information Modeling Standardization.”

Purpose

The bridge lifecycle process map identifies the significant information exchanges that occur over the lifecycle of a bridge. The process map is an important context for developing the IDM and is a resource to create a list of prioritized “use case” exchanges for future IFC development.

Significance

The validation work identified three bridge lifecycle process maps, combined them, and sent the resulting map for external review. The resulting process map represented broader consensus from the bridge community.

Outcomes

The report standardized the exchange definitions and produced an updated process map, titled “Bridge Lifecycle Management Overview Map,” which is found in Appendix 15. These definitions were used for an initial prioritization of exchanges for future IFC development at the annual in-person pooled fund meeting in 2020. (Note that some of the information is contained in interactive features of the PDF that only work in Adobe Acrobat.) The pooled fund members subsequently revisited this prioritization during the annual in-person meeting in 2022. The report will be relevant to the work of the Phase II TPF-5(523) study as well.

Base MVD Recommendation Memo

Type: Memo Completion: Q2-2020

The memo, found in Appendix 9, provided an analysis of the bSI MVD development context and made a recommendation for where to begin to develop a US national bridge MVD.

Purpose

This Pooled Fund study initially planned to develop a US bridge MVD before bSI developed the Information Delivery Specification (IDS) concept and established a policy that limited the number of MVDs that were sanctioned by bSI. Unknown at the time of this memo, beginning in 2022, bSI would support “base MVDs” but not user-defined, or use case-specific MVDs. At the time of this memo, bSI had a standardized, step-by-step procedure for MVD development. However, previously projects had already done a lot of work towards a US national bridge MVD. As a result, the consultant needed to identify the best point at which to step into the bSI MVD process.

Significance

The memo provided a recommendation to base the IFC development work on the MVD referred to as the “Bridge Alignment Reference View” that was understood to be under development by bSI. As the international work evolved, the base MVD became known as the Alignment-based Reference View (AbRV).

Outcomes

While bSI changed its policy regarding user-defined and use case-specific MVDs, the AbRV remains the base MVD that underpins the IFC development work by the consultant to develop a national IDS.

Roadmap Review and Update Recommendations

Type: Report Completion: Q2-2020

This report, found in Appendix 10, prioritized goals and tasks to guide the execution of the TPF-5(372) study.

Purpose

The TPF-5(372) study had several goals and objectives that needed to be carefully sequenced and prioritized to ensure that the IFC development occurred in step with international bSI development and in accordance with the available funds, which were distributed over the duration of the study.

Significance

The report describes the context for the TPF-5(372) study and illustrates where the study activities fit in. It then recommends activities to tackle after the study activities are complete.

Outcomes

The recommendations included establishing a governance body for the data dictionary and IFC-based standard developed by the study, establishing a certification program, and providing ongoing support. These items are still needed. (Note, there is a memo making recommendations for governance and stewardship and an AASHTO committee, J-STAN, which was tasked with governance in AASHTO's AR-1-19 resolution. The Phase II study will address the ongoing support needs. bSI is currently updating the certification program.)

Roadmap Infographic

Type: Infographic Completion: Q2-2020 and subsequent updates

A one-page infographic, found in Appendix 11, communicating the participants in the TPF-5(372) study, the study's overarching objectives, and the roadmap beginning in 2004 with the TransXML schema development and extending to identify future activities after the conclusion of the TPF-5(372) study.

Purpose

The infographic is a tool to communicate the objectives of the study and the broad support for it to the industry at large.

Significance

The infographic is a versatile tool that satisfies several stakeholder engagement purposes.

Outcomes

The infographic has been used innumerable times because it establishes the authoritativeness of the study and demonstrates the long history of work to achieve the study's goals. It has been a useful tool to recruit new study participants and to promote the work of the study. The infographic was a living document that was updated periodically due to the evolving nature of the work. However, the overall vision conveyed in the infographic remained constant.

Stakeholder Engagement Plan

Type: Report Completion: Q2-2020

The stakeholder engagement plan, found in Appendix 12, provided direction on the design and implementation of engagement tools and tactics to be used throughout the study to engage with stakeholders.

Purpose

The primary goals of the plan were to identify key stakeholder audiences and users, assess engagement and communication preferences, offer strategies that will maximize engagement opportunities, and foster adoption of common approach to BIM for Bridges by states.

Significance

The plan was a tool to ensure that all stakeholders were identified and included in outreach activities. It was also a tool to coordinate stakeholder engagement with software vendor engagement.

Outcomes

The plan led to the establishment of a website, a monthly email newsletter, and direct coordination activities. The stakeholder engagement strategy evolved quickly as the work of the study progressed, but it was not considered worth the effort of updating the plan as a nimbler approach to stakeholder engagement was needed.

Proposal for the Creation and Governance of a US Data Dictionary and its Relationship to the buildingSMART Data Dictionary

Type: Report Completion: Q2-2020

A report, found in Appendix 13, that provided suggestions on how the Data Dictionary being created by the TPF-5(372) could be governed and connected to broader national and international efforts.

Purpose

The TPF-5(372) study created a Data Dictionary to describe the information (terms, definitions, and relationships) provided by the IFC standards being developed. The content of this Data Dictionary is intended to be linked directly to the buildingSMART Data Dictionary (bSDD), a service provided by bSI to aggregate and link terms and definitions across domains, geographic, political, and language-specific regions. A governance body is needed to coordinate and maintain the AASHTO Bridge Data Dictionary content in the bSDD.

Significance
While the TPF-5(372) study focused on the requirements of the AASHTO members, the report recognized that input is needed from other related infrastructure industry stakeholder organizations such as FHWA, NSBA/AISC, ACI, PCI, AGC, etc. The report also identifies a need to mitigate several potential intellectual property rights issues (e.g., copyright ownership, usage/licensure, and governance).

Outcomes
The report proposed that a Data Dictionary Working Group be formed by the new buildingSMART USA (bSUSA) chapter for its maintenance and governance, and that bSUSA should be the owner and agency for a United States Data Dictionary (USDD) as it relates to the bSDD. The governance and stewardship recommendations were updated in Q4-2023, and that memo is described below.

Software Vendor Letters of Intent

Type: Letter of Intent template — Completion: Q2-2021

Letters of intent, based on a template found in Appendix 14, addressed to HDR (the study consultant) from various software vendors that lays out the scope of the software vendor's "good faith effort" to implement the US bridge IFC standard.

Purpose
Software vendors were making a significant effort to prepare for and implement IFC within their bridge software products, and AASHTO was making a significant effort to support the vendors through the TPF-5(372) study. The Letters of Intent provided for managed expectations between what AASHTO would provide and the level of "good faith effort" that the vendors would provide in return.

Significance
The letters of intent resolved some uncertainty for the vendors and for AASHTO.

Outcomes
Seven software vendors signed the letters of intent, representing nearly one third of the organizations participating in the software vendor engagement group. However, signing the letters of intent was voluntary. More than seven vendors were actively working to incorporate support for IFC within their bridge software.

Interactive Bridge Lifecycle Management Overview Map

Type: Process Map — Completion: Q2-2020 and subsequent updates

An interactive PDF version of the Bridge Lifecycle Management Overview Map (as amended by the TPF-5(372) study), found in Appendix 15.

Purpose
The document has embedded information describing each model-based exchange that pops up when the reader clicks on the exchange in the process map. However, this functionality is only supported by Adobe Acrobat.

Significance

The interactive PDF provides a detailed description of each activity and each model-based exchange in a convenient and user-friendly format.

Outcomes

The updated process map was used in the Information Delivery Manual (IDM). However, the interactive feature is not available within the published IDM. The process map will be revisited by the TPF-5(523) study in the preliminary work to identify additional exchanges to develop.

Return on Investment Analysis: Literature Review

Type: Memo Completion: Q4-2022

A memo, found in Appendix 16, that summarizes the literature review undertaken to support the development of a white paper describing the benefits and costs of using BIM for bridges.

Purpose

The memo communicated the outcomes of the literature review. The literature review helped to define the parameters of the white paper and was a source of benefit and cost information used in the white paper.

Significance

The memo communicated core concepts such as definitions of “interoperability” and BIM maturity. It described methodologies used to quantify benefits and costs and provided information about previous work to quantify a return on investment (ROI) for BIM adoption and the use of open data standards.

Outcomes

The memo demonstrated the generic benefits of BIM had already been measured. It described some of the challenges for quantifying the ROI associated with implementing BIM and identified some of the strategies for quantifying costs and benefits across an agency’s program as opposed to for a project.

Information Delivery Manual

Type: AASHTO Publication Completion: Q1-2023

The IDM provides a human-readable set of information requirements for the exchange of model-based information to execute the construction of highway bridges in the US. There are subtasks that are supported, including preparing a bid package and initiating fabrication.

Purpose

The IDM outlines the technical process and the required data to be exchanged between the Owner and bridge construction Contractor in the US. (The intent is that this model data be passed through to the Fabricator and Detailer to begin their processes.)

Significance

The IDM is an essential part of the IFC development work, providing a plain-language description of the scope of the exchange and a listing of the information required to satisfy the exchange.

Outcomes

The IDM was balloted by the AASTHO COBS in 2022 and adopted as an AASHTO standard, which led to its publication as *Information Delivery Manual (IDM) for the Design to Construction Data Exchange for Highway Bridges, 1st Edition*. The IDM is available from AASHTO at: https://store.transportation.org/Item/CollectionDetail?ID=241

Return on Investment (ROI) Analysis White Paper

Type: Report Completion: Q4-2023

A white paper, found in Appendix 17, that describes the methodology of conducting an ROI study, introduces the cost and benefit categories and approaches to quantification, describes previously developed ROI analysis tools that can be applied to BIM for bridges, and provides recommendations for addressing methodological issues.

Purpose

The white paper provides guidance to agencies who wish to estimate the ROI of implementing BIM for bridges within their agencies. It provides the information they need to understand the limitations and context for estimating an ROI and prepares them to collect their own data to use in an existing tool.

Significance

There are many studies that address the issue of quantifying benefits and costs of implementing BIM, but they approach the issue generically, or from the perspective of the vertical construction industry. Two studies have focused on highways, but again looking outside the bridge domain. This white paper focuses on the bridge domain.

Outcomes

The white paper provides a qualitative assessment of the benefits and costs of using BIM. It relies heavily on findings reported in the literature and provides an overview of existing tools and resources available for the quantification of benefits and costs. The white paper also identifies the specific data needed to estimate the ROI of using BIM for bridges with one of the existing tools and addresses several methodological issues related to ROI measurement.

Information Delivery Specification (IDS) for the Design-to-Construction Data Exchange for Highway Bridges

Type: Technical Solution Completion: Q4-2023

An IDS is a new open standard developed by buildingSMART International to define IFC based Information Delivery Specifications (https://github.com/buildingSMART/IDS). It is a machine-readable specification of information requirements to automate quality control of IFC data.

Purpose

The IDS for the Design-to-Construction Data Exchange for Highway Bridges (hereafter called "the IDS" because it was the only IDS developed by the study, though more highway bridge exchange IDSs are proposed for the future) is part of the technical specification work and defines the required data for the design to construction exchange for highway bridges. It is an XML file according to the IDS schema definition 1.0 that is expected to be published by bSI in 2024. The IDS can be used by any model checking software with IDS support for quality control of delivered IFC files.

Significance
While the AbRV from buildingSMART is still very broad in terms of domains and use cases covered, the IDS is geared towards the specific needs derived from the “Design to Construction Data Exchange for Highway Bridges” IDM. It thus supports work on the test instructions that could be used in software certification but can also be used for quality control of IFC deliveries for project deliverables.

Outcomes
The result of the work was an IDS-XML file that specifies the whole set of information required for the exchange described by the published IDM.

Technical Solution Summary for the Design-to-Construction Data Exchange Standard for Highway Bridges

Type: Report Completion: Q4-2023

During the course of the TPF-5(372) study, bSI readjusted its technical development framework as laid out in the bSI Technical Roadmap from 2020, which affected the work of the study. This report, found in Appendix 18, explains the role and context of the work conducted by the study and its contribution to facilitate interoperable bridge data.

Purpose
The report is addressed to a technical audience that does not have a thorough understanding of IFC in order to provide a basic understanding of the technical work conducted by the study.

Significance
All stakeholders involved in a project need to have a basic understanding about IFC-based data exchange and how specific requirements such as the “Design to Construction Data Exchange for Highway Bridges” can be delivered according to contract requirements. The report provides necessary knowledge about frequently used terms like AbRV, IDS and bSDD as needed to understand and control the IFC-based data exchange framework.

Outcomes
In addition to explaining the IFC-based data exchange framework—using a brief overview and a one-page graphic—each type of bSI standard and technical solution (namely IDM, bSDD, IFC, AbRV-MVD and IDS) is explained with key facts as well as its status of development and use. This document provides a reference to those who will implement the IFC-based exchange within their software products and workspaces.

Industry Foundation Classes (IFC) Implementation Guide for State Departments of Transportation

Type: Report Completion: Q4-2023

A report, found in Appendix 19, which provides recommendations for conducting activities that will assist State DOTs and other stakeholders to formalize their commitment to the adoption of open data exchange.

Purpose

The purpose of this guide is to provide background to the purpose of implementing IFC-based bridge data exchanges and a guide to how to implement the technical solutions developed by the TPF-5(372) study to facilitate interoperability for the US bridge industry. The guide also provides more general improvements to BIM maturity so that the implementing organizations can optimize the return on their investment in IFC-based standards.

Significance

Agencies need to understand how to implement the outcomes of the TPF-5(372) study within their local standards. The report explains how the study outcomes relate to a State DOT's framework of manuals guidance, and training. The use of IFC-based data exchange depends on stakeholders becoming more mature with their BIM practices to reach optimal benefits. The guide provides examples of additional BIM practice documents such as a Model Development Standards Manual, that agencies can develop to improve BIM maturity within their organization.

Outcomes

The report provides the necessary guidance for State DOTs to improve their BIM maturity and implement the outcomes of the TPF-5(372) study to facilitate interoperable bridge data exchanges.

AASHTO Bridge Data Dictionary

Type: Spreadsheet converted to JSON file format for upload Completion: Q4-2023

The AASHTO Bridge Data Dictionary (ABDD) provides a comprehensive listing of terms, US definitions and properties listed in the IDM. Additional terms, that apply to the overall bridge data exchange process, along with their US definitions have also been included to assist bridge designers during the development of their bridge design model.

Purpose

The ABDD will provide the IFC user with access to US based definitions and properties to be used when exchanging bridge element model data. The properties available in the ABDD have been identified by US bridge engineers as required information that must be available during the development of the bridge model. The ABDD will be a domain within the bSDD service. The bSDD service, when implemented by bridge design software vendors, will give the bridge designer access to the connections, links and properties found in the ABDD.

Significance

The ABDD addition to the bSDD service will provide a connection between the US definitions and properties and the current IFC schema. The ABDD data and its governance is recommended to be controlled by AASHTO, which will provide the US bridge industry with a significant foundation upon which to build the transportation infrastructure's standard data exchange standards.

Outcomes

The ABDD provides the means for the US bridge industry to manage and maintain its standard set of data and its metadata and how it links to the IFC schema. The re-organization of the bSUSA Chapter, and AASHTO's membership therein, has provided an environment where the ABDD can exist and be governed by the US bridge industry. This initial step has greatly increased the potential for other members of the US infrastructure industry to follow step and develop their own data exchange standards.

AASHTO National BIM Standards Governance Technical Memorandum

Type: Memorandum Completion: Q4-2023

A memo, found in Appendix 20, summarizing the various technical products that need ongoing stewardship and governance with updated recommendations based on new developments at bSI and AASHTO following the adoption of AR-1-19, which created a path to bSI membership and established J-STAN.

Purpose

Provides recommendations to AASHTO on how to govern and steward the technical products developed by the TPF-5(372) study. In particular, it summarizes AASHTO's position as a member of bSI and how to use the privileges of membership to steward the standards at an international level.

Significance

IFC is an international industry standard. Its successful use in the US requires that any US national standards be consistent with the evolving international standards.

Outcomes

AASHTO has a considered and recommended path forward to govern and steward the national IFC-based standards. This is a resource for the AASHTO J-STAN and a reference for the TPF-5(523) study.

Unit Test Suite

Type: PDF plans and a spreadsheet Completion: Q4-2023

A collection of detailed construction drawings, in PDF format (sample found in Appendix 21), coupled with IFC mapping specifications in a spreadsheet format. The Unit Test Suite (UTS) will be accessed by software vendors on GitHub at https://github.com/jwouellette/TPF-5_372-Unit_Test_Suite/tree/main. Vendors will provide corresponding IFC files (once validated and deemed "correct") for each Unit Test on the platform as well. Vendors will also be asked to provide native format files for the corresponding complete bridge designs. These will be used for reference by end users and other UTS users.

Purpose

The primary purpose of the UTS is to provide software vendors of bridge modeling applications with a set of modeling and IFC mapping requirements for “workhorse” bridge designs, as specified in the project IDM. These vendors will use the requirements to test and refine the development of functionality within their applications to support the creation of required permutations of bridge elements and overall designs, with the specified level of geometric detail and associated information. In addition, the test instructions specify required IFC schema mappings to these elements and overall designs, including object classes, relationships, and properties (with appropriate values).

The secondary purpose is to provide software vendors with applications that read the resulting IFC files for quantity analysis, quality assurance/control, construction management, and detailing/fabrication, with valid IFC files from the bridge modeling applications to ensure the data can be correctly imported and read, with no important data loss. These vendors will use the test instructions to judge their import results with the different vendor files.

The final purpose of the UTS is to provide a baseline of expectations for software end users – bridge designers, contractors, detailers/fabricators, and owners – on the ability of software to properly model, export, and import bridge designs and their elements. The UTS can be used as a modeling guide for bridge designers, indicating the preferred, as well as optional, levels of geometric detail and associated data and IFC mapping.

Significance

The UTS is a key tool in assisting vendors in development of applications to properly support bridge models, as well as IFC data mapping and file exchange. By providing a common set of specifications, vendors have clear expectations of what modeling conditions need to be supported and how that information is mapped and exported with the correct IFC data structures, as well as any custom conditions and properties. It is also a concrete demonstration to end users that bridge modeling and high-fidelity data exchange are possible with available software.

Outcomes

At the end of the UTS process, a vendor’s successful completion should ensure end users that the software is capable of meeting the modeling and data exchange requirements specified by the IDM. The development of the UTS is a synthesis of modeling and exchange requirements from the IDM, terminology embodied by the Data Dictionary, and IFC exchange functionality as defined by bSI’s AbRV and the project IDS. It is a demonstration of the practical application of the standards to meet the client goals for the modeling and open data exchanges of bridges.

There is a further intent to use the UTS as the basis for Software Certification requirements, as deployed by bSI, a platform with details to be determined. The Software Certification using the UTS and project IDS will demonstrate (1) a BIM-authoring tool for bridge design is able to meet the modeling and IFC requirements, and (2) that BIM viewing and analysis tools are able to correctly import and display the information from the IFC files.

Frequently Asked Questions (FAQ) Handout

Type: Stand-alone document Completion: Q1-2024

A list of Frequently Asked Questions (FAQ) and definitions for select terms formatted as a stand-alone handout and defined terms related to the TPF-5(372) study outcomes. The FAQ Handout is found in Appendix 22.

Purpose

The FAQ handout provides definitions for commonly-used terms and a FAQ that addresses common areas of misunderstanding.

Significance

The technical representatives on the TPF study panel and on the AASHTO committees that steer the work to develop IFC-based interoperability for bridges change frequently. The terms and issues covered by the document address foundational knowledge regarding the outcomes of the TPF-5(372) study that is important context for the TPF-5(523) study.

Outcomes

The document provides a resource to assist new representatives on the TPF-5(372) study panel and the AASHTO committees that may ballot future products developed by the TPF-5(372) study.

Indirect Outcomes

Indirect outcomes were actions by stakeholders that may have been influenced by the study but were not a direct outcome of the study.

Administrative Resolution AR-1-19

Type: AASHTO Administrative Resolution Completion: Q4-2019

An administrative resolution titled "*Adoption of Industry Foundation Classes (IFC) Schema as the Standard Data Schema for the Exchange of Electronic Engineering Data*" Approved by the AASHTO Board of Directors on October 9, 2019. A copy of the resolution is found in Appendix 23.

Connection to Study

The resolution indirectly refers to the TPF-5(372) study by identifying that the AASHTO COBS already has several efforts underway to facilitate the adoption of IFC Bridge as the standard data schema.

Significance

The resolution provides certainty to the industry that AASHTO is committed to IFC. This provides clarity to State DOTs that IFC is the preferred solution to facilitate open data exchanges (and project deliverables), which in turn provides increased incentive for software vendors to implement IFC support in their products. It further identifies the need to adopt IFC for the highway discipline to "ensure and maintain interoperability between these two disciplines." The two referenced disciplines are Bridge and Road.

Outcomes

AASHTO established the Joint Subcommittee on Data Standardization and joined bSI as a Principal Member. At least one software vendor joined bSI as a member following the resolution.

AASHTO Joint Subcommittee on Data Standardization (J-STAN)

Type: AASHTO Joint Subcommittee — Completion: Q2-2020

J-STAN is a relatively new joint subcommittee established by AASHTO's Strategic Management Committee in February 2020. The subcommittee's remit is to coordinate stakeholders within AASHTO and assist with the adoption of standardized data schemas. The latter includes helping to coordinate schema development, identify gaps, resolve conflicts, and avoid duplication of effort. The J-STAN website is at https://transportation.org/data/jstan/.

Connection to Study

The chair of J-STAN represents AASHTO at bSI in the Roads & Bridges Committee, advocating for the needs of the TPF-5(372) study within the international IFC development efforts. J-STAN is also where the responsibility will reside for governing the products of the TPF-5(372) study.

Significance

The establishment of J-STAN overcomes one of the largest hurdles to governing the national standards developed by the TPF-5(372) and provides a means to represent AASHTO's interests within the international standards.

Outcomes

AASHTO has had representation at several bSI international summits and technical meetings.

AASHTO Membership in buildingSMART International

Type: International Representation — Completion: Q1-2023

AASHTO joined bSI as a Principal Member. Principal Members influence the technical developments of bSI such as the services being developed and produced. Principal Members provide technical input to the Technical Roadmap.

Connection to Study

The TPF-5(372) study depends on technical services and standards developed by bSI. Through its membership, AASHTO is able to advocate for the study's needs.

Significance

As a Principal Member, AASHTO can influence the international standards developed by bSI to ensure that the technical needs of the US roads and bridges community are accommodated in the international standards.

Outcomes

AASHTO has been represented in international summits and has representation on the international Roads & Bridges Committee.

Approach to National IFC Standards

Type: Technical Solution Completion: Q1-2024

An approach to develop an IFC-based national standard for an infrastructure domain. The approach involves using the bSI technical standards and services to facilitate open data exchanges using IFC.

Connection to Study

The TPF-5(372) study was a first-of-its-kind effort to develop a national standard for an infrastructure domain using IFC.

Significance

Over the course of the TPF-5(372) study, bSI has continually evolved their approach to developing standards and technical solutions. This development by bSI has sought to streamline processes and make national standards more accessible. However, it has meant that the study has had to develop its products with high agility. As bSI matures the technical services that support local implementation, the approach used by the study provides the foundation of a repeatable path for States and nations to implement reliable IFC-based data exchanges.

Outcomes

The TPF-5(523) BIM for Bridges and Structures - Phase II TPF study will use this framework to develop national IFC-based standards for multiple exchanges in the bridge lifecycle. The framework is also available for the TPF-5(480) BIM for Infrastructure study, if desired, to create national standards for other disciplines.

Chapter 3 – Next Steps

The TPF-5(372) study represents a significant investment by AASHTO in advancing interoperability for bridge and structure data. To maximize the return on the investment, work needs to continue. Key items are described below.

Phase II Pooled Fund

TPF-5(523), Building Information Modeling (BIM) for Bridges and Structures - Phase II study organized in 2022 and began soliciting participants for FY 2023-2027. This Phase II study will provide the primary mechanism for AASHTO to expand and refine the outcomes of TPF-5(372) and develop additional guide specifications for non-proprietary, BIM-compatible national data standards to support model-based exchanges of workhorse bridges.

The study will benefit from the framework for national standards developed by the TPF-5(372) study and from the publication of IFC 4.3 as an official ISO standard, the organization of J-STAN, and AASHTO's membership of bSI. The study will continue to develop the governance and stewardship framework, support software vendors to implement IFC, promote the new bSI certification program when that is released, and provide support to DOTs to implement the IFC-based standards.

BIM for Infrastructure Pooled Fund Coordination

The TPF-5(480) BIM for Infrastructure study organized in 2020, soliciting participation and funding from agencies for the periods FY 2021-2026. This study serves as the mechanism for stakeholders to work collaboratively to advance BIM for Infrastructure. The executive committee for TPF-5(372) began regular meetings with the committee for TPF-5(480) in the Fall of 2023. The meetings will transfer to the executive committee for the TPF-5(523) BIM for Bridges Phase II study in February 2024.

Governance and Stewardship

The TPF-5(372) study has provided recommendations for how to govern and steward the technical products that were created. There are identified roles for J-STAN, acting as both the indicated governance body (per AR-1-19) and as the AASHTO representative executing the privileges of bSI Principal Membership. In addition to facilitating the relationship between AASHTO and bSI, there are recommendations for how to advance the stewardship and governance of the national standard(s) with other stakeholders, such as FHWA, AGC, ARTBA, and NSBA.

State DOT Implementation of IFC

As a result of ongoing changes in the core standards framework at bSI, specifically the final release of the IDS standard, the final publication of IFC 4.3 as an ISO standard, and the revision to the software certification program, aspects of the implementation suite of technical products were not final at the conclusion of the TPF-5(372) study. The IDS specification standard forms the crux of implementing the national IFC-based standard for delivering bridge data for construction (as expressed in the IDM). The IDS produced by this study was developed according to IDS 0.9.6 (which is a pre-release of bSI-IDS format). Consequently, any necessary revisions to the AASHTO IDS will be minor once the final IDS standard is released.

The Technical Solutions Summary report produced by the study provides a basic understanding about IFC-based data exchange and the technical solutions developed by the study work together to support implementation of open, IFC-based data exchanges at State DOTs.

Software Vendor Coordination

As a result of ongoing changes in the core standards framework at bSI, there were delays in developing the final products to support implementation of the US national standard, which were not complete until the end of the study. Software vendors received extensive support to begin the work of implementing support for IFC 4.3 within their software during the study. However, they will require further support to ensure that their software properly implements the US national standard IDS.

Appendices

Appendix 1: AASHTO-buildingSMART Engagement Memo

Appendix 2: AASHTO-buildingSMART International Engagement Update Memo

Appendix 3: Terminology Database Memo

Appendix 4: Software Vendor Engagement Plan

Appendix 5: Software Vendor One-on-One Meetings and Results Memo

Appendix 6: Investigation and Exploration Report: Common Data Standard Efforts

Appendix 7: IFC Development Gap Analysis Report: Analysis of Current IFC 4.2 Efforts

Appendix 8: Bridge Lifecycle Process Map Validation Report

Appendix 9 Base MVD Recommendation Memo

Appendix 10: Roadmap Review and Update Recommendations

Appendix 11: Roadmap Infographic

Appendix 12: Stakeholder Engagement Plan

Appendix 13: Proposal for the Creation and Governance of a US Data Dictionary and its Relationship to the buildingSMART Data Dictionary

Appendix 14: Software Vendor Letter of Intent Template

Appendix 15: Interactive Bridge Lifecycle Management Overview Map

Appendix 16: Return on Investment Analysis: Literature Review

Appendix 17: Return on Investment (ROI) Analysis White Paper

Appendix 18: Technical Solution Summary for the Design-to-Construction Data Exchange Standard for Highway Bridges

Appendix 19: Industry Foundation Classes (IFC) Implementation Guide for State Departments of Transportation

Appendix 20: AASHTO National BIM Standards Governance Technical Memorandum

Appendix 21: Sample Unit Test Instructions

Appendix 22: Frequently Asked Questions Handout

Appendix 23: AASHTO Administrative Resolution AR-1-19

Appendix 1: AASHTO-buildingSMART Engagement Memo

BIM FOR BRIDGES AND STRUCTURES
TPF-5(372)

AASHTO-buildingSMART Engagement Memo

Memo regarding AASHTO's interaction with buildingSMART International
2019-06-06
Version 1.0

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Executive Summary

This memo has been drafted for the TPF-5(372) Communications Working Group as an update to the ongoing process of establishing a working relationship between COBS T-19 and buildingSMART International (bSI). That working relationship is seen as an important component of standards development for both AASHTO and bSI in regard to the use of bSI standards (e.g. IFC) for the infrastructure domain. The initial goal of the HDR team was to negotiate a direct membership between AASHTO and bSI. However, at the TPF-5(372) meeting in Florida in February 2019, it was determined that a direct relationship with an international organization was untenable. The HDR team suggested at that time a working relationship with the US Chapter of bSI, the AGC BIMForum, as an alternative. HDR also informed the TPF-5(372) team that BIMForum had not worked out the process of fully engaging with bSI in projects and end user engagement, requiring additional effort to establish a fully functional relationship.

Since that meeting, the HDR team has made some significant headway to establishing a working relationship. A meeting with the AGC was held at the AGC HQ in Arlington, VA where the topic of establishing an Infrastructure Room – mirroring a component of the organization of bSI - was discussed. It was determined that this group would be created, and that roles and responsibilities should be defined and working members established. We also agreed to a goal of having the Infrastructure Room created and introduced at the BIMForum conference, 16-18 September 2019, in St. Louis, MO, to help build membership.

Following the meeting in Arlington, the Infrastructure Room was established as part of BIMForum. In follow-up meetings, the topics of establishing a chairperson, documenting roles and responsibilities, and creating a membership structure have continued. The HDR team has taken on the responsibility of documenting roles and responsibilities. This memo describes the current state of HDR's work on this topic.

Background Information

Organizations

There are three organizations involved in this proposed working relationship:

buildingSMART International (bSI) is an international non-profit organization (https://www.buildingsmart.org/) which provides and maintains core standards for use by industry, including the Industry Foundation Classes (IFC) data model, the Model View Definition (MVD) specification which indicates a sub-set of the overall schema for a particular data exchange use case, the Information Delivery Manual (IDM) which defines the business case and exchange requirements, the buildingSMART Data Dictionary (bSDD) which acts as a central translation dictionary for industry terms linked to the IFC schema, and the BIM Collaboration Format (BCF) which is the open standard communication protocol for IFC-based workflows.

The **American Association of State Highway and Transportation Organizations (AASHTO)** is a US non-profit professional association (https://www.transportation.org/) which develops and maintains standards for the delivery and lifecycle management of infrastructure projects. In this project context, AASHTO is proposing to adopt bSI's core standards (IFC and IDM) and create implementation standards based on them (e.g. Modeling and Data Standards, MVDs, and BIM Project Execution Plans (BIM PxP)).

BIMForum is the US Chapter of bSI (https://bimforum.org/) and a subsidiary of the **Associated General Contractors (AGC)**, providing an interface for US-based companies and organizations to interact with the bSI community and its activities. Ideally, such interactions are bidirectional.

Engagement Proposal

Organization Responsibilities / Interactions

buildingSMART International (bSI)

bSI maintains websites with organization and industry information, as well as references to its standards and processes. It conducts semi-annual Standards Summits to provide face-to-face interaction among members and the industry to disseminate information about its standards, processes, and projects.

bSI has organized a set of domain-specific "Rooms", groups where various stakeholders with common interest – such as buildings, infrastructure, airports, construction, products, power and communication, etc. – interact, discuss relevant issues, and conduct activities to address issues of the highest priorities. Participation in such Rooms is restricted to international and chapter members.

bSI also provides the governance structure for projects that help further define needed industry standards around BIM implementation, such as extended the IFC schema, creating widely-used MVDs for common data exchanges in different workflows throughout the lifecycles of projects, and documenting uses cases and processes which could lead to harmonization across markets and projects.

BIMForum

BIMForum maintains websites to inform members (and the industry) about its activities. It is recommended that it also create references/links to bSI activities and online resources. This would help in its responsibility as a bSI chapter to disseminate information (e.g. news, project updates, etc.) from bSI to its US members, as well as give both BIMForum and bSI further insight into how US efforts align with international ones.

BIMForum has agreed to create and maintain “Rooms” which mirror the International organization, providing a common focal point of interest and discussion among specific domains. In this case, there will be an “Infrastructure Room” at BIMForum, with a Steering Committee and membership consisting of designers, engineers, contractors, suppliers, software vendors, owners, regulatory officials, and any other individuals, companies, or organizations (e.g. AASHTO, FHWA) directly involved in the infrastructure domain. The BIMForum Infrastructure Room is recommended to maintain regular meetings throughout the year for its members and interact with the bSI Infrastructure Room through its regular meetings and projects. BIMForum should plan to have an “Infrastructure Track” at the annual BIMForum conference to help disseminate information from bSI, as well as US-based projects such as TPF-5(372). While bSI allows members and the general public to attend Standards Summits, BIMForum already has representatives that attend all Summits. It is recommended that the BIMForum Infrastructure Room also establish regular representation at the bSI semi-annual Standards Summits.

AASHTO

The consultant team has recommended that AASHTO become a member of BIMForum and designate representation, such as one or more AASHTO committee or pooled fund members, possibly on a rotating basis, to the organization and respective Committees and/or Rooms of interest (e.g. Infrastructure Room).

As the primary representative of the US Highway system owners, such representation helps AASHTO communicate with the larger buildingSMART community and take advantage of opportunities to influence further bSI standards development. Through TPF-5(372) and future pooled fund projects, AASHTO can use BIMForum and its members as a resource for such standardization projects, as well as standards deployment/implementation education to service providers in the US market via the BIMForum annual conferences. This would allow AASHTO to repeat an effort like TPF-5(372) for other infrastructure types with lower organizational overhead and quicker turnaround by establishing precedent for software vendors and service providers.

As a BIMForum member, AASHTO will be in a position to get assistance from, or contract with, bSI to use their b-cert platform for MVD certification supporting TPF-5(372) and future data exchange standards.

Future Standards Maintenance

During and after the TPF-5(372) project, there will be requirements to adjust and/or maintain standards created by AASHTO and corresponding standards from bSI. The following points lay out the recommended general roles and processes needed to help revise and maintain such standards:

1. Any changes to bSI core standards, from the bSI side, would propagate directly to AASHTO standards via a review and revision/update process by AASHTO, or its designated agents.

2. Changes to AASHTO standards, which may not require any changes to or impact on bSI core standards, would simply be reviewed internally by AASHTO, or its designated agents.

3. Changes to AASHTO implementation standards which require changes to bSI core standards (e.g. IFC schema changes, BCF implementation changes, etc.) would be submitted to BIMForum, and its relevant committees or Rooms, who will be responsible for passing details along to bSI and its Standards Committee Technical Executive.

4. Omissions or Errata in bSI core standards (e.g. IFC schema and schema documentation) can already be submitted to bSI at any time through its official community Forums for discussion and tracking.

Appendix 2: AASHTO-buildingSMART International Engagement Update Memo

BIM FOR BRIDGES AND STRUCTURES TPF-5(372)

Memo

Project:	TPF-5(372) BIM for Bridges and Structures
Date:	2020-01-31
To:	TPF-5(372) Communications Working Group
From:	Connor Christian, HDR & Jeffrey W. Ouellette, consultant
Subject:	AASHTO-bSI Engagement Update

Summary

This memo is an update to the previous memo issued on June 6, 2019, “TPF-5(372)-AASHTO_bSI_Engagement-MEMO_20190606.pdf” (see Appendix). Please refer to said memo for background information and original engagement recommendations.

Changes

Since the memo was last issued, a number of significant changes have taken place which impact the dynamic of how AASHTO interacts with buildingSMART International. The following are summaries of these changes:

1. The Associated General Contractors (AGC) has decided to sever its relationship with BIMForum. This has a significant negative impact on the funding and management staffing of the BIMForum and raises concerns about the longevity of that organization.
2. At the same time, buildingSMART International (bSI) has sought to revoke the buildingSMART U.S. chapter status from BIMForum and search for a new chapter solution. From bSI’s persepctive, it hasn’t been a strong enough partnership and lacked national industry and international organization interactions that other chapters have accomplished. Ian Powell, an original founder of the International Alliance for Interoperability (IAI), the original name of buildingSMART International, has been designated by the bSI Management Office as its official U.S. representative and is tasked with finding a path forward to establish a new US chapter.
3. Additionally, the AASHTO Board of Directors passed an Administrative Resolution (see Appendix) on October 9, 2019, effectively recommending that the IFC schema from bSI be used as the primary data exchange standard for all AASHTO members and their standards. The resolution also authorizes AASHTO to directly engage with

buildingSMART International to investigate possible membership. This will extend support to bSI from AASHTO's commitment to implementing IFC and give AASHTO direct access to the bSI process for future efforts and projects to amend the IFC schema, as well as community support for their ongoing efforts to incorporate IFC.

4. Thus, the project team, led by HDR, is working to facilitate AASHTO's interaction with bSI and assist where it can with the formation of a new US chapter. Hopefully, a new solution will be found during 2020 and AASHTO can also directly engage with the US chapter.

Appendix: Referenced Documents

PDF Attachment 1:
AASHTO-buildingSMART Engagement Memo, 2019-06-06

PDF Attachment 2:
Administrative Resolution AR-1-19: Adoption of Industry Foundation Classes (IFC) Schema as the Standard Data Schema for the Exchange of Electronic Engineering Data

BIM FOR BRIDGES AND STRUCTURES
TPF-5(372)

AASHTO-buildingSMART Engagement Memo

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BIM FOR BRIDGES AND STRUCTURES TPF-5(372)

Executive Summary

This memo has been drafted for the TPF-5(372) Communications Working Group as an update to the ongoing process of establishing a working relationship between COBS T-19 and buildingSMART International (bSI). That working relationship is seen as an important component of standards development for both AASHTO and bSI in regard to the use of bSI standards (e.g. IFC) for the infrastructure domain. The initial goal of the HDR team was to negotiate a direct membership between AASHTO and bSI. However, at the TPF-5(372) meeting in Florida in February 2019, it was determined that a direct relationship with an international organization was untenable. The HDR team suggested at that time a working relationship with the US Chapter of bSI, the AGC BIMForum, as an alternative. HDR also informed the TPF-5(372) team that BIMForum had not worked out the process of fully engaging with bSI in projects and end user engagement, requiring additional effort to establish a fully functional relationship.

Since that meeting, the HDR team has made some significant headway to establishing a working relationship. A meeting with the AGC was held at the AGC HQ in Arlington, VA where the topic of establishing an Infrastructure Room – mirroring a component of the organization of bSI - was discussed. It was determined that this group would be created, and that roles and responsibilities should be defined and working members established. We also agreed to a goal of having the Infrastructure Room created and introduced at the BIMForum conference, 16-18 September 2019, in St. Louis, MO, to help build membership.

Following the meeting in Arlington, the Infrastructure Room was established as part of BIMForum. In follow-up meetings, the topics of establishing a chairperson, documenting roles and responsibilities, and creating a membership structure have continued. The HDR team has taken on the responsibility of documenting roles and responsibilities. This memo describes the current state of HDR's work on this topic.

Background Information

Organizations

There are three organizations involved in this proposed working relationship:

buildingSMART International (bSI) is an international non-profit organization (https://www.buildingsmart.org/) which provides and maintains core standards for use by industry, including the Industry Foundation Classes (IFC) data model, the Model View Definition (MVD) specification which indicates a sub-set of the overall schema for a particular data exchange use case, the Information Delivery Manual (IDM) which defines the business case and exchange requirements, the buildingSMART Data Dictionary (bSDD) which acts as a central translation dictionary for industry terms linked to the IFC schema, and the BIM Collaboration Format (BCF) which is the open standard communication protocol for IFC-based workflows.

The **American Association of State Highway and Transportation Organizations (AASHTO)** is a US non-profit professional association (https://www.transportation.org/) which develops and maintains standards for the delivery and lifecycle management of infrastructure projects. In this project context, AASHTO is proposing to adopt bSI's core standards (IFC and IDM) and create implementation standards based on them (e.g. Modeling and Data Standards, MVDs, and BIM Project Execution Plans (BIM PxP)).

BIMForum is the US Chapter of bSI (https://bimforum.org/) and a subsidiary of the **Associated General Contractors (AGC)**, providing an interface for US-based companies and organizations to interact with the bSI community and its activities. Ideally, such interactions are bidirectional.

Engagement Proposal

Organization Responsibilities / Interactions

buildingSMART International (bSI)

bSI maintains websites with organization and industry information, as well as references to its standards and processes. It conducts semi-annual Standards Summits to provide face-to-face interaction among members and the industry to disseminate information about its standards, processes, and projects.

bSI has organized a set of domain-specific "Rooms", groups where various stakeholders with common interest – such as buildings, infrastructure, airports, construction, products, power and communication, etc. – interact, discuss relevant issues, and conduct activities to address issues of the highest priorities. Participation in such Rooms is restricted to international and chapter members.

bSI also provides the governance structure for projects that help further define needed industry standards around BIM implementation, such as extended the IFC schema, creating widely-used MVDs for common data exchanges in different workflows throughout the lifecycles of projects, and documenting uses cases and processes which could lead to harmonization across markets and projects.

BIMForum

BIMForum maintains websites to inform members (and the industry) about its activities. It is recommended that it also create references/links to bSI activities and online resources. This would help in its responsibility as a bSI chapter to disseminate information (e.g. news, project updates, etc.) from bSI to its US members, as well as give both BIMForum and bSI further insight into how US efforts align with international ones.

BIMForum has agreed to create and maintain “Rooms” which mirror the International organization, providing a common focal point of interest and discussion among specific domains. In this case, there will be an “Infrastructure Room” at BIMForum, with a Steering Committee and membership consisting of designers, engineers, contractors, suppliers, software vendors, owners, regulatory officials, and any other individuals, companies, or organizations (e.g. AASHTO, FHWA) directly involved in the infrastructure domain. The BIMForum Infrastructure Room is recommended to maintain regular meetings throughout the year for its members and interact with the bSI Infrastructure Room through its regular meetings and projects. BIMForum should plan to have an “Infrastructure Track” at the annual BIMForum conference to help disseminate information from bSI, as well as US-based projects such as TPF-5(372). While bSI allows members and the general public to attend Standards Summits, BIMForum already has representatives that attend all Summits. It is recommended that the BIMForum Infrastructure Room also establish regular representation at the bSI semi-annual Standards Summits.

AASHTO

The consultant team has recommended that AASHTO become a member of BIMForum and designate representation, such as one or more AASHTO committee or pooled fund members, possibly on a rotating basis, to the organization and respective Committees and/or Rooms of interest (e.g. Infrastructure Room).

As the primary representative of the US Highway system owners, such representation helps AASHTO communicate with the larger buildingSMART community and take advantage of opportunities to influence further bSI standards development. Through TPF-5(372) and future pooled fund projects, AASHTO can use BIMForum and its members as a resource for such standardization projects, as well as standards deployment/implementation education to service providers in the US market via the BIMForum annual conferences. This would allow AASHTO to repeat an effort like TPF-5(372) for other infrastructure types with lower organizational overhead and quicker turnaround by establishing precedent for software vendors and service providers.

As a BIMForum member, AASHTO will be in a position to get assistance from, or contract with, bSI to use their b-cert platform for MVD certification supporting TPF-5(372) and future data exchange standards.

Future Standards Maintenance

During and after the TPF-5(372) project, there will be requirements to adjust and/or maintain standards created by AASHTO and corresponding standards from bSI. The following points lay out the recommended general roles and processes needed to help revise and maintain such standards:

1. Any changes to bSI core standards, from the bSI side, would propagate directly to AASHTO standards via a review and revision/update process by AASHTO, or its designated agents.

2. Changes to AASHTO standards, which may not require any changes to or impact on bSI core standards, would simply be reviewed internally by AASHTO, or its designated agents.

3. Changes to AASHTO implementation standards which require changes to bSI core standards (e.g. IFC schema changes, BCF implementation changes, etc.) would be submitted to BIMForum, and its relevant committees or Rooms, who will be responsible for passing details along to bSI and its Standards Committee Technical Executive.

4. Omissions or Errata in bSI core standards (e.g. IFC schema and schema documentation) can already be submitted to bSI at any time through its official community Forums for discussion and tracking.

Administrative Resolution AR-1-19
Title: Adoption of Industry Foundation Classes (IFC) Schema as the Standard Data Schema for the Exchange of Electronic Engineering Data

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Whereas, Several data schema exist for the exchange of electronic engineering data, among them Trans XML, Land XML, and various industry schemas; however, there is no single standard data schema recognized by the industry;

Whereas, Transportation agencies need to implement asset management more efficiently throughout the lifecycle of the asset, which requires the ability to exchange data seamlessly;

Whereas, Transportation agencies are progressing toward Building Information Models as the successor to the standard plan set for highway infrastructure projects;

Whereas, Transportation agencies are utilizing a variety of tools and equipment from multiple vendors and manufacturers to gather, display, and work with the data necessary for infrastructure project development, and interoperability of the models is a critical feature so that the agencies have the ability to transfer data seamlessly across these platforms;

Whereas, Seamless data transfer necessitates a single data schema that is recognized as the industry standard, otherwise there is a potential loss of data when translated from one device or one application to another; however, there has been a lack of consensus for adoption of a single schema;

Whereas, To date efforts to establish a national standard data schema have not been successful, in large part due to the inability to identify an agency or entity capable of providing ongoing development, support, and maintenance of the schema, so it would be advantageous to move toward a schema where that support mechanism already exists;

Whereas, There is an international effort underway, led by buildingSMART International, to extend their existing Industry Foundation Classes (IFC) standard data schema to incorporate infrastructure projects including IFC Bridge and IFC Road;

Whereas, Adoption of a single data schema by transportation agencies would give vendors and manufacturers the standard we need to facilitate collaboration on their adoption as well;

Whereas, The AASHTO Committee on Bridges and Structures already has several efforts underway to facilitate the adoption of IFC Bridge as the standard data schema for their discipline, and it would be essential in order to ensure and maintain interoperability between these two disciplines that we adopt IFC Road for highway infrastructure projects; and

Whereas, There are other AASHTO committees with interest in this effort, including but not limited to the Committee on Data Management and Analytics, the Committee on Bridges and Structures, and AASHTOWare; now, therefore, be it

Resolved, That the AASHTO Board of Directors recommends the adoption of IFC Schema as the national standard for AASHTO States;

Resolved, That an internal, cross-committee, multi-disciplined group within AASHTO should be formed to coordinate schema development, identify gaps, resolve any conflicts, and avoid duplication of efforts; and

Resolved, That possible AASHTO membership in buildingSMART International should be investigated to provide representation and participation for the state DOTs in schema development.

Approved by the AASHTO Board of Directors
October 9, 2019

Appendix 3: Terminology Database Memo

Memo

Project:	TPF-5(372) BIM for Bridges and Structures
Date:	11/15/2019
To:	Working Group 1
From:	Francesca Maier and Aaron Costin
Subject:	Terminology Database

Summary

This memo provides an introduction to Terminology Database and the process of creating a Glossary of Terms. An example Glossary of Terms is also provided.

Terminology Database

The terminology database is a Microsoft Excel file that has the following metadata:

- **Term:** The name of entity being described
- **Abbreviation:** Common abbreviation or acronym of the term
- **Definition:** The meaning of the term
- **Definition notes:** Notes that appeared in the source of the term
- **Subject:** The topic that the term falls into
- **Term reference:** The local identification or specific reference of the term within the source
- **Related:** Any similar or related terms, such as any terms within the definition that need to be defined
- **Notes:** Notes from the developer of the Microsoft Excel Terminology Database.
- **Reference:** The reference code or standard that defined the term
- **Source:** The hyperlink to the source. (Any local documents will be updated to link to the final storage of the source, such as the DOI or ISBN)
- **Publication year:** The year of the publication of the source.

Terminology was collected from a variety of sources with the original source definition. The intent of the database is to be the main repository of all the terminology gathered throughout the TPF-5(372) project. During Task 1, the database was established and populated with an initial collection of terminology. This terminology will subsequently be used in other tasks.

The database will continue to grow as more terms are collected and stored during these tasks that use the terminology. The initial collection was approximately 400 terms. The collection now includes over 2,000 terms. In some cases, there are multiple definitions for terms, which will be reconciled when the term is used. Synonyms and related terms will be linked when the terms are used.

The next revision will add terms from the ANSI /AISC 303-16 Code of Standard Practice for Steel Buildings and Bridge, the buildingSMART Data Dictionary, and any other terms needed for the Design to Fabrication IDM Development. The final TPF-5(372) deliverables will include a final version of the database and an updated memo.

Using the Terminology Database

The intended users of the terminology repository are developers, who will use the terminology for specific applications that require terminology. The database stores the terminology to serve different uses over the TPF-5(372) project, such as being curated into a glossary of terms for each specific use case application. The following steps result in a glossary of terms for a specific use:

1. Define the intent
2. Identify the relevant topics
3. Separate into subsections (if necessary)
4. Select necessary terms
5. Export term and definition

Glossaries of terms can be created from the terminology database to support many different use cases, such as stakeholder outreach activities. Term selection is a manual process, as is selecting the most appropriate definition where there are multiple definitions available. The export includes the term, any abbreviations, the definition, and the reference.

- **Intent**: Provide foundational vocabulary for TPF-5(372) technical tasks.
- **Topics:**
  - **General BIM terminology**- High-level terminology needed to understand the basic concepts and functions of Building Information Modeling (BIM)
  - **BIM Processes**- Terminology related to the creation of standardized BIM workflows and information exchanges.
- **Subsections:** General process mapping, Business Process Modeling and Notation (BPMN), BIM standardization, Industry Foundation Classes (IFC), and information management.

Example Glossary of Terms

The following table is an example of a glossary of terms that was curated from the terminology database for the purpose of referencing fundamental vocabulary for the TPF-5(372) project.

Term	Definition
BIM Process Map	A diagram showing how BIM will be applied on a project. The BIM project execution plan proposes two levels of process maps: BIM overview map and detailed BIM use process maps that define associated activities and information exchanges. [National BIM Standard - US V3]. See Process Map.
Building Information Modeling (BIM)	BIM is a term which represents three separate but linked functions: Building Information Modeling: Is a BUSINESS PROCESS for generating and leveraging building data to design, construct and operate the building during its lifecycle. BIM allows all stakeholders to have access to the same information at the same time through interoperability between technology platforms. Building Information Model: Is the DIGITAL REPRESENTATION of physical and functional characteristics of a facility. As such it serves as a shared knowledge resource for information about a facility, forming a reliable basis for decisions during its life cycle from inception onwards. Building Information Management: Is the ORGANIZATION & CONTROL of the business process by utilizing the information in the digital prototype to effect the sharing of information over the entire lifecycle of an asset. The benefits include centralized and visual communication, early exploration of options, sustainability, efficient design, integration of disciplines, site control, as built documentation, etc.– effectively developing an asset lifecycle process and model from conception to final retirement. [National BIM Standard - US V3]
buildingSMART Data Dictionary (bSDD)	A specific Data Dictionary based on EN ISO 12006-3:2016 and is developed and maintained by buildingSMART International. ISO 12006-3:2016 specifies a language-independent information model which can be used for the development of dictionaries used to store or provide information about construction works. It enables classification systems, information models, object models and process models to be referenced from within a common framework. [JRC Technical Report (Poljanšek 2017)]
Classification	categorization, the act of distributing things into classes or categories of the same type
Concept	rules on using a subset of the schema structure identified as a concept template to enable a certain functionality within the context of a concept root contained in a model view. [ISO 16739-1:2018(E)] NOTE The utilization of material definitions for a particular concept root representing a wall is an example of a concept.
Data	Raw factual bits of unprocessed information. Can be structured, but as an aggregate, has no more meaning than the individual facts alone convey. [National BIM Standard - US V3]
Data Dictionary	A data-semantic dictionary specifying concepts (entities, properties, classification and other concepts) and their relations. A data dictionary defines entities and properties uniquely, understandable and machine readable. It is possible to connect different data dictionaries and to harmonize the understanding of the content we want to share. [JRC Technical Report (Poljanšek 2017)]

Term	Definition
Data Exchange	The process of taking data structured under a source schema to transform and restructure into a target schema, so the target data are an accurate representation of the source data within specified requirements and minimal loss of content. ISO 16739 specifies a conceptual data schema and an exchange file format for Building Information Modeling BIM data. The conceptual schema is defined in EXPRESS data specification language (EXPRESS) as specified in ISO 10303-11. ISO 16739 represents an open international standard for BIM data that is exchanged and shared among software Applications used by the various participants in a building construction or facility management project. ISO 16739 consists of the data schema, represented as an EXPRESS schema specification, and reference data, represented as definitions of properties and quantities. [National BIM Standard - US V3]
Data Model	A specified set of entities and their related properties and attributes representing a virtual model of one or more domains structured by a modelling language. The buildingSMART Data Model is the same as the IFC data model. [JRC Technical Report (Poljanšek 2017)]
Detailed BIM Use Process Maps	A comprehensive BIM process map that defines the various sequences to perform a specific application of BIM or BIM use. These maps also identify the responsible parties for each process, reference information content, and the information exchanges, which will be created and shared with other processes. [National BIM Standard - US V3] See Process Map.
Dictionary	collection of words, terms or concepts, with their definition
Document	1. Is a container for persistent information that can be managed and interchanged as a unit. [BS1192:2007] 2. information for the use in the briefing, design, construction, operation, maintenance or decommissioning of a construction project, including but not limited to correspondence, drawings, schedules, specifications, calculations, spreadsheet. [PAS 1192-2:2013]
Exchange Requirement	A non-technical description of the information needed by a business process to be executed, as well as the information produced by that business process. [National BIM Standard - US V3]
Exchange Requirements Model (ERM)	The data model addressing requirements for a single industry process. [National BIM Standard - US V3]
Industry Foundation Classes (IFC)	It is a neutral data format to describe, exchange and share information typically used within the building and facility management industry sector. IFC is the international standard for openBIM and registered as EN ISO 16739:2016. [JRC Technical Report (Poljanšek 2017)]
Information	Data that has been interpreted, translated, or transformed to reveal the underlying meaning. [National BIM Standard - US V3] See also: data

Term	Definition
Information Delivery Manual (IDM)	1. Documentation which captures the business process and gives detailed specifications of the information that a user fulfilling a particular role would need to provide at a particular point within a project. [ISO 29481-1:2016(E)] Note 1 to entry: This can be referred to as an information delivery specification (IDS). 2. A standard for processes specified when certain types of information are required during the construction of a project or the operation of a built asset. It also provides detailed specification of the information that a particular user (such as, architect or building services engineer) needs to provide at a point in time and groups together information that is needed in associated activities: cost estimating, volume of materials and job scheduling are natural partners. [National BIM Standard - US V3]
Information Exchange	Packages of information passed from one party to another in a BIM process, or the act of passing such information. Can be a deliverable. Parties involved agree upon and understand what information content and format will be exchanged. [National BIM Standard - US V3]
Information Model	is a model comprising: documentation, non-graphical information and graphical information (as defined by PAS 1192-2:2013) OR is all documentation, non-graphical information which the Project Team is required to provide into the Information Model by the Scope of Services for the Project Team and which is provided for the purpose of delivering Project Outputs (as defined by the CIC Outline Scope of Services for the Role of Information Management)
Instance	occurrence of an entity NOTE Similar to the term "instance of a class" in object oriented programming. [ISO 16739-1:2018(E)]
Interoperability	Interoperability is the ability of diverse systems and organizations to work together (inter-operate). The term is often used in a technical systems engineering sense, or alternatively in a broad sense, taking into account social, political, and organizational factors that impact system to system performance. [National BIM Standard - US V3]
Library	catalogue, database or holder of data, that is relevant to information in the data set. [ISO 16739-1:2018(E)] NOTE It is information referenced from an external source that is not copied into the data set.

Term	Definition
Model	1. representation of a system that allows for investigation of the properties of the system. ISO 29481-1:2016(E) 2. a data set, governed by the structure of an underlying schema, to meet certain data requirements. [ISO 16739-1:2018(E)] NOTE Information models and building information models are examples for a model. NOTE In scope of this standard IFC models are populations of the IFC schema.
Model View	subset of a schema, representing the data structure required to fulfil the data requirements within one or several exchange scenarios. [ISO 16739-1:2018(E)] NOTE Beside being a subset of a schema, a model view (or model view definition) may also impose additional constraints to the population of the subset schema
Model View Definition (MVD)	An IFC View Definition, or Model View Definition, MVD, defines a subset of the IFC schema that is needed to satisfy one or many Exchange Requirements of the AEC industry. The method used and propagated by buildingSMART to define such Exchange Requirements is the Information Delivery Manual, IDM (also ISO/DIS 29481). An IFC Model View Definition defines a legal subset of the IFC Schema (being complete) and provides implementation guidance (or implementation agreements) for the IFC concepts (classes, attributes, relationships, property sets, quantity definitions, etc.) used within this subset. It thereby represents the software requirement specification for the implementation of an IFC interface to satisfy the exchange requirements. [National BIM Standard - US V3]
Ontology	In computer science and information science, an ontology is a formal data model that represents a domain (such as Architecture or Engineering or Construction or Facilities Management) and is used to reason about the specialized objects in that domain, the relations between them, and then make inferences and conclusions. [National BIM Standard - US V3]
Overview Map	A high-level BIM process map that illustrates the relationship between BIM uses which will be employed on the Facility. Each of the BIM Uses then gets its own lower level Process Map. [National BIM Standard - US V3] See Process Map.
Process Map	representation of the relevant characteristics of a process associated with a defined business purpose. [ISO 29481-1:2016(E)]
Representation	unit of information describing how an object is displayed, such as physical shape or topology.
Roadmap	The overall implementation strategy document used to set the definition, direction, sequence and usually milestones for an initiative. [National BIM Standard - US V3]
Schema	the definition of the structure to organize data for storage, exchange and sharing, using a formal language. [ISO 16739-1:2018(E)] NOTE The formal languages EXPRESS [ISO 10303-11] and XML Schema [W3C Recommendation] are currently used to define the schemata of this standard

Term	Definition
Taxonomy	One of several ways to organize the structure of topics and subtopics for the purpose of retrieval and information exchange. A taxonomy is a tree structure with one root and several branches having unique and common properties. An example is IFC hierarchy, with the controlled vocabulary of floors, walls, etc. The alternative to a hierarchy is a network structure. [National BIM Standard - US V3]
Thesaurus	1. Another way to organize the hierarchical structure of topics and subtopics. A Thesaurus is different from a Taxonomy in that topics are defined, their synonyms are defined, and an effort is often made to show the kinds of relationships between terms. A Taxonomy may be combined with a Thesaurus to create a Taxo-Thesaurus, as the World Bank has done to make document management more accurate and less expensive. Commitments may be made to use a specific controlled vocabulary or ontology for a domain of interest. [National BIM Standard - US V3] 2. A way of organizing subject matter. Differs from a Taxonomy in that topics are grouped with their synonyms or references and these groupings ordered a in nonhierarchical way by name of the topic, rather than being organized as topics and sub-topics in conceptually related groupings. May be combined with a Taxonomy to create a Taxo-Thesaurus. The World Bank has created such a system. [National BIM Standard - US V3]

Appendix 4: Software Vendor Engagement Plan

BIM FOR BRIDGES AND STRUCTURES

TPF-5(372)

Software Vendor Engagement Plan

Recommendations for Software Advisory Group activities to support TPF-5(372)

2019-11-15

Version 1.1

BIM FOR BRIDGES AND STRUCTURES TPF-5(372)

Table of Contents

Introduction

This report, the “Software Vendor Engagement Plan”, documents the components and timetable to enable effective engagement with the software community in the US infrastructure market. The overall purpose of this engagement is to spur vendors to create software solutions to support the development, implementation, and adoption of new BIM-based workflows and standards for AASHTO members in the design, procurement, construction, and operations of bridges and associated structures.

The Software Advisory Group (SAG) was established as the primary interface between software vendors, the consultant team, and pooled fund members. The consultant team uses the advisory group to pass project information along to vendors interested in participating in the project, as well as acting as a communications conduit between the pooled fund members, the consultant team, and the vendors. As the project progresses over its 5-year span, the software development of support for the new workflows and standards will be managed from within the advisory group.

The Software Vendor Engagement Plan (SVEP) shall provide a reference to all project participants during the life of the project, guiding expectations and outcomes from all parties in clear terms. Questions, concerns, adjustments, or feedback regarding software engagement and development during the project should reference this plan.

Background

An integral part of the TPF-5(372) project is the support of making the new standards readily available in software on the general market and in use by AASHTO members and their service providers. For the greatest chances of success, it is important to involve all relevant software vendors throughout the entire project, working to continually inform them of requirements and facilitate their internal development processes and timelines to meet project goals and requirements.

The overall project strategy includes 5 main phases, or components, which span the life of the project and have aspects that touch the many stakeholders in different ways:

- Investigation & Exploration
- IFC Development & Verification
- Economic Analysis
- Industry Organization
- Development & Implementation

These phases are not linear or consecutive, but rather subjects of emphasis which help organize the many components, activities, and outputs of the project.

Within this overall project context, the participation of Software Vendors, can be summarized in the following table:

Project Phase	Vendor Participation
1. Investigation & Exploration	Determine current software capabilities in bridge design using BIM methodologies and technologies, as well as other lifecycle processes
2. IFC Development & Verification	Determine vendor capability for needed IFC support, based on IFC4.2; initial MVD support for Design->Fabrication and Design->Construction
3. Economic Analysis	Hard and soft cost data to help determine economic impact of BIM-based processes
4. Industry Organization	Engaging AASHTO, AGC/BIMForum, and buildingSMART International (especially for tech support and certification)
5. Development & Implementation	Prototyping, beta software development, testing, and eventual release of features and support to satisfy requirements

Table 1: Vendor Participation by Project Phase

Project Year-by-Year Summaries

This project is planned to develop over a five-year period, where each year includes a different sub-set of tasks and emphasis, all executed to meet the overall project goals. For the Software Vendor Engagement portion, the idea is to increase vendor involvement over the course of the project, beginning with simple outreach, recruitment, and education, and ending with certifications of software application implementations to meet the new AASHTO standards.

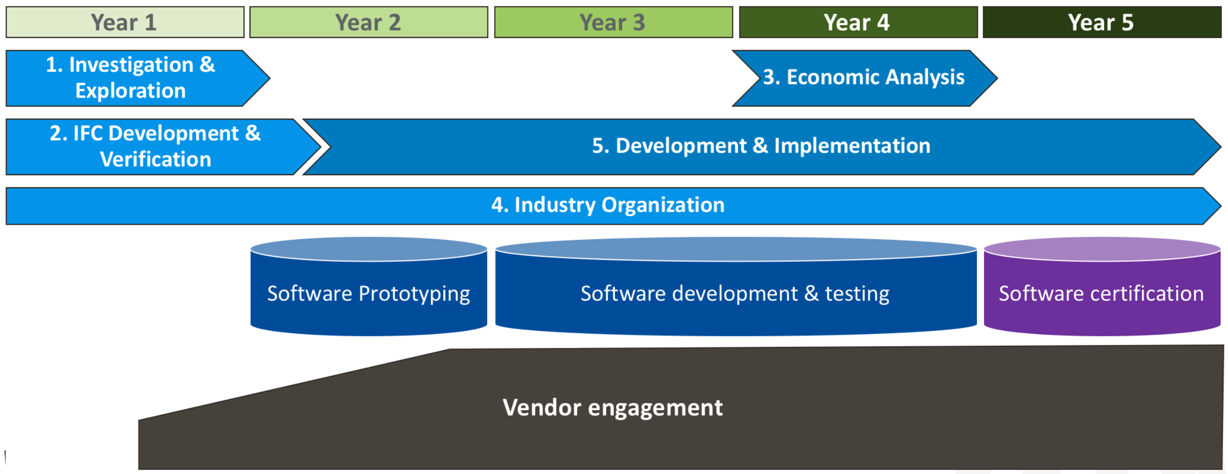

Figure 1: Proposed Vendor Engagement Overview by Timeline

Year 1: Outreach

During the first year of the project, the consultant team is continually reaching out to the software vendor community, providing information, and accumulating interest and participation in the project. The intent is to involve as many different software solutions needed to cover the requirements of the many stakeholders throughout the lifecycle of bridges and associated built structures, as identified by the project team and owners.

The consultant team will also continue to create, update, and disseminate material and project information to the software vendors, providing further clarity for them to make decisions on further participation. This material will include project timelines/schedules, project goals and requirements, …

Year 2: Commitment and Planning

During the second year of the project, the software vendors who have been previously identified and engaged in Year 1 activities will be asked to formalize their participation in the project by signing a Letter of Intent (See Appendix A) which spells out their commitment to fulfilling the goals of the project in providing support for IFC-based data exchanges, and any other open standards identified, in software available to the industry marketplace by the conclusion of the project.

During this year, the consultant team will engage with the pooled fund members and vendors to further clarify and detail the overall software development, testing, and deployment timeline, as well as providing user requirements for vendors. Dialog between the consultant team and software vendors will also help provide the consultant team with feedback, expectations, and guidance from each of the vendors regarding their respective development plans. The intent of the individual dialog is to insulate vendors from disclosing proprietary information to competitors, but still exchange pertinent information regarding project commitment and ability to support it.

In addition, there will be initial testing/validation of IFC4.2 using the Bridge Design Transfer View, developed by the buildingSMART IFC Bridge project team along with the proposed IFC4.2 schema. Details, relevant configuration material, and test files will be provided to selected vendor(s) by the project team.

Year 3: Development, Implementation, and Testing – Phase 1

During the third year of the project, the first steps of software support should be undertaken. This includes core technical development to support IFC4.2 data exchange and data encoding in software. Beta testers shall be identified and a process for distributing Not-For-Resale (NFR) beta versions, test files, issue reporting, and tracking shall be established.

Candidate MVD(s) will be delivered as part of the initial development, implementation, and testing to help vendors verify IFC capabilities and establish benchmarks for further development.

The consultant team will also engage with buildingSMART International, or another specified entity, in discussion about providing certification services of software to support the TPF-5(372) MVDs.

Year 4: Development, Implementation, and Testing – Phase 2

During the fourth year of the project, the maturity of initial development, beta implementations, and testing will allow testing and review of candidate MVD(s) to establish their final form.

While development and beta testing continue, planning for final deployment, documentation, and end user orientation and training will occur.

Year 5: Certification and Deployment

During the fifth year of the project, certification of software implementations for the new standard exchanges will be set up and undertaken.

Final deployment of certified versions will be determined with corresponding documentation and training materials to be delivered.

Beyond Year 5

By the end of Year 5, it should be possible for AASHTO members and their service providers to implement the new standards with certified support from software used by all the stakeholders. It is assumed that these new AASHTO standards and data exchanges will be gradually integrated into the processes of its many members at different times and rates, according to feasibility and workload.

Software Vendor Engagement Plan

The following section of this report provides a more detailed description of each project year's planned emphasis, activities, and goals.

Year 1: Outreach

The primary goal of Year 1 is to engage the software vendors serving the industry and build up the project Software Advisory Group to include as many as possible to meet the needs of the pooled fund members by the end of the project, ultimately in deployment of software to support implementation of the new AASHTO standards.

Recruitment

Year 1 activities include continued outreach to, education, and recruitment of software vendors to join the project Software Advisory Group and address project stakeholder needs for project lifecycle. As part of the recruitment effort, a database of vendors will be established to track vendors and their activities including:

- Vendors contacted
- Primary contact information
- Vendors opting to initially participate
- Meeting/workshop/event attendance
- Quarterly (and more frequent) meetings
- Promotion at industry events (bSI, AASHTO, and general infrastructure industry)
- Product name and type
- Products' support for standards (support type, e.g. IFC import/export, MVD, etc., and version implemented)

Communications

HDR has initiated a Microsoft Team for the project – accessible to participants via the web, mobile, and desktop apps – providing a centralized location for the collection and distribution of information and materials to all project participants and stakeholders. Through Teams, the Software Advisory Group and its members shall communicate with the rest of the project members – advisory group peers, consultant team, and pooled fund members. The consultant team will be responsible for keeping information updated and organized on the Team site.

In addition, there will be an effort to formulate a Marketing Plan to promote vendor participation to AASHTO and buildingSMART communities, as well as the general industry. This may include, but is not limited to:

- Websites (see Collaboration Forum information as a part of Task 5.0);
- Industry events (including AASHTO, buildingSMART, BIMForum, and other relevant industry conferences and events);
- Printed materials (for distribution at events);
- Email campaigns
- Industry press releases
- Industry press articles

Year 2: Commitment and Planning

Vendor Participation and Commitment

Year 2 of the project will push deeper into solidifying commitment by the software vendors to fully participate in the project and support the technical data exchange requirements. If needed, efforts to recruit software vendors will continue.

At this point, the consultant team will distinguish vendors who will commit to continued participation. This may include identifying "Project Participant" versus an "Observer" and formalizing the boundaries and benefits afforded one or the other, such as continued access to the Teams portal, or restricted access which limits the scope and detail of project information and progress. Vendors who choose to commit will be asked to sign a formal "Letter of Intent" (see Appendix A) which establishes the extent of commitment and support of the project on their behalf (e.g. development of solutions, creation of documentation, etc.), as well as the extent of expectations and support from the project management and stakeholders (e.g. technical support, user interactions, marketing, etc.).

The database will continue to be updated to reflect participation.

Product Development Planning

Also, during Year 2 it is crucial to engage the vendors in how they plan to support the data exchange standards through development of their respective software products used by the pooled fund members and their service providers. While Year 1 activities give them a general idea of the overall goals and process of the project, this product development planning step is necessary to verify that both vendors and pooled fund members understand what is needed to succeed.

The consultant team will be responsible for providing User Requirements to all vendors which may address various workflows, data exchanges, and pertinent software throughout the lifecycle of a bridge and associated structures.

The consultant team will work with vendors to establish an overall timeline that reflects the general development of software support, not specific to any single vendor, but an aggregate of vendor efforts to support the identified needs in the User Requirements. This timeline includes, but is not limited to:

- Core IFC4.2 support
- mvdXML support
- User Interfaces (UIs)
- Native software functionality enhancements
- Native-to-IFC data mapping
- Core Export / Import functionality

Initial IFC Testing/Validation

There will be initial testing/validation of IFC4.2 using the Bridge Design Transfer View. This MVD was developed by the buildingSMART IFC Bridge project team, which also developed the proposed IFC4.2 schema. The purpose of this initial IFC testing/validation is to confirm that the Bridge DTV MVD is an appropriate baseline to use for the development of other MVDs identified in the project Roadmap. The project team will communicate with the vendors and select one or more of them to initially test modeling and IFC export of the bridge model concepts. The results of this testing will not preclude or disqualify any vendor from further participation. It is meant to help the project team determine the best route forward in the development of data exchanges for the project.

Exchange details, relevant export MVD configuration material, and test files will be provided by HDR. Validation of exports will be done in conjunction with AEC3.

Test Files

The consultant team will also work to specify the content of test files for use in Years 3 & 4 by the vendors and designated beta-testers. These test files should include base “unit” examples, where a single object or type of object is modeled and exchanged, aggregate unit examples, a bit more complexity with multiple units to test certain spatial and connective relationships, and finally more complex “complete” models which reflect existing or potential design and built conditions to ultimately test the data exchange support. Besides varying in scope or extents, these test files may also vary in detail of geometry and information (aka LOD, LOI, or LOX), to address the different data requirements during multiple stages of a project lifecycle.

In addition, the consultant team and vendors will work to establish and document procedures for the use of the test models, including their creation in different tools, exchanges, verification of files produced (aka Quality Assurance or Quality Control), the reporting of results, as well as the reporting, tracking, and resolution of issues.

Communications

Communication and marketing activities established in Year one will continue with increasing frequency of project meetings with vendors (e.g. monthly) and further project promotion at identified industry events.

Year 3: Development, Implementation, and Testing – Phase 1

Initial Core Development

Year 3 of the project marks the beginning of actual development work in software. It is expected that throughout the year, vendors will pursue internal developments based on the planning documentation from Year 2, including but not limited to:

- Core support for IFC4.2 (IFC5?)
- Mapping of native objects and attributes/properties to desired IFC objects and attributes/properties
- Core IFC export / import support
- mvdXML support

The consultant team should be able to track progress of all vendors who have committed to continuing participation and support development. This includes monthly, if not bi-weekly, meetings with developers to update progress and project schedules.

Beta Testing Program

As development proceeds, the software beta testing program shall be established. This includes the identification of beta testers, identification of software to be tested, planning of testing schedule, signing of vendor NDAs by beta testers, distribution of NFR/beta version software licenses by vendors to designated testers, and launch of issue support, reporting, tracking, and resolution process and tools. Selected beta testers shall include a variety of project stakeholders, as defined by the IDM and the particular workflow/data exchange identified for further development under this project. These testers may include:

- Designers
- Engineering

- Contractor
- Owner
- Fabricators
- … and any other software users necessary to carry out the identified workflow(s).

It will be crucial for the consultant team to deliver the "Candidate version" of the MVD(s) identified for further development under this project to the testers and software vendors. This includes the mvdXML file as well as any other text-based specifications.

Test files, including native and IFC, will be created by beta testers based on the specifications from Year 2 and NRF/beta software delivered by vendors.

Preliminary Certification Discussions

In anticipation of certifying software for its support of the MVDs defined by the AASHTO standards, discussions should commence with buildingSMART International (bSI), or another viable entity, to set up an AASHTO-specific software certification regime. It is assumed that bSI could provide such services on their "b-cert" platform. Other viable alternatives can be offered and discussed. These discussions will include, but not limited to:

- MVD(s) to be tested;
- Identification of development time by bSI, or others, to set up AASHTO certification;
- Identification of AASHTO representatives to administer certification;
- Identification of costs by bSI, or others, to set up and maintain certification;
- Plan for funding of certification through AASHTO investment and vendor fees;

Such discussion will enable bSI, or alternative, to begin work on the AASHTO certification in anticipation of beginning the first testing by vendors by the end of Year 4/beginning of Year 5, with preliminary testing of the platform in the later quarter of Year 4.

Communications

Communication and marketing activities established in Year 1 will continue with increasing frequency of project meetings with vendors (e.g. bi-weekly) and further project promotion at identified industry events.

Year 4: Development, Implementation, and Testing – Phase 2

Over the course of Year 4, User Requirements, standard MVDs, and software implementations should reach final status and full, deployable maturity.

Late-Stage Beta Testing

Beta testing begun in Year 3 shall continue with the goal of wrapping up the majority of development by the end of Year 4. During this time period, MVDs used for testing should reach "Final Standard" status and be available for late-stage beta testing.

Deployment Planning

At this point, the consultant team and software vendors should develop a plan for the deployment of the "final" versions of software developed to support the identified standards. This assumes that the software will be made available to the general market, as well as AASHTO members and their service providers through the usual means of each software vendor's release schedules and processes. The planning will help AASHTO members and service providers anticipate availability and timing for acquisition and deployment in their own organizations.

In addition, the deployment planning should include coordination of documentation and training necessary to inform users about the new processes, workflows, functionality, and data exchange standards and how they are supported in each of the participating software platforms.

Certification Development

Year 4 should see the development and testing of the Certification Platform, as identified in Year 3, in anticipation of vendors being prepared to apply and run through the certification regime in Year 5. All costs and funding necessary to proceed with development and maintenance should be finalized at the beginning of the year to allow development to proceed.

The consultant team will provide the bSI Software Certification team, or alternative team, with the final test models, mvdXMLs, and instructions/documentation for software vendors to utilize in the certification process. The TPF stakeholders shall have identified representatives to administer software certification in cooperation with bSI or alternative and have said representatives trained by bSI or alternative.

The project team should work with the bSI Software Certification team or alternative to develop documentation for the processes, cost schedule/fees, promotional materials, and certificates/logos for the certification regime.

Communications

Communication and marketing activities established in Year 1 will continue with increasing frequency of project meetings with vendors (e.g. bi-weekly or weekly) and further project promotion at identified industry events.

Year 5: Certification and Deployment

Certification

By the beginning of Year 5, set up of the bSI b-cert platform, or alternative, for AASHTO certification should be complete. Documentation of processes, cost schedule/fees, and certificates/logos, as well as promotional/press release templates should be complete. Processes and templates for providing information on AASHTO and certification websites will be complete.

Deployment

After a software vendor's certification is complete and officially granted by the AASHTO Certification team, software vendors will make certified versions available to the marketplace. Promotional efforts will be coordinated between the consultant team, AASHTO, and the software vendors to announce availability.

At the time of deployment, documentation and training to support the workflows and standards should also be made available as either inclusions in the software's standard user manuals, addendums to said documentation, or special documentation to address the AASHTO standards.

Communications

Communication and marketing activities established in Year 1 will continue with increasing frequency of project meetings with vendors (e.g. bi-weekly) and further project promotion at identified industry events. There will also be an increased AASHTO member outreach to help in the education and training in the use of the new standards in available, certified software.

Appendix A: Software Vendor Letter of Intent to Support TPF-5(372)

The following items are recommended to be part of the Letter of Intent, to be signed by authorized representatives of each of the vendors choosing to participate in TPF-5(372) beyond Year 2. The final form of the letter shall be drafted in Year 2, after review of these items from project stakeholders.

Benefits to Vendors

- Immediate availability to marketplace and deployments of AASHTO standards to new projects across all 50 states;
- Technical support by the project team and its consultants in the development and deployment of support for the new standards;
- Marketing by the project team to AASHTO members, the buildingSMART International community, and infrastructure industry in general regarding participation;
- Discounted certification fees.

Responsibilities of Vendors

- Providing NFR and beta versions of software for testing, per consultant team requests;
- Have membership in buildingSMART International (bSI) or the US Chapter for bSI, as well as participating in the bSI Implementation Support Group (ISG);
- Participation in all project meetings;
- Participation in AASHTO and AASHTO member events, as identified by the consultant team;
- Participation in issue tracking program for project beta testing;
- Certification of software after completion of development to support standards;
- Commitment to make applicable, certified software version available to the marketplace by the end of Year 5 of the project.

Additional Notes

It is not expected that vendors will need to share proprietary information regarding their own tool development. However, vendors should accurately respond to project stakeholder requests for clarification on development progress to support their project goals.

There is NOT a requirement for any Intellectual Property (IP) transfer or exposure to the project or project participants.

BIM FOR BRIDGES AND STRUCTURES TPF-5(372)

Appendix 5: Software Vendor One-on-One Meetings and Results Memo

Memo

Project:	TPF-5(372) BIM for Bridges and Structures
Date:	November 1, 2020
To:	Transportation Pooled Fund Study Members
From:	Software Vendor Engagement Team, by Jeffrey W. Ouellette, Sr. Advisor
Subject:	Report of Software Vendor One-on-One Meetings and Results

Summary

Through the month of September, the HDR project team offered one-on-one meetings to the software vendors currently engaged in the project. The purpose of these meetings was to foster an open, frank, and semi-confidential dialog to help the HDR team assess the status of vendors moving forward. This included:

- identifying which vendors were most motivated to follow through to the end of the project;
- how the vendors responded to the Software Vendor Engagement Plan and overall project goals;
- identifying any possible issues the vendors may have in pursuit of implementation and deployment;
- how the HDR team can help them overcome any obstacles to succeed.

Nine of the twenty-two vendors that have participated in previous Software Advisory Group (SAG) meetings participated in these one-on-one meetings.

In general, those software vendors that participated in the one-on-one discussions indicated that the Software Vendor Engagement Plan (SVEP), project goals, and timeline are feasible. Five of the vendors (i.e. ALLPLAN, Autodesk, Bentley, Open Design Alliance (ODA), and Trimble) are also participating in the bSI IFC4.3 Infra and Rail Schema Deployment projects, which should help to measure the progress these software vendors make in the TPF project.

There was a generally positive attitude from the vendors as they are encouraged by the continued open communications and documentation from the project team. However, in light of the low number of vendors who chose to participate in the discussions, it may be helpful to engage in more direct outreach and communication with those vendors that did not participate in order to expand the level of concrete participation through the end of the project.

List of Acronyms

API	Application Programming Interface
BCF	BIM Collaboration Format
bSDD	buildingSMART Data Dictionary
IFC	Industry Foundation Classes
MVD	Model View Definition
SAG	Software Advisory Group
SDK	Software Development Kit
SVEP	Software Vendor Engagement Plan

TPF-5(372) Software Vendor Consultations Agenda

The agenda of one-on-one meetings focused on determining whether and how the vendors were planning to implement and deploy the technology needed to support the standards being developed in the project. The intent of the meetings was twofold:

1. to gauge how seriously and actively vendors were pursuing the project, and
2. to uncover any concerns or issues the vendors may have in this effort.

From this, the project team can further determine how best to support the vendors to be responsive and achieve high-quality results within the project timeframe.

Jeffrey Ouellette, John Reese, and Connor Christian led the discussions, which provided an open forum for the vendors to ask and answer questions. Roger Grant joined some of the meetings. The team kept the number of participants small, with familiar faces, to encourage robust and candid interaction. The HDR team took notes but did not record the meetings. The HDR team did not share specific responses from each vendor with the others, so as to respect each vendor's internal development discussions and process. However, all vendors agreed that the HDR team could share generalized, and anonymized, answers to questions and further questions from their side with everyone.

The following questions were sent as part of the meeting sign-up invitations and used as the meeting agenda:

A) IFC4.3 implementation
   1) Do you license an IFC SDK or develop your own?
   2) Can you meet the timeframe from the SVEP to include base IFC4.3 support in 2021?
   3) Are there any major obstacles in developing IFC4.3 support we should be aware of?
   4) Is there any way we can assist to help you meet those goals?

B) MVD implementation
   1) Are MVD options hardcoded in your UIs or can you handle mvdXML definitions of MVDs?
   2) If not mvdXML, what form of MVD documentation is preferred?
   3) How long does it take to implement an MVD? Will you be able to meet the timeframe to include the identified MVD support in 2021/2022?
   4) Are there any major obstacles in developing MVD support we should be aware of?

5) Is there any way we can assist to help you meet those goals?

C) BCF Support
1) Do you currently support BCF (XML and/or API)?
2) Can you develop BCF support to meet the deployment timeline for this project?
3) Are there any major obstacles in developing BCF support we should be aware of?
4) Is there any way we can assist to help you meet those goals?

D) bSDD Support
1) buildingSMART International is currently working on version 5 of the bSDD with a new API. This project is developing specific content (a "US Infrastructure DD") for this project.
2) Will you be able to implement this in your product?
3) Are there any major obstacles in developing bSDD support we should be aware of?
4) Is there any way we can assist to help you meet those goals?

E) Test Files / Certification
1) Besides the Michigan DOT files currently available, we will be developing a suite of unit test files for your use in development testing, as well as for certification. Can you think of any requirements you may have from your perspective for these files to be of the most use to you?
2) Will you be able to meet the timeframe to certify your implementation in 2023?
3) Are there any major obstacles in meeting that goal that we should be aware of?
4) Is there any way we can assist to help you meet those goals?

F) Letter of Intent

The SVEP states that Vendors who wish to continue participation in the project and pursue full implementation, deployment, and certification sign a Letter of Intent.

The purpose of the letter is to formalize the vendor's commitment to the project and provide assurances that the utmost effort will be made to meet the project goals. In return, your company will be included in marketing and communications for the project, hopefully raising the profile of both. It will also indicate which vendors will have software available to the AASHTO members and their service providers, to begin planning for deployment and adoption in 2023.

1) Will your company sign the Letter of Intent?
2) What prevents your company from signing the Letter?

Vendors were also encouraged to ask the project teams questions to help clarify requirements, process, and/or intent.

Participants

The following table lists the current members of the SAG who participated in these meetings and those who did not. Nine vendors participated out of the twenty-two vendors currently involved in SAG meetings and have access to HDR's Microsoft Teams portal for the project. Each vendor provided between two and six representatives to participate in the discussion.

Software Vendor	Meeting Date
Trimble	September 2, 2020
LARSA 4D	September 3, 2020
ALLPLAN	September 11, 2020
Promiles & Michael Baker (AASHTOWare BrD/BrR)	September 23, 2020
University of Florida, Bridge Software Institute (FB-MultiPier)	September 23, 2020
Bentley Systems	September 24, 2020
Mayvue (AASHTOWare BrM)	September 25, 2020
Open Design Alliance (ODA)	September 30, 2020
Autodesk	September 30 , 2020
*AgileAssets, Inc.	-
*Asite	-
*BridgeSight, Inc.	-
*CSI	-
*Eriksson Software	-
*Glider Technology Ltd.	-
*InEight	-
*Infotech (AASHTOWare Project)	-
*Invicara	-
*LUSAS	-
*MIDASoft	-
*Red Equation / OpenBrIM	-
*Solibri	-
**Participating in Software Advisory Group (SAG), but did not meet*	

Conclusions

The vendors who met with the team demonstrated a positive attitude toward this project and seemed encouraged by the continued open communications and documentation from the project team. There are a few points, regarding vendor participation in the project, that need to be addressed by the project team and Pooled Fund members. These points are outlined in the following list:

1) Participation

   Even though the largest and most well-known vendors (ALLPLAN, Autodesk, Bentley Systems, and Trimble) participated in the discussions, a majority of the vendors involved in the quarterly SAG meetings did not take the opportunity to meet one-on-one with the project team. This may be due to several factors including:

   a. Reluctance to commit to a project at a relatively early stage;
   b. Waiting to see how the project progresses, if at all;
   c. Lack of understanding where their software fits into the goals of the project, if at all;
   d. Lack of IFC knowledge and uncertainty about how to address functionality in their software.

   This doesn't automatically prohibit the other vendors from continuing general participation, but the project team has indicated in previous SAG meetings that preferential development, implementation, and deployment support, as well as preferred external marketing exposure during the duration of the project, will be given to those companies that sign the Letter of Intent.

   However, this is an opportunity to address issues and boost the participation and enthusiasm of vendors beyond the recent nine that engaged in the one-on-one meetings. This includes:

   a. **Finish the work of the IDM / MVD development.** This would clarify what workflow(s), and subsequent tools, might be addressed with the initial data exchange requirements. It would be helpful to provide plain language narrations of the workflow(s), identifying stakeholders, use of data, potential types of tools for the use of data, and desired results. This would help all vendors understand the value of pursuing the project immediately and keeping pace with the project goals and timeline.

   b. **Further outreach by the Pooled Fund members.** The vendors that engaged in the one-on-one discussions fully understand the AASHTO intentions to pursue the data interoperability goals of this project and beyond using IFC. ALLPLAN, Autodesk, Bentley Systems, Trimble and ODA have extensive previous experience with IFC-based interoperability and the needs expressed by asset owners and project delivery process stakeholders within the building domain. To them, this is an extension of the work they have done in the past. The other vendors may need more encouragement by Pooled Fund members, project delivery teams and service providers, as well as the other SAG members to move beyond their past experiences with bridge data standardization, which did not come to fruition.

   c. In the case of AASHTOWare, it would be very helpful to the various software development contractors of the different AASHTOWare modules to have **further direction from the**

AASHTOWare Special Committee and Technical and Applications Architecture Task Force on how best to proceed. This includes determining if the proposed model-based workflows are well-suited for the platform and, if so, what means of providing IFC support for data exchange (e.g. an IFC import/export toolkit) should be used.

2) Development, Implementation, and Deployment Timeline

The current timeline appears to be within the capacity of the vendors to meet the development, implementation, and deployment goals of the project. Vendors indicated that timely execution requires getting more detailed IFC and MVD information and development support (e.g. Unit Test files) as soon as possible. This includes the following items that need to be addressed by the project team as highest priority:

a. Wrapping up MVD development and decision on how MVDs will be documented and delivered to vendors (e.g. HTML documentation, EXP, XSD, and mvdXML files);

b. Providing more information on the project's Data Dictionary progress and how it is intended to be used and deployed (e.g. content development and use of bSDD service from buildingSMART International). Providing preliminary data for testing would be helpful;

c. Design of the Unit Test Plan and development of the Unit Test Suite of files. This is specific to the requirements of support for this project, supplemented by files the vendors may already have access to as part of the bSI IFC4.3 Infra and Rail Deployment projects;

d. Determining the certification process, technology, and costs (e.g. use of buildingSMART International's b-cert.org platform).

3) Letter of Intent

The Letter of Intent contains a formal pledge of support for the standards and an intent to pursue development, implementation, and deployment of technology supporting the standards in exchange for further marketing/promotional and technical development and deployment support opportunities for their company and products. For the most part, the vendors agreed to the stated principals of the Letter of Intent. The vendors also agreed that, while not legally binding, such a letter is a good faith gesture on both sides and has recognizable value.

Appendix 6: Investigation and Exploration Report: Common Data Standard Efforts

BIM FOR BRIDGES AND STRUCTURES TPF-5(372)

Investigation and Exploration

Task 1 Report
February 2020
2.1

BIM FOR BRIDGES AND STRUCTURES TPF-5(372)

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List of Abbreviations

AADT	Average Annual Daily Traffic
AASHTO	American Association of State Highway Transportation Officials
BIM	Building Information Modeling
BME	Bridge Management Elements
BrIM	Bridge Information Modeling
bSDD	buildingSMART Data Dictionary
bSI	buildingSMART International
CDX	Common Data Exchange
COBS	Committee on Bridges and Structures
CSI	Construction Specifications Institute
ERM	Exchange Requirements Mode
FDE	Fundamental Data Elements
FHWA	Federal Highway Administration
GUID	Globally Unique Identifier
IDM	Information Delivery Manual
IFC	Industry Foundation Classes
ISO	International Organization for Standardization
KCJIS	Kansas Criminal Justice Information System
MAP-21	Moving Ahead for Progress in the 21st Century
MIRE	Model Inventory of Roadway Elements
MVD	Model View Definition
NBE	National Bridge Element
NBI	National Bridge Inventory
NBIMS-US™	National Building Information Modeling Standard – United States
NIEM	National Information Exchange Model
NSBA	National Steel Bridge Alliance
OGC	Open Geospatial Consortium
SCOA	Special Committee on AASHTOWare
TPF	Transportation Pooled Fund
XML	eXtensible Markup Language

Chapter 1 – Introduction

The report documents the outcome of research to find comparative implementation efforts of common data standards and makes terminology recommendations for Building Information Modeling (BIM) for Bridges and Structures. The goal of the first task is to document and report on comparable industry efforts that require a shared vocabulary and definition of terms. The goal of the second task is to create a reference document of standardized terminology and definitions for BIM for Bridges and Structures. These topics are covered in Chapters 2 and 3, respectively.

Purpose

Business processes in transportation are increasingly being digitized and automated; there is an ongoing need to standardize digital information exchanges. These information exchanges happen both within an agency and with external public agencies at the local, state, and national level. To execute an information exchange, the data fields in a source database must be matched to the data fields in a target database. Data dictionaries that use standardized terminology and data definitions that include the format, resolution, and accuracy of the data make it easier to execute both planned and *ad hoc* information exchanges.

The first task identified potential targets for digitally exchanging information from BIM for Bridges and Structures. The second task created a compendium of standard terminology that will be used to build a data dictionary for BIM for Bridges and Structures. Figure 1 shows the steps from identifying terminology to producing an Information Delivery Manual (IDM). This report describes the first two steps. Steps three and four are part of the TPF-5(372) project Task 4: Industry Foundation Classes (IFC) Development and Verification. Task 4 includes additional steps to create the IDM.

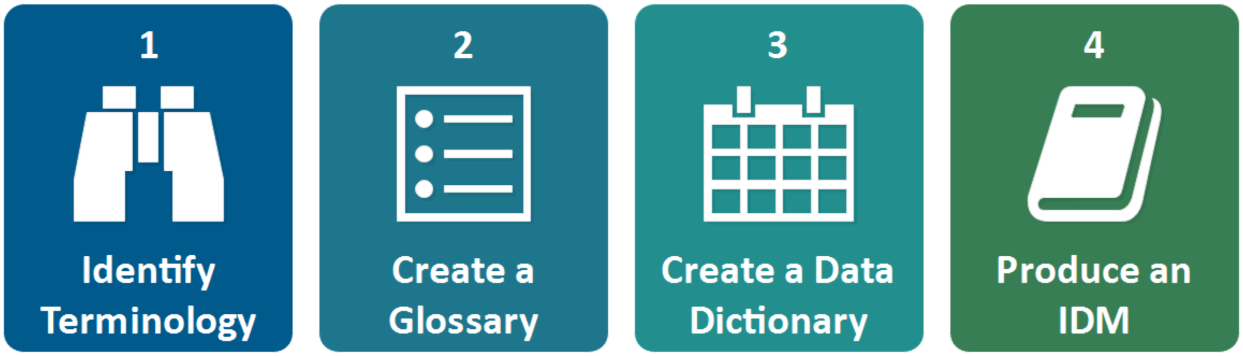

Figure 1: The path for terminology from identification to IDM.

A secondary purpose of the standardized terminology is to support stakeholder engagement and outreach activities. The compendium of terminology will serve as a reference for consistent messaging and as a glossary of terms for stakeholders.

Chapter 2 – Comparable Efforts

This section summarizes comparable implementation efforts for creating common data standards. The identified efforts share vocabulary and definitions of terms with BIM for Bridges and Structures. Each effort was described in terms of its purpose, governance, relationship to bridges and structures, and types of exchanges of BIM for bridges and structures information. Each comparative effort was also assessed in four qualitative categories:

- **Resolution**: Describes the level of detail at which bridges and structures are represented; i.e., is the bridge described as a single entity (*low*), as general systems (*medium*) or in detail (*high*). These options are presented in Figure 2.
- **Scale**: Describes whether the standard applies at the *local*, *national*, or *international* level. These options are presented in Figure 3.
- **Phase**: Describes the phase in the lifecycle of bridges and structures at which the standard applies; i.e. whether it describes bridge information during *design*, *construction* (including fabrication), operations, or *maintenance*. These options are presented in Figure 4.
- **Coordination**: Describes whether the BIM for Bridges and Structures project should *monitor* the standard, *align* to the standard, *collaborate* with the standard's governing body, or *inform* the governors as part of the stakeholder engagement and outreach activities. These options are presented in Figure 5.

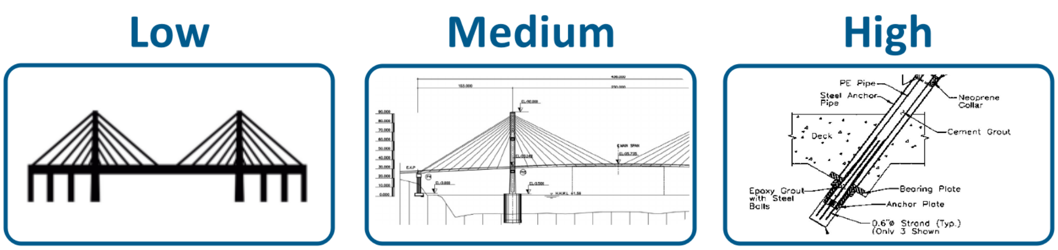

Figure 2: Options for Resolution

Figure 3: Options for Scale

Figure 4: Options for lifecycle Phases

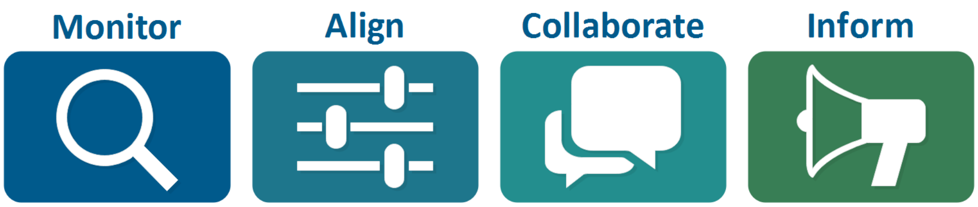

Figure 5: Options for level of Coordination

The standards are grouped by domain, from general, multi-industry standards to transportation standards and standards that are focused specifically on bridges and structures.

General Standards

This section summarizes standards for information exchanges with a broad purview.

National Information Exchange Model (NIEM)

The National Information Exchange Model (NIEM) is a data model made up of core elements (the NIEM Core) with definitions that are universal (e.g. person, location, activity) and elements defined by communities. It is an XML-based information exchange framework. The NIEM model establishes the rules and methods for using the model and a standardized information exchange development lifecycle. (National Information Exchange Model, 2019) There are 14 communities within NIEM and more are likely to be added in the future. The communities include Surface Transportation, Infrastructure Protection, and Emergency Management. NIEM is developed for the U.S. by U.S. government agencies, but it is used by public and private organizations in the U.S. and internationally.

Purpose

NIEM facilitates inter-agency coordination and data sharing. NIEM was initially designed for the law enforcement and homeland security communities. The Kansas Bureau of Investigation and the Kansas Department of Transportation used NIEM to create the Kansas Criminal Justice Information System (KCJIS). KCJIS enables various state and local agencies to submit and store disposition reports (relating to criminal driving violations) in one electronic repository. (National Information Exchange Model, 2015)

Governing Body

NIEM is governed by committees operating in four areas:

- An **Executive Steering Council**, which makes organizational decisions about membership, funding needs, program direction, technical direction, and staffing.
- A **Management Office**, which manages daily operations, markets the standard, coordinates with stakeholders and other information-sharing initiatives, and provides oversight to the working groups and committees.
- A **Business Architecture Committee**, which establishes the business architecture and requirements, manages the NIEM Core, and regulates how the NIEM domains are added and how they coordinate.
- A **Technical Architecture Committee**, which establishes the technical architecture, manages technical specification documents, and develops the NIEM Core and related processes for developing data definitions and information exchange specifications.

Role of Bridges

"BridgeStructure" is a facility type defined in the Surface Transportation domain, one of 14 NIEM domains. The "BridgeStructure" facility type refers to bridge, underpass, overpass, or tunnel structures and can be linked to the National Bridge Inventory (NBI). The information connected to the "BridgeStructure" facility type is aggregate; examples are contact information, capacity, location (which could be an address or a geospatial coordinate), and a facility diagram that is an image.

The Surface Transportation domain includes limited, aggregate information about the highway transportation system. There are federal identifiers, such as the National Highway System (NHS) route code, Average Annual Daily Traffic (AADT), functional class, access control and operation information (one-way or two-way operations) and limited geometric information such as width and slope.

Exchange Types

The Surface Transportation domain is intended for transportation regulators, operators, and users, including law enforcement and emergency management partners. Exchanges would occur during operations and maintenance phases, such as when an incident occurs or a structure is closed or significantly modified.

Summary

NIEM is a low-resolution standard with a national scale. It applies during the operations phase of a bridge. The TPF-5(372) project should monitor the NIEM standard for any efforts to expand the scope of the Surface Transportation domain to define bridges in more detail. NIEM does not currently break a bridge down into components. Figure 6 summarizes the characteristics of NIEM.

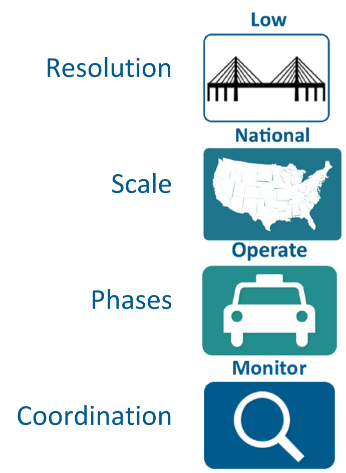

Figure 6: Characteristics for NIEM

buildingSMART Data Dictionary

The buildingSMART Data Dictionary (bSDD) is one of the services that buildingSMART International (bSI) provides to support the implementation of bSI standards, such as IFC. The bSDD is a shared library of building and construction industry objects and their attributes, which is organized using a standard ontology (ISO 12006-3). (buildingSMART International, 2019) The bSDD is intended to serve as the highest level of knowledge representation and developers can continue to add more detail to it. The bSDD includes over 200,000 “concepts” with over 800,000 “names” (drawing from multiple languages) and over 800,000 “relationships” between them. (buildingSMART International, 2019)

Purpose

The bSDD is a tool that enables members of the global building and construction industry to share product information. The bSDD is a tool for content owners to align their data to the IFC standard and to produce an IDM. (buildingSMART International, 2019)

Governing Body

bSI owns the copyright to the bSDD, but it is a user service that is implemented by users; local chapters play a key role in delivering the service.

Role of Bridges

There is space in the bSDD specifically for bridge property sets. Bridges and their sub-components are subjects in the bSDD. For example, a Bridge is a subject with properties of location, position, and point. It has many subtypes, including arch bridge and truss bridge. Bridge subjects are part of a larger object group that includes road, tramway, street, and railroad subtypes.

Exchange Types

The bSDD is a tool for creating IDMs and thus it serves all exchanges in the bridge asset lifecycle.

Summary

The bSDD is a high-resolution standard with an international scale. It applies during all phases of the bridge lifecycle. The standard developed by the TPF-5(372) project should align to the bSDD standard and could potentially add to it. Figure 7 summarizes the characteristics of the bSDD.

Figure 7: Characteristics for bSDD

ISO 19650 Building Information Modeling

The International Organization for Standardization (ISO) standard for Building Information Modeling (BIM), ISO 19650, evolved from the United Kingdom 1192 series of publicly available specifications for BIM Level 2. The ISO 19650 is an international standard for managing information about built assets (including buildings and civil works) using BIM over the asset lifecycle. The standard is officially called *“Organization and digitization of information about buildings and civil engineering works, including* *building information modelling -- Information management uses building information modelling."* Two standards in the series have been published to date:

- BS EN ISO 19650-1, which covers concepts and principles, (International Organization for Standardization, 2018) and
- BS EN ISO 19650-2, which covers the delivery phase of the assets. (International Organization for Standardization, 2018)

Purpose

The ISO 19650 standard establishes the foundation of business processes for information management (ISO 19650-1) and specific requirements for the information (ISO 19650-2) to be used with BIM.

Governing Body

The standard was developed by Technical Committee ISO/TC 59, *Buildings and civil engineering works*, SC 13, *Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM)* and is maintained by the ISO.

Role of Bridges

Bridges are one of the built assets—along with roads, buildings, etc.—covered by the standard.

Exchange Types

The standard applies to all phases of the asset lifecycle.

Summary

ISO 19650 is a high-resolution standard with an international scale. It applies during the whole lifecycle of a bridge. The standard and guidelines developed by the TPF-5(372) project should align to the ISO 19650 standard. Figure 8 summarizes the characteristics of ISO 19650.

Figure 8: Characteristics for ISO 19650

IFC4 Precast

There is already an IFC standard for the design-to-fabrication exchange for precast architectural elements, which was developed in 2009 by a committee of the Precast/Prestressed Concrete Institute with support from Georgia Tech. (National Institute of Building Sciences, 2009) However, there is not yet an IFC standard for taking shop models to production. This is particularly important for automated fabrication equipment, such as precast manufacturing execution systems (MES) and Production Planning Software (PPS) systems. (buildingSMART Deutschland, 2018)

Purpose

The IFC4 Precast project aims to create an international standard for exchanging data from shop models to MES and PPS systems. Specifically, the project aims to extend the reach of open BIM into precast production, bridge the gap between shop models and MES/PPS systems with a standardized data exchange based on the IFC standard, and improve data flow across the building asset lifecycle. (buildingSMART Deutschland, 2018)

Governing Body

The buildingSMART German Chapter oversees the execution of the IFC4 Precast project.

Role of Bridges

Precast concrete bridge elements are within the scope of precast elements covered by the standard.

Exchange Types

The standard applies to the fabrication phase only, which is a subset of the construction phase.

Summary

The IFC4 Precast project is a high-resolution standard with an international scale. It applies during the construction phase of a bridge. The standard and guidelines developed by the TPF-5(372) project should align to the IFC4 Precast standard. Figure 8 summarizes the characteristics of the IFC4 Precast project.

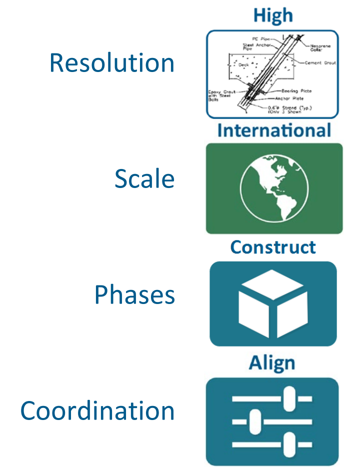

Figure 9: Characteristics for IFC4 Precast

National Building Information Modeling Standard-United States® Version 3

The National Building Information Modeling Standard-United States® version 3 (NBIMS-US™ V3) is an open consensus standard. That is, NBIMS-US™ V3 is a framework for using BIM based on industry-accepted open standards. NBIMS-US™ V3 uses reference standards (such as the ISO 16739 standard for IFC 2x3 and OmniClass™), has a compendium of terms and definitions, uses reference information exchange standards (such as Construction Operations Building information exchange version 2.4), and references practice guidelines such as the U.S. Army Corps of Engineers contract requirements for design-build projects and the BIMForum Level of Development Specification. (National Institute of Building Sciences, 2015)

Purpose

NBIMS-US™ V3 is a curation of notable practices for using BIM that enables owners and practitioners to select the best-available process and open data exchange for using BIM.

Governing Body

The National Institute of Building Sciences (NIBS) governs NBIMS-US™ V3.

Role of Bridges

NBIMS-US™ V3 could be used on bridge construction projects or bridge owners could use NBIMS-US™ V3 to develop their own BIM standard and practice guidelines.

Exchange Types
NBIMS-US™ V3 is primarily for information exchanges during construction project delivery, though it is intended to support BIM uses throughout the asset lifecycle. These include delivering the project specifications (i.e. design-to-construction exchanges) as well as furnishing facility information for asset management (i.e. construction-to-operations exchanges).

Summary
NBIMS-US™ V3 is a high-resolution standard with a national scale. It applies primarily during the design and construction of a bridge. The TPF-5(372) project should align to NBIMS-US™ V3. Figure 10 summarizes the characteristics of NBIMS-US™ V3.

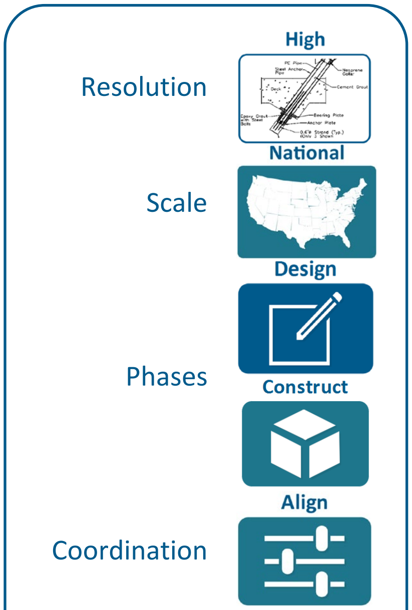

Figure 10: Characteristics for NBIMS-US™ V3

Common Data Exchange

Common Data Exchange (CDX) is a communication framework that is being developed to streamline information management at the construction project level. It promotes open data standards and transparent workflows for data exchange. (Construction Progress Coalition, 2018)

Purpose
CDX enables project stakeholders to identify their data needs, actors, and relevant standards to implement the data exchanges through valid workflows.

Governing Body
The Construction Progress Coalition, a non-profit organization, governs CDX.

Role of Bridges
CDX could be used on bridge construction projects.

Exchange Types
CDX is for information exchanges during construction project delivery. These include delivering the project specifications (i.e. design-to-construction exchanges) and exchanging information througout the project, such as for Requests for Information.

Summary
CDX is a high-resolution standard with a national scale. It applies during the design and construction of a bridge. The TPF-5(372) project should inform Construction Progress Coalition as part of stakeholder engagement and outreach activities. Figure 11 summarizes the characteristics of CDX.

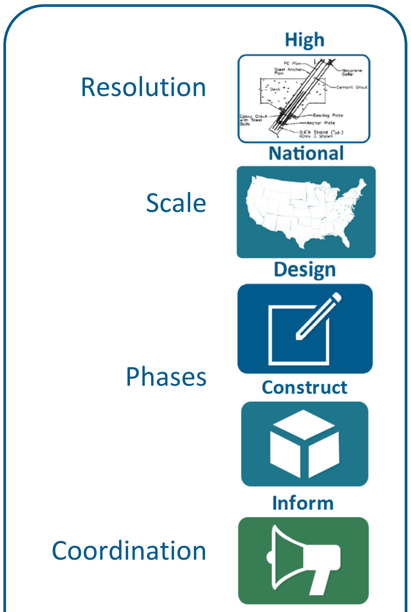

Figure 11: Characteristics for CDX

CSI Project Dynamo

The Construction Specifications Institute (CSI) is a national membership association representing the building construction and materials industry. CSI has a mission to advance building information management, education, and facility performance. CSI's activities include developing and maintaining standards such as MasterFormat®, UniFormat®, and OmniClass®. UniFormat® is widely used to organize BIM objects. CSI Project Dynamo is a pilot program to expand these three CSI standards to improve how they connect BIM objects to specification information. (Construction Specifications Institute, 2018)

Purpose

BIM provdies the physical geometry required for construction, but a lot of construction requirements are provided by specifications. CSI Project Dynamo is a pilot project to better connect the specification information to the physical geometry contained in BIM.

Governing Body

CSI Project Dynamo is a CSI initiative.

Role of Bridges

Bridges and structures are just one of many types of built assets that CSI Project Dynamo would serve.

Exchange Types

CSI Project Dynamo relates to connecting BIM objects to specification information. This is related to the design and construction phases of the lifecycle (including fabrication). These exchanges could be for bidding and estimating bridge projects or for fabricating and constructing bridges.

Summary

CSI Project Dynamo is a high-resolution standard with a national scale. It applies during the design and construction phases of a bridge. The TPF-5(372) project should inform CSI Project Dynamo as part of stakeholder engagement and outreach activities. Figure 12 summarizes the characteristics of CSI Project Dynamo.

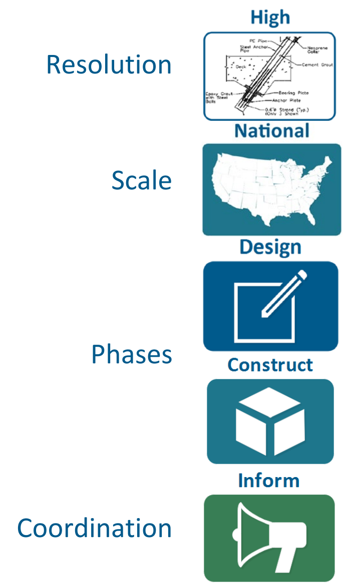

Figure 12: Characteristics for CSI Project Dynamo

Transportation Standards

This section summarizes standards for information exchanges within the transportation industry.

Model Inventory of Roadway Elements

The Model Inventory of Roadway Elements (MIRE) is a framework for roadway inventories. It provides a comprehensive list of data elements and a data dictionary. MIRE is specifically for data-driven safety analysis, but the second version (MIRE 2.0) is consistent with other federal data programs: Highway Performance Monitoring System, Long-Term Pavement Performance program, and the Second Strategic Highway Research Program Roadway Information Database. (Lefler, et al., 2017)

Purpose

Data-driven safety requirements have been part of the federal transportation law since the Moving Ahead for Progress in the 21st Century (MAP-21) Act in 2012. MIRE was created as part of implementing MAP-21. MIRE provides a structure for roadway inventory data that enables roadway owners to use their own inventory data with analysis tools and to comply with requirements for Highway Safety Improvement Program funds.

Governing Body

The Federal Highway Administration (FHWA) safety program office governs MIRE.

Role of Bridges

Part of the process of creating MIRE 2.0 involved reviewing the NBI data dictionary and database. Bridges are not one of the 37 Fundamental Data Elements (FDE) in MIRE. Bridge descriptors are one of several "supplemental databases" identified in the MIRE 2.0 report that agencies could include in their safety analysis, but are not required to by law. Other "supplemental databases" include signs, roadside fixed objects, speed data, and pavement data.

The MIRE elements are grouped into six main sections: Segment, Intersection, Intersection Leg, Interchange/ramp, Horizontal Curve, and Vertical Grade. "Bridge Numbers for Bridges in Segment" is the 109th and last element for Segments. This element is the official bridge number and can be used to link the safety data to the NBI record or to the record in the bridge owner's bridge inventory.

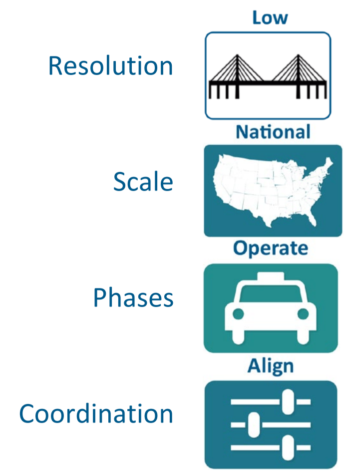

Figure 13: Characteristics for MIRE

Exchange Types

MIRE is specifically for exchanging safety data. It could be used to locate crash data for bridge assets.

Summary

MIRE is a low-resolution standard with a national scale. It applies during the operations phase of a bridge. The standard developed by the TPF-5(372) project should align to the MIRE standard. This would occur at the highest level, as MIRE does not break a bridge down into components. Figure 13 summarizes the characteristics of MIRE.

IFC-Alignment & IFC Infra Overall Architecture

The IFC-Alignment & IFC Infra Overall Architecture projects provided the foundational, common elements that were required in order to extend the IFC schema to support linear infrastructure assets. The IFC-Alignment project provided the data structures for alignments and alignment-based positioning. The IFC Infra Overall Architecture project provided additional basic data structures and made recommendations for developing extensions for infrastructure assets. The two projects were developed in parallel and in partnership with the Open Geospatial Consortium (OGC) in order to create aligned conceptual models and a common basis for IFC-Infra and InfraGML. (Borrmann, et al., 2017)

Purpose

The IFC-Alignment project and the IFC Infra Overall Architecture project are extensions to the IFC standard to enable its expansion to support road, rail, bridge, and tunnel assets. Both elements were adopted into the IFC standard as part of the IFC 4.1 release.

Governing Body

The IFC Infra Room, a subcommittee of bSI, governs the IFC-Alignment and IFC Infra Overall Architecture standards.

Role of Bridges

The schema extensions provide foundational elements that support bridge geometry and bridge project elements. These are:

- alignment and alignment-based positioning geometry,
- representations for stringlines, cross-sections, surfaces, and solids, and
- terrain objects (as Triangulated Irregular Networks)

Exchange Types

The standard applies to all phases of the asset lifecycle.

Summary

IFC-Alignment and IFC Infra Overall Architecture are high-resolution standards with an international scale. They apply during all phases of the bridge lifecycle. The standard developed by the TPF-5(372) project should align to the IFC-Alignment and IFC Infra Overall Architecture standards. Figure 14 summarizes the characteristics of IFC-Alignment and IFC Infra Overall Architecture.

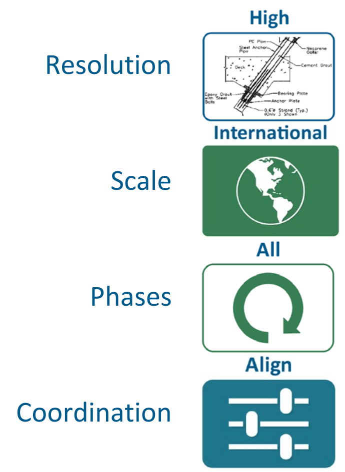

Figure 14: Characteristics for IFC-Alignment & IFC Infra Overall Architecture

IFC Road

IFC Road extends the IFC schema to describe road semantics and geometry. The IFC Road project intends to publish the schema extension as an ISO standard. The project began with leadership from the Korean chapter in 2012 and joined the bSI Infra Room in 2014. The project was delayed to allow the IFC Infra Overall Architecture and IFC-Alignment projects to complete. The Korean chapter continued development, diverging the Korean IFC Road standard from the IFC Road project. The Korean IFC Road standard was adopted by bSI as a bSI SPEC. A bSI SPEC is a publicly accessible specification, which differs from a bSI standard in that it does not need to reach consensus. An organization that is interested in standardizing a practice, without advancing it to a bSI Standard, can publish a bSI SPEC and receive comments. (Moon, et al., 2018)

Purpose

The IFC Road project is an extension to the IFC standard to support road and highway assets.

Governing Body

The IFC Infra Room, a subcommittee of bSI, governs the IFC Road project. The Korean chapter of bSI governs the Korean IFC Road SPEC, which diverged from the international IFC Road project in 2016.

Role of Bridges

The schema extension provides support for the roadway elements that may form part of bridge construction projects.

Exchange Types

The IFC Road standard applies to all phases of the asset lifecycle.

Summary

IFC Road is a high-resolution standard with an international scale. It applies during all phases of the bridge lifecycle. The standard developed by the TPF-5(372) project should align to the IFC Road standard. Figure 15 summarizes the characteristics of IFC Road.

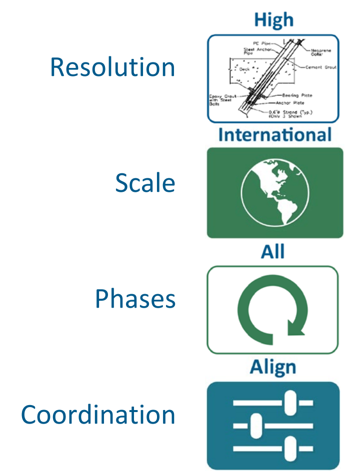

Figure 15: Characteristics for IFC Road

AASHTOWare Data Integration Framework

AASHTOWare products provide critical business systems for many State transportation agencies. Currently, there is no comprehensive AASHTOWare data dictionary and the AASHTOWare products integrate in an *ad hoc* manner with other agency business systems. The AASHTOWare Data Integration Framework is a research project to identify product integration points, develop a data dictionary, and create a process to integrate AASHTOWare with other agency systems. (Edwards, 2018)

Purpose

Increasingly, agencies need the mission-critical business data stored in AASHTOWare product databases to perform analyses. The AASHTOWare Data Integration Framework will create a data dictionary and a path to integrate the business data stored in AASHTOWare with other agency business systems.

Governing Body

AASHTOWare is governed by the American Association of State Highway Transportation Officials (AASHTO) Special Committee on AASHTOWare (SCOA).

Role of Bridges

AASHTOWare Bridge is one of the four main AASHTOWare product groups.

Exchange Types

The AASHTOWare Data Integration Framework seeks to integrate data across all phases of the asset lifecycle. Specifically for bridges, bridge data may be connected to the related data residing in the three other AASHTOWare products groups: Project (construction and materials information), Pavement, and Safety. The AASHTOWare Data Integration Framework (especially through the data dictionary) could connect bridge data to related data residing in non-AASHTOWare agency business systems.

Summary

The AASHTOWare Data Integration Framework is a medium-resolution standard with a national scale. The AASHTOWare Data Integration Framework applies to all phases of the bridge lifecycle. The TPF-5(372) project should collaborate with SCOA. Figure 16 summarizes the characteristics of the AASHTOWare Data Integration Framework.

Figure 16: Characteristics for the AASHTOWare Data Integration Framework

Bridge Standards

This section summarizes standards that are focused specifically on bridges.

IFC Bridge

IFC Bridge extends the IFC schema to describe bridge semantics and geometry. The IFC Bridge project is a two-step project to extend the IFC schema to support bridges. The first step is to implement basic “workhorse” bridge support in IFC 4.2 and expand the complexity of bridge elements supported by the IFC standard in the 5.0 release. (Castaing, et al., 2017)

Purpose

The IFC Bridge project is an extension to the IFC standard to support bridge assets.

Governing Body

The IFC Infra Room, a subcommittee of bSI, governs the IFC Bridge project.

Role of Bridges

Bridges are the focal element of this schema extension.

Exchange Types

The standard applies to all exchanges of bridge geometric information. It is currently being developed to support design-to-construction, design-to-fabrication, and construction-to-operations exchanges.

Summary

IFC Bridge is a high-resolution standard with an international scale. It applies during all phases of the bridge lifecycle. The TPF-5(372) project should collaborate with the IFC Bridge project. Figure 17 summarizes the characteristics of IFC Bridge.

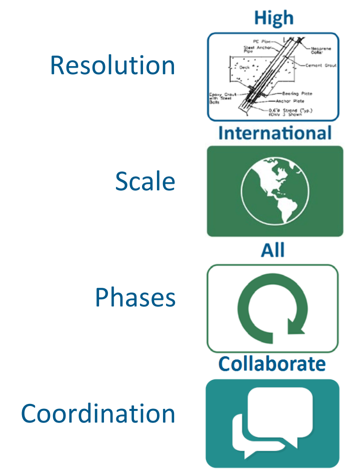

Figure 17: Characteristics for IFC Bridge

National Bridge Inventory

The FHWA is required by 23 U.S.C. 144 to maintain an inventory of all highway bridges on public roads and to classify the bridges by a number of criteria. The inventory is the NBI. Agencies are also required to conduct regular element-level inspections of bridges included in the NBI and submit routine reports to the FHWA.

Purpose

The Specification for NBI Elements provides the framework for collecting and reporting the required data to the FHWA. The AASHTO Manual for Bridge Element Inspection provides further guidance. (Federal Highway Administration, 2014)

Governing Body

The FHWA governs the NBI.

Role of Bridges

Bridges are the focal element of this database.

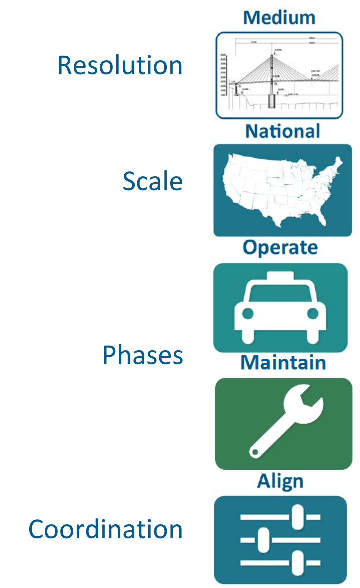

Figure 18: Characteristics for the NBI

Exchange Types

The standard applies to routine reporting of bridge inventory and element-level condition information.

Summary

The NBI is a medium-resolution standard with a national scale. The NBI applies to the operations and maintenance phases of the bridge lifecycle. The TPF-5(372) project should align to the NBI. Figure 18 summarizes the characteristics of the NBI.

Manual for Bridge Element Inspection

The Manual for Bridge Element Inspection is a manual for bridge owners to guide element-level condition assessments. Element-level bridge assessment became typical in the 1990s and best practices have continued to evolve. The Manual for Bridge Element Inspection provides guidance for two element types: National Bridge Elements (NBEs) and Bridge Management Elements (BMEs).

NBEs are structural elements, such as superstructure and deck, necessary to determine the safety and condition of primary load-carrying members. NBE data is consistent from agency-to-agency and includes the core data reported to the NBI. BMEs are additional elements (such as joints and coatings) that agencies manage as part of their Bridge Management Systems. BMEs may vary from agency-to-agency. The manual also includes Agency Developed Elements, which gives agencies a way to customize their inspection data models.

Purpose

The Manual for Bridge Element Inspection provides a consistent framework for element inspection. The consistent approach to element inspection enables the FHWA to use the NBI to develop national policy and it enables states to share best practices.

Governing Body

The AASHTO Committee on Bridges and Structures (COBS) governs the Manual for Bridge Element Inspection.

Role of Bridges

Bridges are the focal element of this manual.

Exchange Types

The Manual for Bridge Element Inspection is specifically for the collection and sharing of bridge inspection information. It is used to exchange bridge condition information between inspection software and the Bridge Management System or from the Bridge Management System to the NBI.

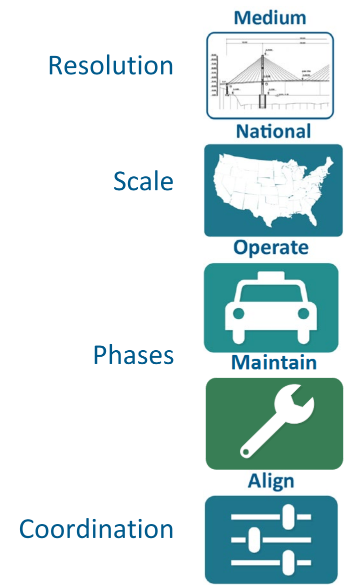

Figure 19: Characteristics for the Manual for Bridge Element Inspection

Summary

The Manual for Bridge Element Inspection is a medium-resolution standard with a national scale. The Manual for Bridge Element Inspection applies to the operations and maintenance phases of the bridge lifecycle. The TPF-5(372) project should align to the Manual for Bridge Element Inspection. Figure 19 summarizes the characteristics of the NBI.

Bridge Information Modeling Data Dictionary

The Bridge Information Modeling (BrIM)[1] Data Dictionary is a project conducted by the National Steel Bridge Alliance (NSBA) through its Task Group 15: Data Modeling for Interoperability. NSBA previously developed an initial taxonomy of "workhorse" bridge terms. There is a current NSBA project to formalize that taxonomy into a data dictionary. (National Steel Bridge Alliance, 2019)

Purpose

Steel bridge fabricators have a desire to receive digital information to estimate and fabricate bridges.

Governing Body

The NSBA Task Group 15: Data Modeling for Interoperability governs the BrIM Data Dictionary.

Role of Bridges

Bridges are the focal element of this data dictionary.

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[1] Bridge Information Modeling (BrIM) is the name of the NSBA project. COBS adopted a resolution to use the term "BIM for Bridges and Structures," which is the preferred term for the TPF-5(372) project.

Exchange Types

The BrIM Data Dictionary is being developed for the exchange from designer to erector. However, a data dictionary is a tool for creating IDMs and thus it serves all exchanges in the bridge asset lifecycle.

Summary

The BrIM Data Dictionary is a high-resolution standard with a national scale. The BrIM Data Dictionary applies primarily to the construction (specifically, fabrication) phase of the bridge lifecycle. The TPF-5(372) project should collaborate with the NSBA Task Group 15. Figure 20 summarizes the characteristics of the BrIM Data Dictionary.

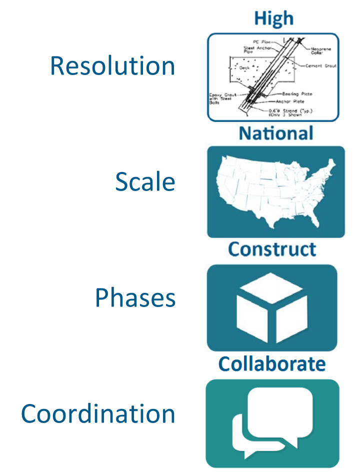

Figure 20: Characteristics for BrIM Data Dictionary

Project Delivery Workflow and National Library

The Project Delivery Workflow and National Library (PDW&NL) research project has two objectives. The first is to study workflows for bridge and roadway project delivery and asset management. The second is to develop a conceptual framework for a national library of BIM-based object definitions and a process to create and maintain the library.

Purpose

The first objective is to create guidelines for incorporating BIM into highway and bridge development and management processes. The second objective is to support crowd sourcing for highway and bridge BIM object definitions, as well as to facilitate digital exchange and digital linking of BIM-based highway and bridge data.

Governing Body

The FHWA oversees the PDW&NL research project.

Role of Bridges

Bridges are one of the two focal elements of this research.

Exchange Types

The PDW&NL project applies to all exchanges of bridge geometric information.

Summary

The PDW&NL project is a high-resolution guide with a national scale. The PDW&NL project applies to all phases of the bridge lifecycle. The TPF-5(372) project should collaborate with the PDW&NL project research team. Figure 21 summarizes the characteristics of the Project Delivery Workflow and National Library research.

Figure 21: Characteristics for the PDW&NL project

Summary

The research identified sixteen comparable efforts, which were grouped by the domain that they serve. Each comparable effort was described qualitatively in terms of its purpose, governaning body, the role of bridges, and the information exchanges that were facilitated. Each comparable effort was also assessed in terms of the resolution, scale, lifecycle phase, and recommended level of coordination with the TPF-5(372) project.

Table 1 summarizes the comprable efforts to create general standards. All the identified efforts continue to evolve. NBIMS-US™ V3 is a standard-of-standards; the standards and guidelines referenced by NBIMS-US™ V3 continue to evolve. NIBS has initiated work to develop NBIMS-US™ V4. The CDX and CSI Project Dynamo efforts are candidates to include in the TPF-5(372) stakeholder outreach.

Table 1: General Standards Summary

Comparable Effort	Governing Body	Resolution	Scale	Phase	Coordination
NIEM	Four governing committees	Low	National	Operations	Monitor
bSDD	bSI	High	International	All	Align
ISO 19650	ISO	High	International	All	Align
IFC4 Precast	buildingSMART Deutschland	High	International	Construction	Align
NBIMS-US™ V3	NIBS	High	National	Design and Construction	Align
CDX	Construction Progress Coalition	High	National	Design and Construction	Inform
CSI Project Dynamo	CSI	High	National	Design and Construction	Inform

Table 2 summarizes the comprable efforts to create transportation-domain standards. The AASHTOWare Data Integration Framework project is a candidate for collaboration with the TPF-5(372) project in order to serve the data integration needs of States that use AASHTOWare Bridge products.

Table 2: Transportation Standards Summary

Comparable Effort	Governing Body	Resolution	Scale	Phase	Coordination
MIRE	FHWA Safety Program Office	Low	National	Operations	Align
IFC Infra Overall Architecture & IFC-Alignment	bSI	High	International	All	Align
IFC Road	bSI	High	International	All	Align
AASHTOWare Data Integration Framework	AASHTO SCOA	Medium	National	All	Collaborate

Table 3 summarizes the comprable efforts to create bridge-specific standards. The IFC Bridge project is an ongoing project to extend the IFC standard to support bridge geometry and semantics that are common globally. The TPF-5(372) project should collaborate with the IFC Infra Room to advocate for the inclusion of geometry and semantics that are critical for US bridges in the official IFC standard. The NBI and Manual for Bridge Element Inspection are sources of critical US bridge data that may be unique to US-based bridge owners. The BrIM Data Dictionary and the Project Delivery Workflow and National Library project are two ongoing efforts that are parallel to the TPF-5(372) project and are candidates for collaboration.

Table 3: Bridge Standards Summary

Comparable Effort	Governing Body	Resolution	Scale	Phase	Coordination
IFC Bridge	bSI	High	International	All	Collaborate
NBI	FHWA	Medium	National	Operations	Align
Manual for Bridge Element Inspection	AASHTO COBS	Medium	National	Operations	Align
BrIM Data Dictionary	NSBA	High	National	Construction	Collaborate
Project Delivery Workflow and National Library Project	FHWA	High	National	Design and Construction	Collaborate

Chapter 3 – Compendium of Terms

The compendium of recommended terminology serves two purposes. Firstly, it will enable the creation of a data dictionary to support the Design to Fabrication IDM as part of the IFC Development and Verification task of the TPF 5(372) project. Secondly, it will support the outreach and stakeholder engagement activities.

Terminology is essential for the streamlined communication of information between stakeholders and information systems. Terminology describes what information is being exchanged, as well as the intent and how the terms are used in the context of a specific use case. Semantically rich data structures, such as schemas, taxonomies, and ontologies, are used to define the intent and usage of the terms. The purpose of the data dictionary is to serve as the central repository of terms and relevant information needed to produce workflows and data exchanges. Developers can then use the data dictionary to create the various taxonomies and other semantic data structures. (Costin, 2016)

The various organization structures and formats relating to terminology described below are visually represented in Figure 22:

- **Taxonomy**: A hierarchical structure of defined terms that represent the relationships and attributes among those terms.
- **Data Dictionary**: Centralized repository of terms, relevant information about the terms, metadata, and other user-defined information. Each term is assigned a Globally Unique Identifier (GUID) that keeps each term unique.
- **Dictionary**: A collection of terms with definitions and examples of use. Additional information about the terms (origin, phonetics, grammar, etc.) may be included.
- **Glossary**: A collection of specialized terms with definitions used in a particular domain. A glossary defines the meaning of the terms that apply to a specific publication.
- **Classification System**: A formalized structure that organizes terms based on shared qualities or characteristics. ISO 22274:2013 is the relevant standard for developing classification systems.

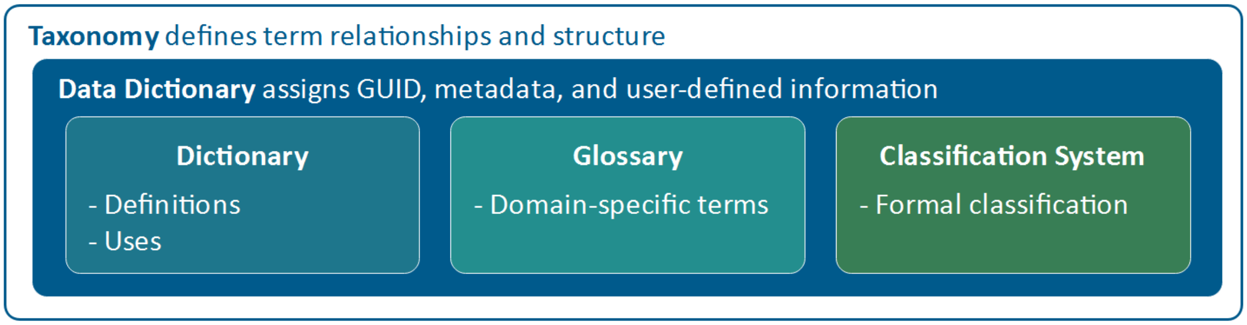

Figure 22 : Structure of an Data Dictionary (Adapted from Costin, 2016)

Terminology Identification

There is a plethora of terminology that exists in a variety of formats. The first step was to identify the intent and scope of the terms needed. The following subjects were identified:

- **General Bridge and Transportation Terms:** Information that describes bridges and other transportation related terms are important for high-level information, such as project information and structure types. There are further sub-categories, e.g., NBI data, transportation structures, policy, etc.
  Sources include the AASHTO Transportation Glossary, AASHTO LRFD Bridge Design Specification, various State manuals and guides, and the OmniClass® classification.
- **Bridge Data:** Each workflow requires detailed information about that specific use case. Detailed bridge information for a specific use case may include fabrication data, design data, analysis data, or asset management data. The specific data that need to be collected will be based on a specific intent or use case.
  Sources include AASHTO and NSBA standards, AASHTO bridge guides, and industry specifications (e.g., American Institute of Steel Construction, American Concrete Institute, Precast/Prestressed Concrete Institute).
- **General BIM Terms:** Information that describes general BIM terms are needed to maintain consistency with other BIM efforts.
  Sources include the U.S. National BIM Standard, ISO BIM Standards, and buildingSMART International guides.
- **BIM Processes and Workflows:** In order to create the processes and workflow for BIM data exchanges, terms that relate to describing the processes for managing these are needed.
  Sources include the U.S. National BIM Standard, ISO Standard for Business Process Model and Notation, and ISO Standard for IDMs.

Terminology Aggregation

Various reports and standards were explored to identify relevant terminology. A terminology database was created to store and sort the information. The metadata that was recorded includes (but is not limited to):

- the term,
- abbreviation,
- definition,
- definition notes,
- related terms,
- source,
- reference, and
- publication year.

Due to the large amount of terminology, the current database only includes terms relevant to BIM, including general terms, processes, and workflows.

Recommendations

The collected terms and definitions are often vague and can be prone to misuse, especially the ones relevant to BIM processes and workflows. Although most are published in a standardized format (e.g., ISO), there are variations among the sources that define the same term. Additionally, there are many terms that are very similar by definition that could potentially cause confusion and misuse. Therefore, recommendations for the creation of a standard dictionary of terms to minimize the issues are:

- Curate the terminology and definitions for their intended purpose. For example, each derivative product such as the process maps, data dictionary, and stakeholder outreach materials should have their own glossary of terms.
- Select the most appropriate definition based on the intent, while referencing the original source. This will enable a clear definition and usage for terms that otherwise may be vague.
- Provide detailed examples and usages of how each term is properly used.

There is no single source that is exhaustive of terminology or processes for a specific purpose. For example, the OmniClass® tables currently lack entities needed for bridges and other transportation assets, but these are available in many ISO standards. Therefore, it is recommended that:

- Collect all sources of terminology in a central repository.
- Incorporate linked data to connect to the variety of sources.
- Terminology that best fits the intent can be selected and assigned.

A few current efforts have similar goals, but the processes, terminology, and definitions vary. Therefore, it is recommended to:

- Create a collaboration mechanism so that related efforts can be aligned.
- Identify a central entity that can be a mutual liaison amongst the efforts.
- Create a central repository so that terms, processes, and information can be shared.

Future Goals

The data dictionary could serve as the central repository for terminology used to create workflows and interoperable data exchanges for bridges. Specifically, this data dictionary will be used for the other tasks within this project, such as the use for the Design to Fabrication IDM. As seen in Figure 21, the data dictionary includes classification systems. This creates an opportunity to collaborate with CSI to create classification tables for bridges elements. Furthermore, there is an opportunity to collaborate with the bSI Infra Room to incorporate elements from the data dictionary into the bSDD. Finally, being an open data repository, the data dictionary can serve as an alignment mechanism for the other ongoing efforts, e.g., the BrIM Data Dictionary, CDX, the FHWA Highway Data Element Dictionary, (US Department of Transportation, 2018) and the FHWA Workflows and National Library project.

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Appendix 7: IFC Development Gap Analysis Report: Analysis of Current IFC 4.2 Efforts

BIM FOR BRIDGES AND STRUCTURES

TPF-5(372)

IFC Development

Task 2.3 Analyze Current IFC 4.2 Efforts

Date: April 2020

Draft Version: 2.1

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1 Summary - Task 2.3 FHWA IFC4.1/bSI IFC 4.1/4.2 Gap Analysis

This gap analysis report analyzes the differences between the previous MVD work done in the Federal Highway Administration (FHWA) project[1] and the parallel developments at buildingSMART International (bSI). The main rationale of the gap analysis is to identify whether all functionality that had been defined within the *IFC Bridge Design to Construction Information Exchange (U.S.)* Model View Definition (MVD), had been transferred to the international work, or whether there are gaps that still need to be addressed.

In general, the gap analysis identified that almost all definitions that were included in the *IFC Bridge Design to Construction Information Exchange (U.S.)* MVD (hereafter referred to as “the US MVD”) had been added in parallel to the international IFC definitions, leading to the release of IFC4.1 in 2017. There are only few minor differences that are elaborated in detail in this report.

Moreover, the ongoing international work extended the 2017 official published version of IFC4.1 into the 2019 version of IFC4.2 International, adding particular support for bridge design. Taking this further progress into account, there are benefits to basing further work on IFC4.2 International.

2 Comparison of the US MVD with buildingSMART work

The work that led to the US MVD provided valuable input into MVD development and implementation support both in the US and internationally. As part of the gap analysis, the US MVD was reviewed and compared with the parallel work at bSI at that time. The bSI work led to the publication of the official version of IFC 4.1 (hereafter referred to as “IFC 4.1 International”). The work products used for the analysis are:

- http://docs.buildingsmartalliance.org/IFC4x2_Bridge/ (US MVD based on IFC4.1 working draft)
- https://standards.buildingsmart.org/IFC/RELEASE/IFC4_1/FINAL/HTML/ (IFC 4.1 International)

NOTE: It is unclear why the URL for the website where the US MVD is published uses “IFC4x2” in its path definition. The starting page clearly reads: “IFC4.1 Model View Definition” as seen in **Error! Reference source not found.**.

Figure 1: Screenshot of the website where the US MVD is published

[1] *IFC Bridge Design to Construction Information Exchange (U.S.),* National Institute of Building Sciences (NIBS), 2016. Available at: http://docs.buildingsmartalliance.org/IFC4x2_Bridge/

3 Task 2.3 FHWA IFC4.1/bSI IFC 4.1/4.2 Gap Analysis

This chapter conducts a gap analysis between:

- the working draft of IFC 4.1 used in the US MVD (based on Release Candidate 1),
- the final release of IFC 4.1 International (which went through two subsequent release candidate versions) published by bSI, and
- the current working draft IFC 4.2 that includes further development to support bridge definitions.

3.1 General gap analysis of the IFC4.1 schemas

The initial step of the gap analysis was a comparison of the underlying IFC schema for the US MVD and IFC 4.1 International. The purpose of this step was to verify that all definitions that were used in the US MVD in 2016 were still part of the IFC 4.1 International release in 2017.

Table 1 provides an initial overview of the differences between the two versions of the IFC 4.1 schema. Only two minor changes were identified for types (out of 210 type definitions in the schema) and two minor changes for entities (out of 801 entity definitions in the schema).

Table 1:Overview of differences between definitions used in the US MVD and the official IFC 4.1 International release

Constructs	US Working Draft of IFC 4.1	International Official Final Release IFC 4.1
	Date 2015	Date 2017
Entity	**IfcClothoidalArcSegment2D**	The specific definition of IfcClothoidalArcSegment2D has been replaced by IfcTransitionCurveSegment2D. The new entity defines all different transition curves, including clothoid. It therefore expands the functionality.
	IfcRelPositions	It had not been taken over due to concerns of complexity, however IfcRelPositions were later included in the candidate standard of IFC 4.2 and is also present in the final version of IFC4.2.
Enumeration Types	**IfcAlignmentPlacementEnum**	All functionalities were taken up by IfcDistanceExpression, which exists in IFC4.1 international.
	IfcAlignmentTransformEnum	It was not adopted because the geometry description would have become too complex for reliable data exchange.

These differences and their consequences for the further work in this project, are described in chapter 3.2.2.b and 3.2.3.

3.2 Detailed technical difference analysis of the IFC4.1 schemas

3.2.1 Changes in inheritance

The alignment is foundational to bridge design and construction. Both versions of IFC 4.1 used by the US MVD and IFC 4.1 International include alignment schema definitions. However, the alignment definitions underwent continued development beyond the working version used in the US MVD.

In the working version of IFC 4.1 used by the US MVD, *IfcAlignment* belongs to *IfcPositioningElement*. In IFC 4.1 International, *IfcAlignment* belongs to *IfcLinearPositioningElement*. Figure 2 illustrates the differences in entity inheritance. The change made in IFC 4.1 International was mainly to provide better clarity of the underlying schema and does not introduce a change in functionality (therefore no loss in functionality).

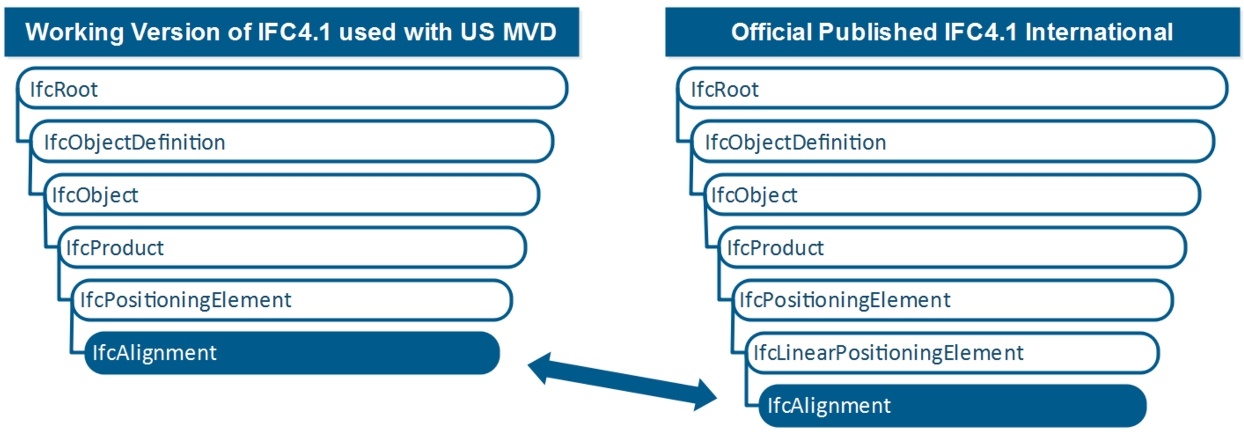

Figure 2:Comparison of entity inheritance for IfcAlignment

3.2.2 Additional Content

In addition, there were other developments that can only be found in IFC 4.1 International, as illustrated in Figure 3.

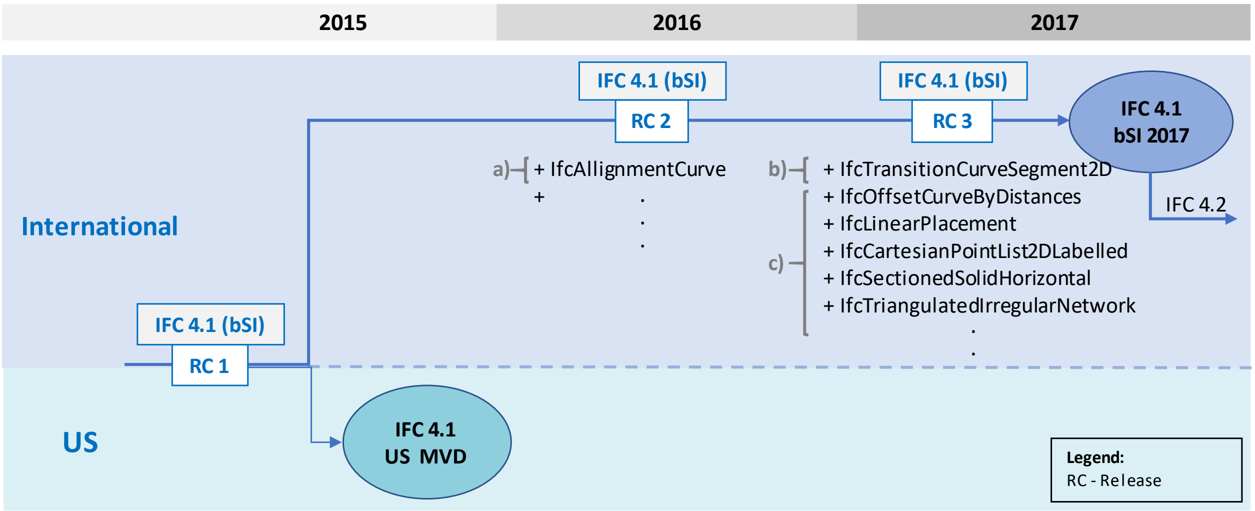

Figure 3: Developments in IFC 4.1 beyond the working version used in the US MVD

The most important developments are explained in points a-c (see also Figure 3).

a *IfcAlignmentCurve*

Release Candidate 2 introduced *IfcAlignmentCurve* as a geometric curve to separate the semantic and geometric concepts of alignment.

b *IfcClothoidalArcSegment2D*

Release Candidate 3 completed the alignment and geometry definitions for infrastructure and was the final release candidate before the publication of IFC 4.1 International.

- A new general transition curve type *IfcTransitionCurveSegment2D* can be used in IFC 4.1 International to define various transitions between straight segments and circular arcs. Therefore, *IfcClothoidalArcSegment2D* can be replaced by *IfcTransitionCurveSegment2D*.

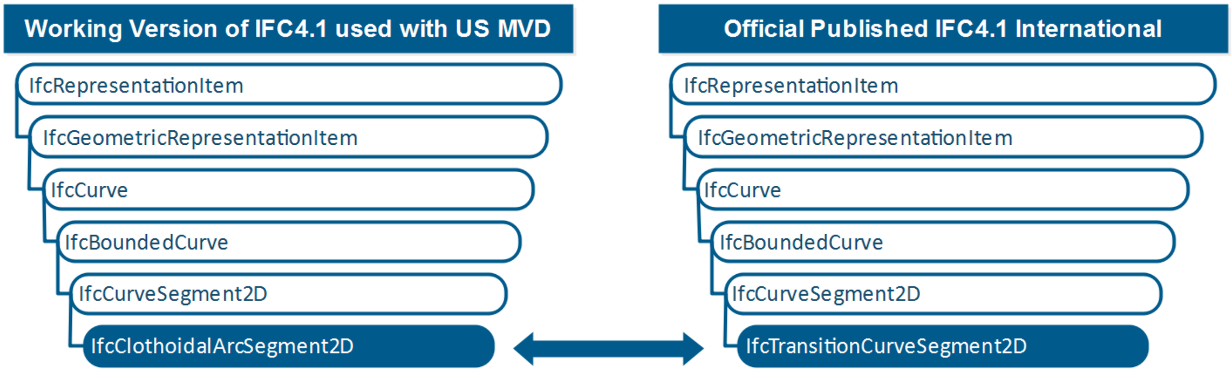

Figure 4: Comparison of entity inheritance for complex curves

The official published version of IFC 4.1 International introduced additional *TransitionCurves*, such as *ClothoidCurve*, *SineCurve, CosineCurve, CubicParabola, BlossCurve* and *BiquadraticParabola*. These are mainly used for railway and bridge design. The *ClothoidCurve* from the working version of IFC 4.1 used in the US MVD is now on included in the options for *IfcTransitionCurveSegment2D* in IFC 4.1 International. Therefore, there is no loss of functionality between these two versions of the IFC 4.1 schema.

c Further developments in an infrastructure context

The following entities have been added to IFC 4.1 International to allow more detailed descriptions of infrastructure projects.

- A new geometric curve type *IfcOffsetCurveByDistances* can be used in IFC 4.1 International to define stringlines that have variable lateral and vertical offsets relative to a parent alignment curve.
- A new placement structure *IfcLinearPlacement* in IFC 4.1 International enables physical and spatial objects to be positioned along alignment curves or derivative string line curves.
- A new data structure *IfcCartesianPointList2DLabelled* in IFC 4.1 International enables cross-sections to be defined where individual points are associated with string lines, to define geometry where the cross-section varies along an alignment.
- A new geometric solid type *IfcSectionedSolidHorizontal* in IFC 4.1 International can be used to define swept solids for road surfaces or bridge decks with control over the orientation of cross-sections.
- A new tessellated geometry type *IfcTriangulatedIrregularNetwork* in IFC 4.1 International can be used to efficiently define terrain surfaces with breaklines, holes, and voids.

3.2.3 Changes in structure and naming

The entity *IfcRelPositions* had not been accepted at the time that IFC 4.1 International was published. After further consideration, some parts (*RelatingElement, RelatedPositioningElement, Axes and RelativePlacement*) were added in IFC4.2. The Attributes *DistanceAlong, OffsetLateral, OffsetVertical* and *PlacementType* (and therefore *IfcAlignmentPlacementEnum*) are taken up by *IfcDistanceExpression* in IFC 4.1 International. The functionalities of *IfcAlignmentPlacementEnum* are included in the new term *AlongHorizontal*. The type *IfcAlignmentTransformEnum* was not included in IFC 4.1 International because the geometry description would have become too complex for reliable data exchange. These differences are illustrated graphically in **Error! Reference source not found.**.

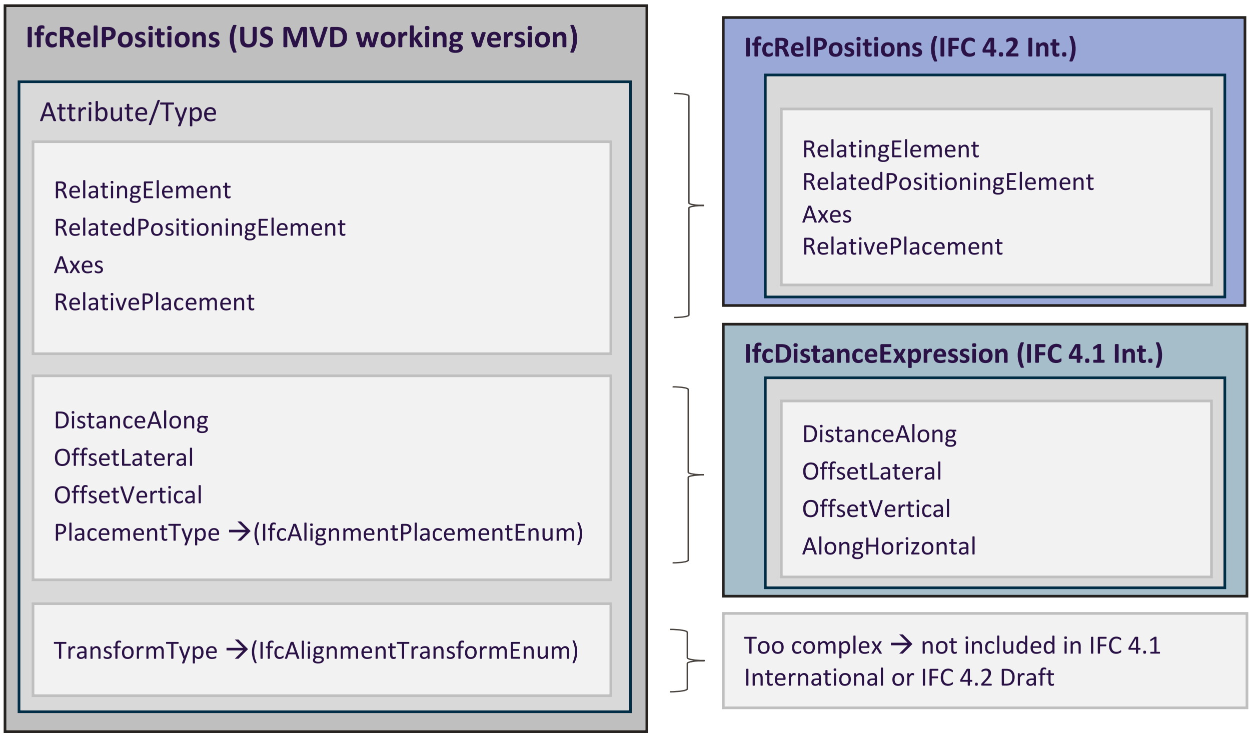

Figure 5: IfcRelPositions / IfcAlignment PlacementEnum / IfcAlignmentTransformEnum

3.3 Comparison of further extensions of IFC4.2 International(final bSI work)

Work continued within bSI in 2018-19 to execute the IFC Bridge extension project. The results of this work were published in Spring 2019 as IFC 4.2 in the status “Candidate Standard” (hereafter referred to as “IFC 4.2 International”), which is still in progress.

Table 2 provides an initial overview of the differences between the two schemas. The most important types of definitions were selected as examples and compared with one another from a quantitative point of view. To take into account the further developments of the bSI since 2017, the extensions in the most recent version of IFC 4.2 International should also be considered. A key focus is the integration of bridge-specific definitions. Terms such as *IfcBearing, IfcBridge, IfcCaissonFoundation, IfcDeepFoundation, IfcRelPositions* have already been included and are relevant to bridge constructions.

Table 2: Comparison of further extensions to the IFC schema included in IFC 4.2 International

	IFC 4.1 International Date 2017 - official version	**IFC 4.2 International** Candidate Standard since 2019-04
Defined Types	**130 definitions**	**130 definitions**
	0 identified additions compared with IFC 4.1 International	
Enumeration Types	**210 definitions**	**217 definitions**
	7 identified additions compared with IFC 4.1 International	
		IfcBearingTypeDisplacementEnum IfcBearingTypeEnum IfcBridgePartTypeEnum IfcBridgeTypeEnum IfcCaissonFoundationTypeEnum IfcTendonConduitTypeEnum IfcVibrationDamperTypeEnum
Select Types	**60 definitions**	**60 definitions**
	0 identified additions compared with IFC 4.1 International	
Entities	**801 definitions**	**816 definitions**
	15 identified additions compared with IFC 4.1 International	
		IfcBearing IfcBearingType IfcBridge IfcBridgePart IfcCaissonFoundation IfcCaissonFoundationType IfcDeepFoundation IfcDeepFoundationType IfcFacility IfcFacilityPart IfcRelPositions IfcTendonConduit IfcTendonConduitType IfcVibrationDamper IfcVibrationDamperType
Functions	**47 definitions**	**47 definitions**
	0 identified additions compared with IFC 4.1 International	

4 Conclusion

The work on the US MVD, which concluded in 2016, defined the IFC schema necessary to develop the subset MVD for the process of transfering bridge data from the design phase to the construction phase for the purpose of bidding. This gap analysis identified that almost all definitions that where included in the published US MVD had been added in parallel to the international IFC definitions, leading to the release of IFC4.1 International in 2017. The minor differences were elaborated in the previous chapter.

Moreover, the ongoing international work had extended the 2017 version of IFC 4.1 International into the 2019 version of IFC 4.2 International, adding particular support for bridge design. Taking this further progress into account, basing further work on IFC4.2 International would incorporate both the progress from defining the US MVD and the subsequent international work. The international community is currently in the process of developing the following Bridge Model Views based on the IFC 4.2 International release:

- Bridge Reference View
- Bridge Alignment Reference View
- Bridge Design Transfer View

The project team recommends to further analyse the international model views regarding their current status and capability to form the baseline for the *design-to-construction* and *construction-to-fabrication* information exchanges. After a first initial contact with bSI and the bSI IFC Bridge Development team the further workflow could be:

- Assess the current status of the *Bridge Alignment Reference View* and *Bridge Design Transfer View*, which are both in an early phase of development,
- Select the most appropriate model view for the scope of the project,
- Develop the model view within the project for the particular demands of the US market (lead the developments)[2],
- Present the developments back to bSI for potential adaption by other stakeholders (assuming that the US *design-to-construction* and *construction-to-fabrication* MVDs would also be beneficial partially or in total in other regions. If so, it would increase the coverage for software developers and would help to accellerate software adoption.

[2] There is currently no active international IFC Bridge project; the IFC Bridge project concluded with the publication of IFC4.2 International.

Appendix 8: Bridge Lifecycle Process Map Validation Report

BIM FOR BRIDGES AND STRUCTURES TPF-5(372)

Process Map Validation

Task 2.1 Report
April 2020

BIM FOR BRIDGES AND STRUCTURES
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List of Abbreviations

AASHTO	American Association of State Highway Transportation Officials
ACI	American Concrete Institute
AISC	American Institute of Steel Construction
BIM	Building Information Modeling
BPMN	Business Process Modeling and Notation
BrIM	Bridge Information Modeling
bSI	buildingSMART International
CSI	Construction Specifications Institute
DOT	Department of Transportation
EM	Exchange Model
ERM	Exchange Requirements Model
FHWA	Federal Highway Administration
IDM	Information Delivery Manual
IFC	Industry Foundation Classes
ISO	International Organization for Standardization
MVD	Model View Definition
NBIMS-US™	National Building Information Modeling Standard – United States
NIBS	National Institute of Building Sciences
NSBA	National Steel Bridge Alliance
OMG	Object Management Group
PCI	Precast/Prestressed Concrete Institute
TPF	Transportation Pooled Fund
XML	eXtensible Markup Language

List of Definitions

Concept Rules on using a subset of the schema structure identified as a concept template to enable a certain functionality within the context of a concept root contained in a model view (ISO 2018).

Data Raw factual bits of unprocessed information. Can be structured, but as an aggregate, has no more meaning than the individual facts alone convey (NIBS 2015).

Data Dictionary A data-semantic dictionary specifying concepts (entities, properties, classification and other concepts) and their relations (Poljanšek 2017).

Data Exchange The process of taking data structured under a source schema to transform and restructure into a target schema, so the target data are an accurate representation of the source data within specified requirements and minimal loss of content (NIBS 2015).

Exchange Model (EM)	1. A software-neutral and semantically rich data definition of the content needed in the exchange requirement (Chipman et al. 2016). 2. Defines the content and requirements of the exchange between actors at a given stage in a process including: The description of exchange (purpose, major elements, level of detail), how the data is being sent and received (import and export software), and meta data about the exchange (project stage, exchange disciplines). (Costin 2016).
Exchange Requirement (ER)	1. A non-technical description of the information needed by a business process to be executed, as well as the information produced by that business process (NIBS 2015). 2. Defined set of information units that needs to be exchanged to support a particular business requirement at a particular process phase (or phases)/stage (or stages) (ISO 2018).
Exchange Requirements Model (ERM)	The data model addressing requirements for a single industry process (NIBS 2015). These are typically non-schema dependent.
Industry Foundation Classes (IFC)	A neutral data format to describe, exchange and share information typically used within the building and facility management industry sector. IFC is the international standard for openBIM and registered as EN ISO 16739:2016 (Poljanšek 2017).
Information	Data that has been interpreted, translated, or transformed to reveal the underlying meaning (NIBS 2015).
Information Delivery Manual (IDM)	1. Documentation which captures the business process and gives detailed specifications of the information that a user fulfilling a particular role would need to provide at a particular point within a project (Poljanšek 2017). 2. A standard for processes specified when certain types of information are required during the construction of a project or the operation of a built asset (NIBS 2015).
Information Exchange	Packages of information passed from one party to another in a BIM process, or the act of passing such information. Parties involved agree upon and understand what information content and format will be exchanged (NIBS 2015).
Interoperability	Interoperability is the ability of diverse systems and organizations to work together (inter-operate). The term is often used in a technical systems engineering sense, or alternatively in a broad sense, taking into account social, political, and organizational factors that impact system to system performance (NIBS 2015).
Model	1. Representation of a system that allows for investigation of the properties of the system. Information models and building information models are examples for a model (ISO 2016).

2. A data set, governed by the structure of an underlying schema, to meet certain data requirements. In scope of this standard IFC models are populations of the IFC schema (ISO 2018).

Model View Subset of a schema, representing the data structure required to fulfil the data requirements within one or several exchange scenarios. Besides being a subset of a schema, a model view (or model view definition) may also impose additional constraints to the population of the subset schema (ISO 2018).

Model View Definition (MVD) An IFC View Definition, or Model View Definition, MVD, defines a subset of the IFC schema that is needed to satisfy one or many Exchange Requirements of the AEC industry. The method used and propagated by buildingSMART to define such Exchange Requirements is the Information Delivery Manual, IDM (also ISO/DIS 29481). An IFC Model View Definition defines a legal subset of the IFC Schema (being complete) and provides implementation guidance (or implementation agreements) for the IFC concepts (classes, attributes, relationships, property sets, quantity definitions, etc.) used within this subset. It thereby represents the software requirement specification for the implementation of an IFC interface to satisfy the exchange requirements (NIBS 2015).

Overview Map A high-level BIM process map that illustrates the relationship between BIM uses which will be employed on the Facility. Each of the BIM Uses then gets its own lower level Process Map (NIBS 2015).

Process Map Representation of the relevant characteristics of a process associated with a defined business purpose (ISO 2016).

Roadmap The overall implementation strategy document used to set the definition, direction, sequence and usually milestones for an initiative (NIBS 2015).

Schema The definition of the structure to organize data for storage, exchange and sharing, using a formal language. The formal languages EXPRESS [ISO 10303-11] and XML Schema are currently used to define the schemata of the IFC standard (ISO 2018).

BIM FOR BRIDGES AND STRUCTURES TPF-5(372)

Executive Summary

This report documents the outcome of the analysis and validation the original bridge life cycle process map published by the Federal Highway Administration (FHWA) as part of the HIF-16-011 “Bridge Information Modeling Standardization” project (Chipman et al. 2017). The results of this report will be used to create a list of prioritized “use case” exchanges and Model View Definitions (MVDs) for future development.

Process mapping is an integral part the buildingSMART International (bSI) implementation of standard information exchanges. Process maps are essential in displaying the logical sequence how information is exchanged in standard business processes. These business processes are described in non-technical information delivery manuals (IDMs) that are turned over to software experts who, in turn, convert the processes into Model View Definitions (MVDs) of the Industry Foundation Classes (IFC). These MVDs are finally incorporated into software to enable the end goal of interoperable information exchange.

This study revealed three iterative versions of the bridge life cycle process map and model exchanges. An analysis of the maps concluded that all versions were similar, but had various degrees of differences, especially pertaining to the scope. In addition to the review, the most recent process map, version 3, was sent for three external reviews. The results of the reviews are provided in more detail in this report.

This report and the validation process resulted in the prioritization of the next exchange models. The project team will further process these results to identify the MVDs that are associated with these exchanges and will follow up with the IFC Working Group. The top five exchange models are as follows:

1. Final Structural Model
2. As-built Model
3. Fabrication Detail Model
4. Structural Condition Model
5. Initial Structural Model

In conclusion of this report, the following suggestions are recommended:

- The process map should be renamed to “Bridge Lifecycle Management Overview Map”
- The overview map should adhere to proper BPMN Rules and Notation
- The overview map should be updated to reflect the current design-bid-build process
- An Information Delivery Manual of the Bridge Lifecycle Management Process needs to be created to define the overview map and exchanges in more detail.
- The final overview map and process map should be encoded in an open, non-proprietary BPMN enabled software.
- An updated Overview map will be developed during the IDM development task of this TPF-5(372) project.

Chapter 1 – Introduction

The report documents the outcome of the analysis and validation the original bridge life cycle process map published by the Federal Highway Administration (FHWA) as part of the HIF-16-011 "Bridge Information Modeling Standardization" project (Chipman *et al.* 2017). The results of this report will be used to create a list of prioritized "use case" exchanges and Model View Definitions (MVDs) for future development.

Figure 1 shows the steps from this task took in the validation process. The first identified and collected all relevant documentation relating to the original process map. The second step analyzed the documentation to identify consistency, errors, or gaps. In step three, the analysis report was sent for external review to a team of bridge designers, contractors, engineers, detailers, and fabrication experts. Finally, the results were documented and reported in step four.

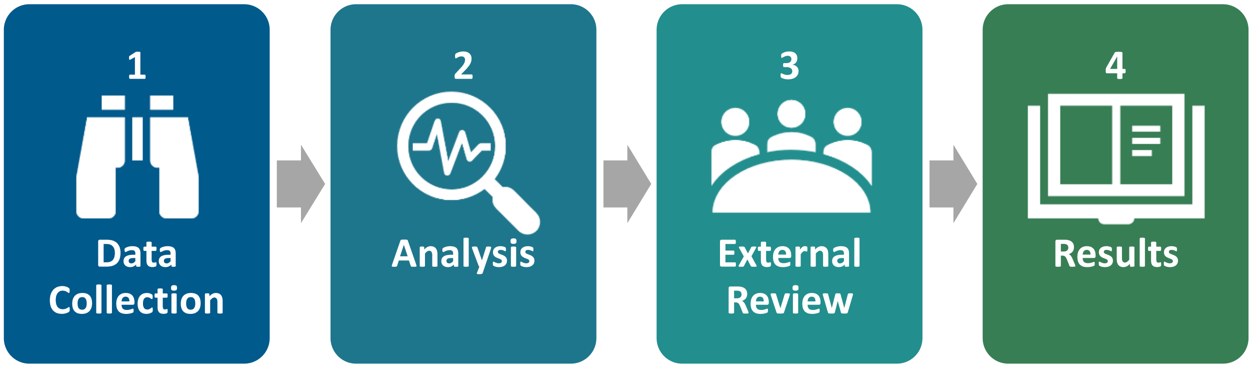

Figure 1: The Validation Process

Chapter 2 – Overview of Process Maps

This section summarizes the purpose and importance of process maps in the scope of creating information exchanges. The buildingSMART International (bSI) implementation of standard information exchanges requires a four phased process (Davis et al. 2012): 1) capturing the domain knowledge in an IDM; 2) converting the knowledge into the IFC via MVD; 3) implementing and certifying the MVDs into software; and validating that the software meets the needs that were defined in the original IDM (Figure 2).

Figure 2: Transformation of Needs into Operational Solutions (Davis et al. 2012)

The first phase creates the IDM, which is the documentation that captures the business process and detailed specifications of the information that an end user requires. Process mapping is an integral part of creating an IDM since it maps out the business use cases (Figure 3). Once the IDM is fully defined by the industry domain experts, it is then handed over to the software experts to be developed into Model View Definitions (MVDs).

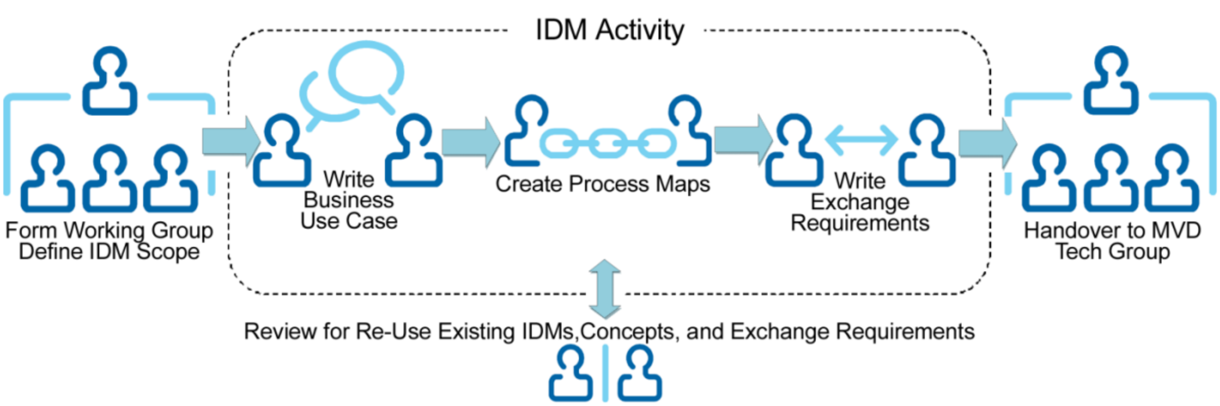

Figure 3: Identifying Processes Supported by IFC Based Data Exchange (Davis et al. 2012)

A process map is a representation of the relevant characteristics of a process associated with a defined business purpose. The representation is graphically mapped out using standard Business Process Modeling and Notation (BPMN) templates (Object Management Group 2011). The process map identifies the content and boundaries of the specific business process, including who is involved (actors), where information is created or used (activities), when the activities happen as it pertains to the lifecycle of the project (phases). The process map displays the logical sequence of the activities including how information is passed (flows) and the points of information exchange (exchange models). Details about each activity are written in a narrative form to provide more information, which is included in the IDM.

Business Process Modeling and Notation (BPMN)

The basic notation and definitions of the elements of process maps are described below (Object Management Group 2011, NIBS 2015):

- **Activity:** Work that a company or organization performs using business processes. The types of Activities that are a part of a Process Model are: Process, Sub-Process, and Task. The graphical form of an Activity is a square with rounded corners (Figure 4).
- **Actor (Participant)**: Person, organization, or organizational unit involved in a Process. Some BIM Process Maps define Actors based on Disciplines.
- **Data Object:** A type of artifact that provide information about what Activities require to be performed and/or what they produce. Data Objects can represent a singular object or a collection of objects. The graphical form of a Data Object is an icon of a paper with the top right corner folded (Figure 5a).
- **Disciplines:** Practice areas and specialties of the Actors (Participants) that carry out the Activities and Processes. The National BIM Standard classifies Disciplines based on the Construction Specifications Institute OmniClass Table 33 (CSI 2019).
- **Event:** An Event is something that "happens" during the course of a Process. These Events affect the flow of the model and usually have a cause (trigger) or an impact (result). There are three types of Events, based on when they affect the flow: Start Events (Figure 5b), intermediate events, and End Events (Figure 5c) are circles with open centers.
- **Gateway:** A Gateway is used to control the divergence and convergence of Sequence Flows in a Process. Thus, it will determine branching, forking, merging, and joining of paths. Internal markers will indicate the type of behavior control. The graphical form of a Gateway is a diamond line with arrow (Figure 5d).
- **Information (Message) Flow:** An Information Flow, or Message Flow, represents the passing of information from one source to another, such as Messages or Data Objects. The graphical form of an Information Flow is a dashed line with arrow (Figure 6).
- **Message:** A Message is used to depict the contents of a communication between two Actors (Participants). The graphical form of a Message is an icon of an envelope (Figure 5e).
- **Overview Map:** A high-level BIM Process Map that illustrates the relationship between BIM uses which will be employed on the Facility. Each of the BIM Uses then gets its own lower level Process Map.
- **Pool:** A Pool is the graphical representation of an Actor (Participant) in a Collaboration Process. It also acts as a "swimlane" and a graphical container for partitioning a set of Activities from other Pools, usually in the context of Business to Business (B2B) situations (Figure 7)

- **Process:** A sequence or flow of Activities in an organization with the objective of carrying out work. In BPMN, a Process is depicted as a graph of Flow Elements, which are a set of Activities, Events, Gateways, and Sequence Flow that adhere to a finite execution semantics.
- **Process Map:** Representation of the relevant characteristics of a process associated with a defined business purpose
- **Sequence Flow:** A sequence flow connects the objects to represent the order of the process, which typically connects activities and events. The graphical form of a sequence flow is a solid line with arrow (Figure 6).

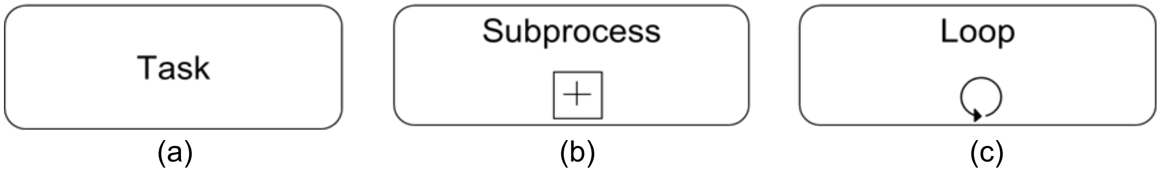

Figure 4: Activity notation: (a) Task; (b) Sub process; and (c) Loop.

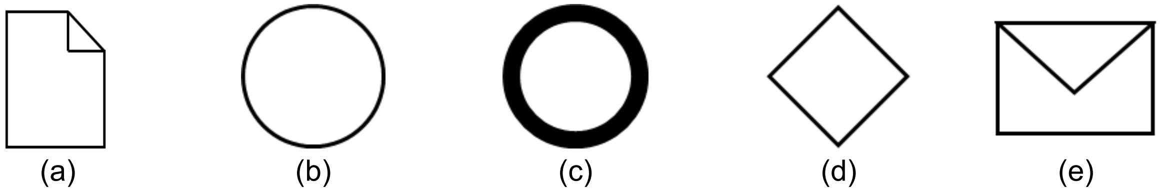

Figure 5: Elements: (a) Data Object; (b) Start Event; (c) End Event; (d) Gateway; and (e) Message

Figure 6: Information (Message) Flow (left) and Sequence Flow (right)

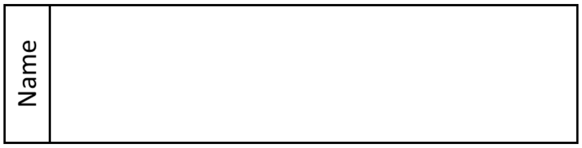

Figure 7: Pool or "Swim lane"

Chapter 3 – Bridge Lifecycle Process Map

Background

Bridge Lifecycle Process Map – Version 1

The first published Bridge Lifecycle Process Map was developed by Chen et al. 2013a under the FHWA Cooperative Agreement DTFH61-11-H-0027, "Bridge Data File Protocols for Interoperability and Life Cycle Management." The purpose of this project was to develop and implement a roadmap to move the bridge and transportation industry to open, BIM-based project delivery and lifecycle management. The authors also produced the process map to identify and characterize the current process for bridge project development and life cycle management. This "Bridge Enterprise Process Map" identified the relevant stakeholders, activities, and exchanges in the design, construction, operation, and management of bridges (Figure 8).

This version of the process maps adopts the notation from similar BIM projects in the AECO industry (Eastman et al. 2011). Noticeably, this notation includes a color scheme (versus monochromatic) to identify the BIM model based exchanges (green data objects) from the non-model exchanges (yellow data objects). Below is a list of the high-level activities identified in the bridge lifecycle process identified by (Chen et al. 2013a; Chen et al. 2013b):

- Bridge Planning
- Conceptual Estimate
- Structure Type, Size and Location Design
- Preliminary Estimate
- Preliminary Roadway Geometry Development
- Preliminary Aesthetic Design
- Preliminary Structural Design
- Updated Preliminary Cost Estimate
- Final Roadway Geometry Development
- Aesthetic Design Development
- Structural Design Development
- Preliminary Detailing Design
- Detailed Engineer's Cost Estimate
- Initial Load Rating
- Construction Documentation Preparation
- Initial Cost Estimate
- Bid Development
- Final Review / Integration of Structural System
- Detailing Design Development
- Construction Planning and Scheduling
- Production Scheduling
- Erection Plan and Analysis
- Modification / Integration of Final Detailing Documents
- Product Manufacturing
- Structural As-Built Data Development
- Project Contract Claim / J.O.C. Cost Estimates
- Construction Coordinating and Monitoring
- Construction Execution
- Post-construction Load Rating
- Inspection Review
- Inspection
- Updated Load Rating
- Maintenance
- Routing and Permitting

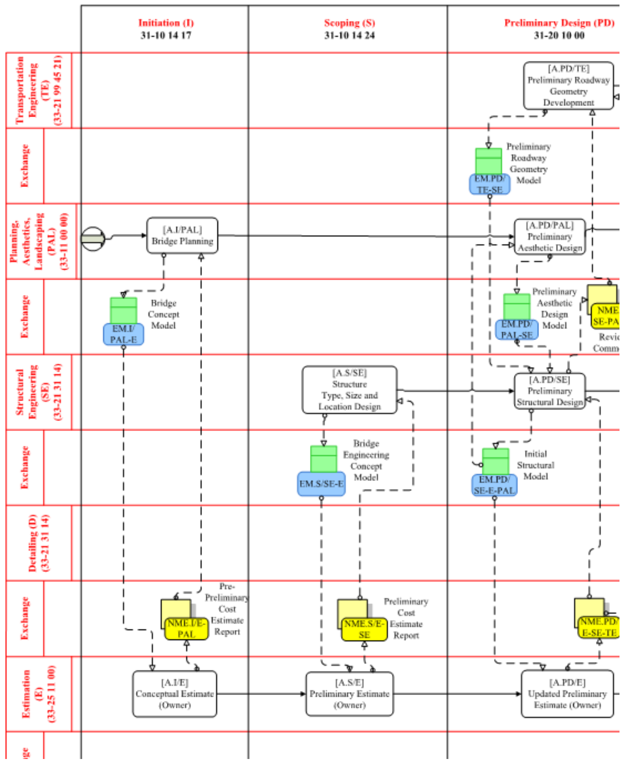

Figure 8: Portion of the Bridge Enterprise Process Map (Chen et al. 2013a)

It is important to note that this is not an exhaustive list of all the activities in the bridge lifecycle. This map of the bridge lifecycle represented a typical design-bid-build steel girder bridge. Despite being limited to a specific bridge type and project delivery model, the resulting process map is complex and contains a substantial number of activities and tasks.

In order to make an activity happen, there needs to be one or more actors to complete the tasks. The same actor may carry out different activities, with different roles for each activity. Any entity that has a role in a process is considered an actor, for example, a person, an organization, or a person acting on behalf of an organization. Below is a list of the disciplines (in which the actors reside) identified in the process map (left vertical column), in which each term is followed by its number of the OmniClass Construction Classification System (OCCS, 2015):

- Transportation Engineering (TE), (33-21 99 45 21)
- Planning, Aesthetics, Landscaping (PAL), (33-11 00 00)
- Structural Engineering (SE), (33-21 31 14)
- Detailing (D), (33-21 31 14)
- Estimation (E), (33-25 11 00)
- Construction Management (CM), (33-41 14 00)
- Fabrication (F), (33-25 41 11)
- Construction Engineering (CE), (33-41 11 00)
- Inspection (I), (33-21 31 14)
- Load Rating (LR), (33-21 31 14)
- Routing and Permitting (RP), (33-21 31 11)
- Maintenance and and Management (MM), (33-55 24 00)

The previous list comes from Table 33, Disciplines, from the OmniClass Construction Classification System. Currently, an actor is a person doing the task, and the OmniClass number of the actor should reference Table 34, Organizational Roles, which by definition are “the technical positions occupied by the participants, both individuals and groups, that carry out the processes and procedures which occur during the life cycle of a construction entity” (CSI 2019). Moreover, Table 33, “Disciplines are presented without regard to the job functions that may be performed by individuals or teams, which are classified by Table 34 – Organizational Roles. Disciplines from Table 33 can be combined with entries from Table 34 - Organizational Roles to provide a more complete classification of a construction participant's role, such as an Electrical Contracting (discipline) Supervisor (organizational role)" (CSI 2019). Therefore, a combination of both tables is important to identify the true scope of the actors and responsibilities.

The bridge life phases identified (top horizontal row) with the OmniClass Table 31, phases, designation (OCCS, 2015) includes the following:

- Initiation (I), 31-10 14 17)
- Scoping (S), (31-10 14 24)
- Preliminary Design (PD), (31-20 10 00)
- Final Design (FD), (31-20 20 00)
- Bidding and Letting (BL), (31 30 30 00)
- Post-Award / Pre-Construction Planning / Detailing (CD), (31-40 10 00)
- Fabrication (F), (31-40 40 14 21)
- Construction (C), (31-40 40 14)
- Inspection and Evaluation (IE), (31-50 20 21)
- Maintenance and Management (MM), (31-50 20 31)

The most significant aspect of the process map is the identification of the exchange models (EM). Chen et al. (2013b) identified 18 exchange models (See Appendix). Importantly, high-priority use cases were discovered that identified major pain points existing in the current practice. The three high priority use cases:

- Final Roadway Design
- Preliminary Bridge Detailing
- Bridge Detailing and Fabrication

Bridge Lifecycle Process Map – Version 2

The next major revisions to the Bridge Lifecycle Process Map occurred in a follow-up FWHA study Bridge Information Modeling Standardization (FHWA-HIF-16-011). This effort was made to compare the various exchange models defined by initial process map (Chen et al. 2013a; Chen et al. 2013b) with other industry process maps. This version adapted the first process map to include other industry exchanges, such as those identified by the American Concrete Institute (ACI), the Precast/Prestressed Concrete Institute (PCI), and the American Institute of Steel Construction (AISC) (Costin 2016). Among the various sets, there are slight misalignments due to scope, purpose, and exchange model being passed. Therefore, it was proposed that all three sets of exchanges are to be investigated in more detail and determine the best way to merge or “reuse” the information. For example, some exchanges can be one-to-one (use “as is”), while most are partially filled (only some of the data can be used). The intents of the exchanges need to be defined with more detail. Additional work is needed to develop the new exchanges, since it relies heavily on industry input. An initial integration of these is shown in Figure 9. In addition to the original exchanges (Chen et al. 2012), this version identifies where other industry exchanges could be used.

The study that led to this version analyzed the process map exchanges and found:

Contract Exchanges not in the University of Buffalo Process Map
EM 2.5 Template Exchange

University of Buffalo Exchanges not in the Contract Exchanges
14 [EM.C/CE-SE-E-LR] As-Built Model
15 [EM.IE/I-SE] Prior Inspection Model

Gaps in University of Buffalo Process Map
Soil conditions (e.g. 2.2 Surveying Exchange)
Existing utilities (e.g. 2.3 Utility Exchange)
Template exchange
Procurement exchanges

Gaps in Contract Model
Roadway Design
Bridge design (including aesthetics)
Inspection
GIS model

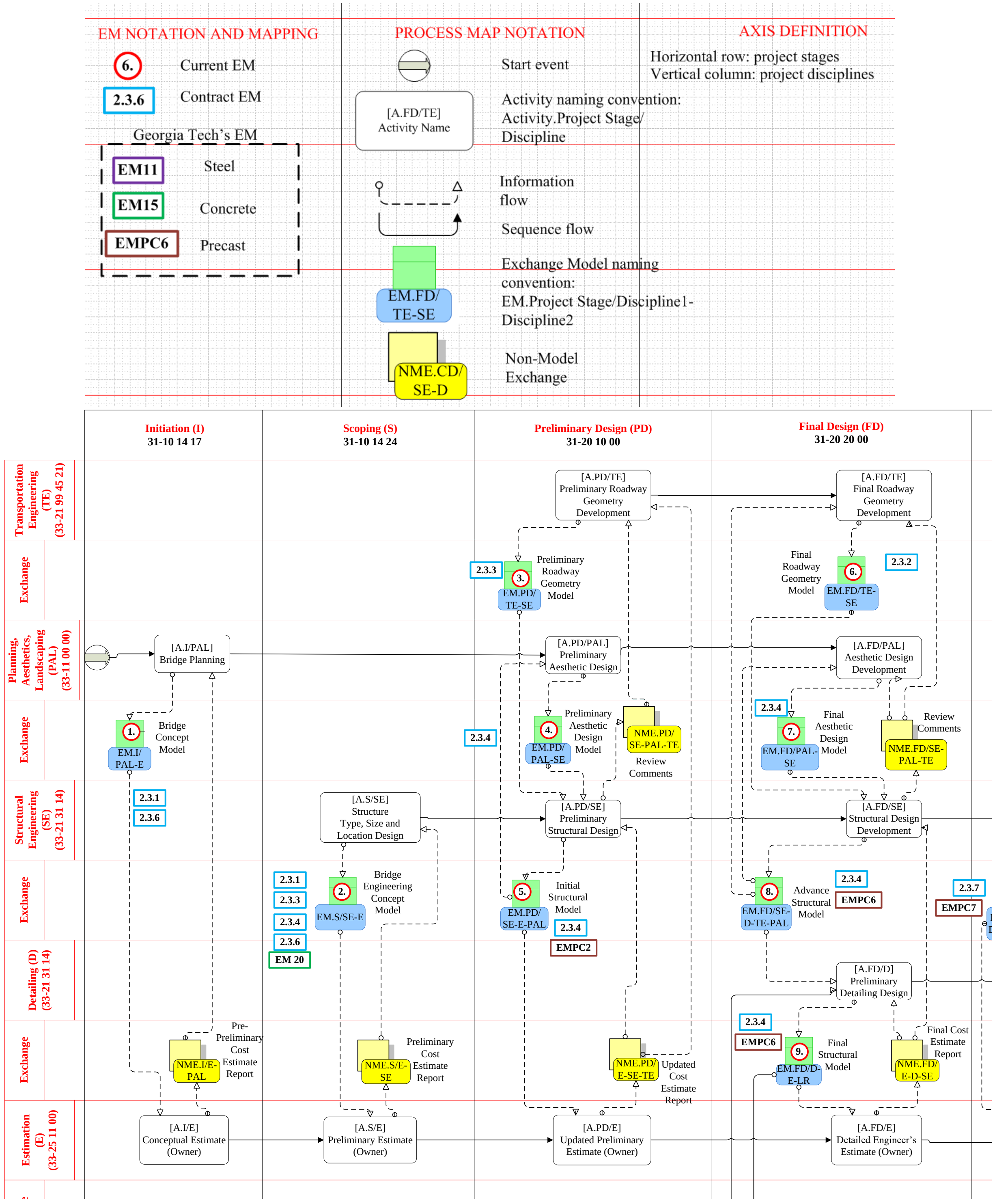

Figure 9: Portion of the Bridge Lifecycle Process Map (Version 2) with Notation (Costin 2016)

Bridge Lifecycle Process Map – Version 3

The final published version of the BrIM Process Map was converted into business process model and notation (BPMN) file format (Figure 10) (Chipman et al. 2016). The purpose of this version is to identify high-level classes of exchanges currently used in DOT agencies. The researchers concluded that the highest priority information exchanges are those that are between parties under contract, for which there is added value in using standardized and documented digital exchanges as opposed to other data formats already in use (Chipman et al. 2016). Table 1 lists the high-level exchanges identified from the DOT agencies and other industries needed during the life cycle of a Design-Bid-Build bridge project. Regarding the source notation:

- FHWA exchanges are from the original Process Map report (Chen et al. 2016)
- PCI exchanges from the PCI MVD (Eastman 2012).
- AISC exchanges are from the AISC MVD (Digital Building Laboratory n.d.)
- ACI exchanges from the ACI MVD (ACI Committee 131 2015).
- DOT are DOT agency exchanges (Chipman et al. 2016)

Table 1: List of Exchanges in Final Bridge Lifecycle Management Process Map (Chipman et al. 2016)

Exchange	Source
Survey Model	DOT, ACI(EM3, EM19)
Utility Model	DOT
Preliminary Roadway Geometry Model	FHWA, PCI(BC), AISC(EM1, EM4)
Preliminary Aesthetic Design Model	FHWA, AISC(EM1, EM4)
Initial Structural Model	FHWA, PCI(PC), AISC(EM2, EM3, EM5)
Final Roadway Geometry Model	FHWA, PCI(PCD), AISC(EM6), ACI(EM1)
Final Aesthetic Design Model	FHWA, AISC(EM6)
Advance Structural Model	FHWA, PCI(EDD), AISC(EM7)
Final Structural Model	FHWA, PCI(AC), AISC(EM9), ACI(EM6, 18)
Construction Contract Model	FHWA, PCI(EC), AISC(EM6, EM7), ACI(EM5)
Advanced Detailing Model	FHWA, PCI(PDC), AISC(EM10), ACI(EM8)
Erection Analysis Model	FHWA, PCI(PED), ACI(EM20)
Final Detailing Model	FHWA, PCI(FPCD), AISC(EM11), ACI(EM9, EM10, EM14)
As Built Model	FHWA, ACI(EM23, EM24)
Structural Deterioration Model	FHWA
Retrofit Model	FHWA
GIS Model	FHWA

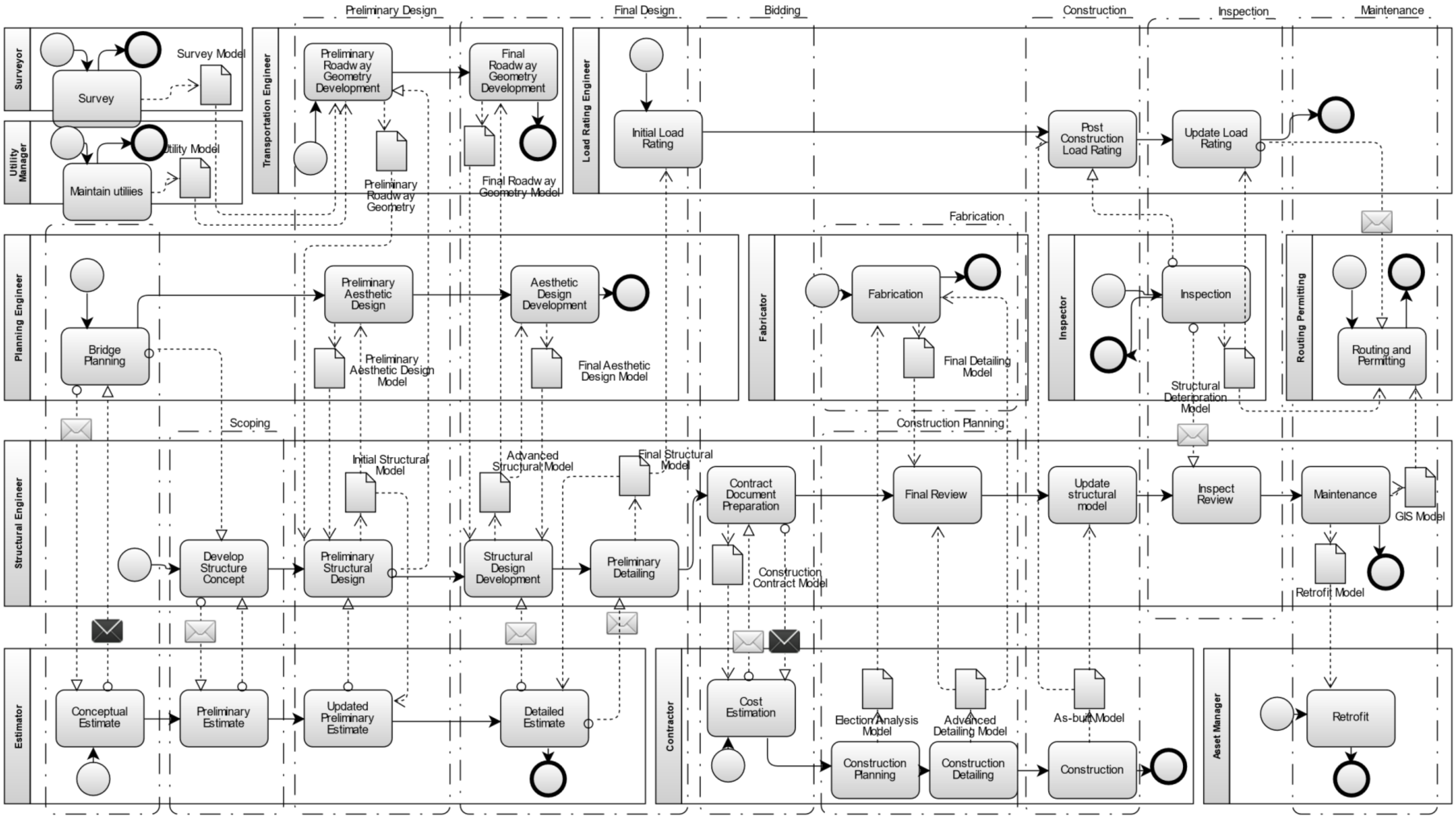

Figure 10: Published Bridge Lifecycle Management Process Map (Ver. 3) (Chipman et al. 2016)

Chapter 4 – Analysis of the Bridge Lifecycle Process Maps

Names of Process Maps

- Version 1 (Chen et al. 2013a, 2013b)
    - Bridge Lifecycle (Enterprise) Process Map
    - Bridge Enterprise Process Map Version
    - Bridge Lifecycle Process Map
- Version 2 (Costin 2016)
    - Bridge Lifecycle Process Map
- Version 3 (Chipman et al. 2016)
    - Bridge Lifecycle Management Process Map

Exchange Models Comparison

Table 2: Comparison of Process Maps based on Exchange Model

Exchange Model	Version 1 (Chen et al. 2013)	Version 3 (Chipman et al. 2016)	Review Recommendations
Bridge Concept Model	Included	N/A	N/A
Bridge Engineering Concept Model	Included	N/A	N/A
Survey Model	N/A	Included	Needs Update
Utility Model	N/A	Included	Needs Update
Geotech Model	N/A	N/A	New
Preliminary Roadway Geometry Model	Included	Included	Needs Update
Preliminary Aesthetic Design Model	Included	Included	No Change
Initial Structural Model	Included	Included	No Change
Final Roadway Geometry Model	Included	Included	Needs Update
Final Aesthetic Design Model	Included	Included	No Change
Advance Structural Model	Included	Included	No Change
Final Structural Model	Included	Included	No Change
Contract Model	Included	Included	Rename
Advanced Detailing Model	Included	Included	Needs Update
Erection Analysis Model	Included	Included	No Change
Final Detailing Model	Included	Included	Needs Update
As Built Model	Included	Included	Needs Update
Prior Inspection Model	Blank	N/A	N/A
Structural Deterioration Model	Included	Included	Rename
Retrofit Model	Included	Included	Update Exchange
GIS Model	Blank	Included	No Change

Chapter 5 – Results

Validation

External Review 1

The first round of external validation of the process map was to verify if it still stands “as-is”, or if any modifications are needed. The first group consisted of the joint AASHTO and NSBA Collaboration, which included contractors, bridge engineers, fabricators, and detailers. The consensus of the review was that the current process map is sufficiently complete and could stand “as-is”. However, a few concerns were raised, which led to proposed modifications.

- **The current process map is hard to read.** The current process map is difficult to read, as it is mono-colored, has many similarly looking lines, and does not have clear annotations. Even with the appropriate documentation of how to read the map (Bridge Information Modeling Standardization Volume 1: Information Exchange), it still presented challenges. The previous process map (Version 2) was presented, and it was found to be easier to read, due to color, open spaces, and annotations. However, it is a much larger document, which makes it hard to read when zoomed out.
- **Supporting documentation needs to be elaborated.** *Bridge Information Modeling Standardization Volume 1: Information Exchange* does provide information on how to read the process map, including the various exchange. However, some parts are vague and needs to be elaborated more (e.g. actor roles, activities, model exchanges, non-model exchanges).
- **Design to Fabrication MVD exchanges are not explicitly defined.** The current exchanges that will be represented by the Design to Fabrication MDV need to be highlighted. Currently, there is no “Design to Fabrication” exchange from the “Contract Document Preparation” activity. The Fabricator looks directly at the contract plans, independent of the general contractor, which is not shown on the map.
- **Missing Actor.** An erector and/or erection engineer may need to be added. Currently, the “Erection Analysis Model” is sent directly to the Fabricator.
- **Missing Exchange.** It was agreed, that if the bridge is to be retrofitted, there needs to be an updated Load Rating. Currently, there is no exchange or indication on the process map how the Update Load Rating activity, under “Load Rating” swim lane, can be updated after Retrofit activity under the “Assent Management” swim lane.

External Review 2

The second round of external validation of the process map was to identify the changes necessary to the current process map. The review team consisted of the TPF-5(372) Senior Bridge Advisory Team. The consensus of the review was that there were major revisions needed to the process map. Some of the proposed comments and modifications include:

- **Some activities seemed to be out of sequence or not useful to portray the bridge model exchange process.** This includes:
    - Removal of “Conceptual Estimate,” “Develop Structural Concept,” and “Preliminary Estimate”
    - Change “Maintain Utilities” to “Utility Survey,” “Preliminary Detailing” to “Structural Surveying,” “Contract Document Preparation” to “Contract Deliverable Preparation,” “Final Review” to “Erection Model Review,” and “Maintenance” to “Maintenance/Retrofit”
    - Add “Geotechnical Survey,” “Shop Model Preparation,” “Shop Model Review,” and “Fabrication”
- **Update exchange models:**
    - Survey Model
        - Does not typically include soil conditions
        - Soil conditions have more to do with the Geotechnical investigations
        - The roadway engineer needs Geotechnical information
        - Roadway borings would be need to be obtained in addition to structure borings
        - Geotechnical Engineer is responsible for obtaining borings and evaluating soil conditions
        - Survey usually shows up in multiple phases and is not shown here. Should survey be represented in multiple phases. Repeating sub-process or gateway may be able to represent it.
        - Geotechnical Engineer may need to be added as an actor.
    - Utility Model
        - What does "Maintain Utilities" mean? (utilities is spelled wrong)
        - Suggest "Utility Survey" as a replacement
        - No Import or Export tools?
    - Preliminary Roadway Geometry Model
        - Importing tools include OBM, take out LEAP Geomath
        - What's being imported and what is being exported (could this be made more clear?)
    - Preliminary Aesthetic Design Model
        - Colby stated that he does not typically receive information from a planning engineer.
        - Aesthetic does not really fit either if it is a description of typical geometry. If it is a description of the look of the bridge the aesthetics are typically a guideline.
        - When the box is open its hard to see the next category
        - They like the word "Sizing" more than aesthetic

- There is no link from Preliminary Roadway to Bridge Planning. Bridge planning comes after preliminary roadway. Maybe change to Roadway and Bridge Planning.
- It seems that 4 should go to develop structure concept
- Conceptual Estimate should be tied to Develop Structure Concept
- Out of this phase comes the Preliminary estimate

- Initial Structural Model
  - Original Purpose was accurately written, current purpose needs updating
  - Should go back to Roadway Designer; add Transportation Engineer to the list of Users in the pop-up box for Initial Structural Model
  - Need to make it clear how this completes to initiate the next phase.
  - Add Roadway software to importing tools
- Final Roadway Geometry Model
  - Alignment, Stationing, Profile Grade, and Super elevation for special attributes
  - It was also noted that stationing is part of an alignment
  - What are Special Attributes?
  - Suggest removal of Special Attributes
  - On Major Elements don't say Included but not limited to. Just list items.
- Final Aesthetic Design Model
  - Some discussion as to if this activity exists. Not conclusive.
  - Would go into Preliminary detailing not the Structural Design Development
- Final Structural Model
  - Change major elements to talk about a contract package. Remove specific reference to plans. Substitute "deliverable" for plans
- Erection Analysis Model
  - Would not dictate schedule
  - More about Temporary structures
  - Would be submitted to Structural Engineer for Review
- Advanced Detailing Model
  - Goes to Fabricator only
- As-Built Model
  - Change As-Built Model update language to reflect that a 3D model is not part of the deliverable from the contractor (Construction Update Model)
  - Change the name of item 14 to be something different from As-Built Model. Suggest Construction Update Model.
  - Show another exchange resulting from Update Structural Model as the Final As-Built Structural Model.

        - As-Built Model from the engineer should go to Post Construction Load Rating and Inspection
    - Structural Condition Model
        - Structural Condition Model needs to go to Inspection Review
- **Some model names need to change to reflect the data exchange,** such as:
    - Structural Deterioration Model to Structural Condition Model.
    - Final Detailing Model to Fabrication Detailing Model.
- **Some sequence flows need to be changed**, such as:
    - Removing the arrow from Inspection to Post Construction load rating
    - Contractor generally is not capable of updating the model. They provide information back to the designer to create the Model.
    - As-Built Model from the engineer should go to Post Construction Load Rating and Inspection
    - Information from Update Load Rating needs to go to maintenance. If it is 2D information, it is missing from the map.
    - Structural Condition Model needs to go to Inspection Review
    - Updated Model should come from Inspection Review to Retrofit
    - Retrofit Model should go to Load Rating
    - Final Detailing Model needs to go to contractor to Structural Engineer
- **Updating phases and activities:**
    - Scoping phases is not necessary.
    - New Load Rating task in the Maintenance Phase
    - Merge Asset Management and Maintenance into own box just left of Inspection Review
    - Fabrication should be broken into Shop drawing and Actual Fabrication
    - Change Inspect Review to Inspection Review
- **Legend needs to be added to explain the notation and elements**.
- **Messages and other non-model data objects need to be added**.
- **Decision Gateways need to be added where appropriate.**
- **There are spelling mistakes and misnamings**.
- **Some disciplines need to be changed**, such as Planning Engineer to Bridge Architect.

External Review 3

The third round of external validation of the process map was to identify if the updated proves map met the needs of the various DOT agencies. The review team consisted of the DOT members that attended the TPF-5(372) process map workshop on February 25, 2020 in San Diego, CA. The two main outcomes are as follows:

- **The process map needs more detail.** One major finding is that the current process map lacks the process showing bidding, letting, and estimation. It was recommended that the update version should include these activities and any related exchanges.

- **Prioritization of the top 5 exchange models.** An interactive activity was done to prioritize the development of other MVDs in the future. Each participant was given 12 pennies which they could "spend" on 17 different exchanges that were identified in the bridge lifecycle process map (See Table 3). The exchanges associated with design to construction/fabrication (design to bid) exchanges were excluded since the associated MVD is already part of the scope of the pooled fund efforts. The team will further process these results to identify the MVDs that are associated with these exchanges and will follow up with the IFC Working Group. The results of the prioritization activity were as follows:
    1. Final Structural Model
    2. As-built Model
    3. Fabrication Detail Model
    4. Structural Condition Model
    5. Initial Structural Model

Table 3: Exchange Model Prioritization Based on Rank

Model #	Exchange Model	Votes	Rank
10	Final Structural Model	42	1
16	As-Built Model	39	2
14	Fabrication Detail Model	34	3
17	Structural Condition Model	31	4
5	Initial Structural Model	21	5
7	Final Roadway Geometry Model	19	6
8	Advance Structural Model	17	7
1	Survey Model	15	8
4	Preliminary Roadway Geometry Model	13	9
2	Utility Model	12	10
3	Geotech Model	11	11
15	Construction Update Model	10	12
12	Erection Analysis Model	5	13
9	Final Aesthetic Design Model	2	14
19	GIS Model	2	14
6	Preliminary Aesthetic Design Model	1	16
18	Retrofit Model	0	17

Recommendations

There have been many changes to the Bridge Lifecycle Process Map, from its inception through several iterations. Based on the substantial proposed changes, it is recommended that the process map be updated to reflect the current state of practice for BIM-based delivery of design-bid-build bridge projects. In addition to the content, other recommendations include the following:

- **Update process map to reflect current lifecycle process.** As part of this analysis the Bridge Lifecycle Process Map was reviewed by three groups as stated in Chapter 5.
    - External Review 1: Joint AASHTO and NSBA Collaboration
    - External Review 2: TPF-5(372) Senior Bridge Advisory Team
    - External Review 3: AASHTO COBS members (San Diego, February 25, 2020)

        Top five recommended Exchange Models to be considered for MVD study from External Review 3 (Table 3):

        1. Final Structure Model
        2. As-Built Model
        3. Fabrication Detail Model
        4. Structural Condition Model
        5. Initial Structural Model

    The conclusion and recommendations from these workshops and reviews should be considered when developing the next version of the *Bridge Lifecycle Process Map*. Upon the conclusion of bSI's IFC4x2 Bridge Project (2018), the IR-Bridge-WP1 Requirement Analysis Report was produced and contains an international update of the Bridge Lifecycle Management Process Map Version 3 (Chipman et al. 2016). The international updates reflect bSI's final process and was used to aid in the development of the IFC4x2 Bridge MVDs.

- **Process Map Name Change.** The Bridge Lifecycle Process Map needs to be high level to enable expansion and extension of other MVDs, but detailed enough to enable the users (e.g. DOTs) to identify the main information exchanges. Therefore, to fit with the definition, it is recommended that this new map be referred to as an "Overview Map" while the subsequent maps be referred to as process maps. The purpose of the overview map is to illustrate the relationship between BIM uses employed on a typical bridge project, while subsequent process maps can be produced from this overview map to be more detailed towards a specific use case (e.g. Design to Fabrication Process Map). The recommended name is the "Bridge Lifecycle Management Overview Map."

- **Rules and Notation**. The updated Overview Map needs to adhere to the rules and notations of BPMN. In addition, standard templates and representations should be used to promote consistency.

- **Open BPMN Software**. The final Overview Map (and subsequent process maps) need to be encoded in an open, non-proprietary BPMN enabled software.

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Appendix A - Original Exchange Models (Chen et al. 2013b)

Exchange Model Template	
Exchange Model	Name of Exchange Model
Project Stage	What is the OmniClass design stage? What is the project phase?
Exchange Disciplines	Participates in this exchange OmniClass discipline number and name (can be > 2 disciplines, but using the same basic data)
Description	Verbal description of: 1. Purpose of the exchange 2. Major elements 3. Level of detail 4. Special attributes
Example Software: Export and Import	**Import from: Export to:**
Related Exchange Models	Other exchanges this one interacts with (proceeding and succeeding exchanges)

1. [EM.I/PAL-E] Bridge Concept Model
31-10 14 17 Initiation
(33-11 00 00) Planning, Aesthetics and Landscaping (33-25 11 00) Estimation
Purpose: this model is created by engineer to help define candidate projects based on program goals. **Major elements:** the content of this model includes but is not limited to 1) a description of the problem, 2) a preliminary project objective(s) and description, 3) project elements to be investigated, 4) preliminary environmental classification, 5) issues or circumstances which may arise, and 6) preliminary schedule. **Level of detail:** conceptual **Special attributes:** project objectives, environmental recommended classification, etc.
Import from: Mathcad, Microsoft Excel **Export to:** Mathcad, Microsoft Excel
EM.S/SE-E, Bridge Engineering Concept Model EM.PD/SE-E-PAL, Initial Structural Model EM.FD/SE-D-TE-PAL, Final Structural Model

2. [EM.S/SE-E] Bridge Engineering Concept Model
31-10 14 24 Scoping
(33-21 31 14) Structural Engineering (33-25 11 00) Estimation
Purpose: this model helps stakeholders better understand problems and define project scope, cost and schedule. **Major elements:** the content of this model includes but is not limited to 1) project area's information, 2) project objective(s), 3) design criteria, 4) feasible alternative(s), 5) key environmental issue. **Level of detail:** sufficient for developing Preliminary Cost Estimate **Special attributes:** type, size and location
Import from: Mathcad, LEAP Bridge, AASHTOWare BrD **Export to:** Microsoft Excel

EM.I/PAL-E, Bridge Concept Model EM.PD/SE-E-PAL, Initial Structural Model EM.FD/SE-D-TE-PAL, Final Structural Model
3. [EM.PD/TE-SE] Preliminary Roadway Geometry Model
31-20 10 00 Preliminary Design
(33-21 99 45 21) Transportation Engineering (33-21 31 14) Structural Engineering
Purpose: the model has been developed to provide minimum safe geometrics for the bridge project. **Major elements:** the content of this model includes but is not limited to 1) bridge roadway, 2) facility widths, and 3) vertical under-clearances, 4) vertical profile of all roads, 5) horizontal alignment data. **Level of detail:** preliminary **Special attributes:** vertical clearance, etc.
Import from: InRoads, MicroStation **Export to:** LEAP Geomath
EM.FD/TE-SE, Final Roadway Geometry Model

4. [EM.PD/PAL-SE] Preliminary Aesthetic Design Model
31-20 10 00 Preliminary Design
(33-11 00 00) Planning, Aesthetics and Landscaping (33-21 31 14) Structural Engineering
Purpose: The model contains aesthetic design data. **Major elements:** The content of this model includes but is not limited to 1) location and surroundings, 2) horizontal and vertical geometry, 3) superstructure type and shape, 4) pier shape and placement, 5) abutment shape and placement, 6) appurtenance details, 7) colors, 8) textures, and 9) ornamentation. **Level of detail:** preliminary **Special attributes:** slenderness ratios, etc.
Import from: MicroStation **Export to:** LEAP Bridge, AASHTOWare BrD
EM.FD/PAL-SE, Final Aesthetic Design Model

5. [EM.PD/SE-E-PAL] Initial Structural Model
31-20 10 00 Preliminary Design
(33-21 31 14) Structural Engineering (33-25 11 00) Estimation (33-11 00 00) Planning, Aesthetics and Landscaping
Purpose: this model is created to help structural engineer select the most appropriate alternative to be advanced. **Major elements:** the content of this model includes but is not limited to 1) substructure location, 2) span length, 3) full transverse section, 4) boring locations, etc. **Level of detail:** preliminary **Special attributes:** initial component sections
Import from: LEAP Bridge, CSiBridge, AASHTOWare BrD **Export to:** Estimating Link, Microsoft Excel
EM.I/PAL-E, Bridge Concept Model EM.S/SE-E, Bridge Engineering Concept Model EM.FD/SE-D-TE-PAL, Final Structural Model

6. [EM.FD/TE-SE] Final Roadway Geometry Model
31-20 20 00 Final Design
(33-21 99 45 21) Transportation Engineering (33-21 31 14) Structural Engineering
Purpose: the model contains updated roadway geometry data. **Major elements:** the content of this model includes but is not limited to 1) bridge roadway, 2) facility widths, and 3) vertical under-clearances. **Level of detail: s**ufficient for final Plans, Specifications, and Estimate **Special attributes:** stations, grades, azimuth, etc.
Import from: MicroStation, InRoads, LEAP Geomath **Export to:** LEAP Bridge, AASHTOWare BrD, CSiBridge

7. [EM.FD/PAL-SE] Final Aesthetic Design Model
31-20 20 00 Final Design
(33-11 00 00) Planning, Aesthetics and Landscaping (33-21 31 14) Structural Engineering
Purpose: the model contains updated aesthetic design data. **Major elements:** the content of this model includes but is not limited to 1) location and surroundings, 2) horizontal and vertical geometry, 3) superstructure type and shape, 4) pier shape and placement, 5) abutment shape and placement, 6) appurtenance details, 7) colors, 8) textures, and 9) ornamentation. **Level of detail: s**ufficient for final Plans, Specifications, and Estimate **Special attributes:** overhang details, etc.
Import from: MicroStation **Export to:** LEAP Bridge, AASHTOWare BrD, CSiBridge
EM.PD/PAL-SE, Preliminary Aesthetic Design Model

8. [EM.FD/SE-D-TE-PAL] Advance Structural Model
31-20 20 00 Final Design
(33-21 31 14) Structural Engineering (33-21 31 14) Detailing (33-21 99 45 21) Transportation Engineering (33-11 00 00) Planning, Aesthetics and Landscaping
Purpose: this model is used for an independent technical progress review, and then used to finalize completed contract plans and specifications. **Major elements:** this model contains 80% of the final structural plan and specification data, including typical bridge section, bridge plan, girder section, etc. **Level of detail:** 80% of final PS&E **Special attributes:** bridge components, reinforcement
Import from: LEAP Bridge, AASHTOWare BrD, CSiBridge **Export to:** Tekla, ProStructures
EM.I/PAL-E, Bridge Concept Model EM.S/SE-E, Bridge Engineering Concept Model, EM.PD/SE-E-PAL, Initial Structural Model

9. [EM.FD/D-E] Final Structural Model
31-20 20 00 Final Design
(33-21 31 14) Detailing (33-25 11 00) Estimation
Purpose: this model is used to develop detailed cost estimate and assembled to a contract package to enable bridge owner to advertise, let, and award. **Major elements:** final structural model contains the data of the final structural plans and specifications including completed general notes, bearing tables, camber tables, etc. **Level of detail:** sufficient for final cost estimate and contract package **Special attributes:** reinforcing bar list, etc
Import from: Tekla, ProStructures **Export to:** Microsoft Excel, Estimating Link
EM.BL/SE-D-E-CM, Contract Model EM.CD/D-SE, Advance Detailing

10. [EM.BL/SE-D-E-CM-CE] Contract Model
31-30 30 00 Bidding and Letting
(33-21 31 14) Structural Engineering (33-21 31 14) Detailing (33-25 11 00) Estimation (33-41 14 00) Construction Management (33-41 00 00) Construction Engineering
Purpose: for contractors to develop contractor's cost estimate, construction planning and detailing. **Major elements:** contract package containing final contract plans, specifications and cost estimate. **Level of detail:** sufficient for contractors to understand the project **Special attributes:**
Import from: MicroStation, LEAP Bridge, AASHTOWare **Export to:** Microsoft Project, Estimating Link, Tekla, ProStructures, UT Bridge
EM.FD/D-E, Final Structural Model EM.CD/D-SE, Advance Detailing Model EM.F/D-F, Final Detailing Model

11. [EM.CD/D-SE] Advance Detailing Model
31-40 10 00 Post Award / Pre-Construction Construction Planning / Detailing
(33-21 31 14) Detailing (33-21 31 14) Structural Engineering
Purpose: bridge detailing for bridge owner and designer to review **Major elements:** typical sections of components, shear key details, reinforcement layout, rebar list, welding detail, bolt locations, etc. **Level of detail:** fabrication detailing – some components **Special attributes:**
Import from: Tekla, ProStructures **Export to:** MicroStation
EM.FD/D-E, Final Structural Model EM.BL/SE-D-E-CM, Contract Model EM.F/D-F, Final Detailing Model

12. [EM.CD/CE-F-CM] Erection Analysis Model
31-40 10 00 Post Award / Pre-Construction Construction Planning / Detailing
(33-41 00 00) Construction Engineering (33-25 41 11) Fabrication (33-41 14 00) Construction Management
Purpose: this model is used for development of construction schedule **Major elements:** information used for erection including erection calculation, procedure, method, crane types, etc. **Level of detail:** as required by contractor and erector **Special attributes:** erection plan, rigging details, etc.
Import from: UT Bridge **Export to:** Microsoft Project, LARSA 4D
N/A

13. [EM.F/D-F] Final Detailing Model
31-40 40 14 21 Fabrication
(33-21 31 14) Detailing (33-25 41 11) Fabrication
Purpose: provide steel components and/or reinforcing concrete components detail layout, with all members defined and rebar placed, for fabrication. **Major elements:** typical sections of components, shear key details, reinforcement layout, rebar list, welding detail, bolt locations, etc. **Level of detail:** fabrication detailing – all components **Special attributes:** welding, splice, prestressing strand pattern, etc.
Import from: Tekla, ProStructures **Export to:** CNC file
EM.FD/D-E, Final Structural Model EM.BL/SE-D-E-CM, Contract Model EM.CD/D-SE, Advance Detailing Model

14. [EM.C/CE-SE-E-LR] As-Built Model
31-40 40 14 Construction
(33-41 00 00) Construction Engineering (33-21 31 14) Structural Engineering (33-25 11 00) Estimation (33-21 31 14) Load Rating
Purpose: this model is used by structural engineers to calculate load rating factors and by inspector for bridge inspection. **Major elements:** final PS&E with modifications due to change in bridge construction. **Level of detail:** sufficient for creating as-built drawings **Special attributes:**
Import from: Microsoft Project **Export to:** MicroStation, Estimating Link, AASHTOWare BrR
EM.BL/SE-D-E-CM, Contract Model

15. [EM.IE/I-SE] Prior Inspection Model
31-50 20 21 Inspection and Evaluation
(33-21 31 14) Inspection (33-21 31 14) Structural Engineering
Purpose: **Major elements:** **Level of detail:** **Special attributes:**
Import from: Export to:
EM.C/CE-SE-E-LR, As-Built Model

16. [EM.IE/I-LR-SE] Structural Deterioration Model
31-50 20 21 Inspection and Evaluation
(33-21 31 14) Inspection (33-21 31 14) Load Rating (33-21 31 14) Structural Engineering
Purpose: the model is used for structural engineers to make load rating calculation, and for bridge owner to permit and route vehicles. **Major elements:** bridge deterioration data including section loss, strand loss, crack, etc. **Level of detail:** sufficient for load rating **Special attributes:**
Import from: InspectTech **Export to:** AASHTOWare BrR, LEAP Bridge, CSiBridge, LARS
EM.IE/I-SE, Prior Inspection Model

17. [EM.MM/SE-MM] Retrofit Model
31-50 20 31 Maintenance and Management
(33-21 31 14) Structural Engineering (33-55 24 00) Maintenance and Management
Purpose: this model is used for development of bridge retrofit / rehabilitation program. **Major elements:** **Level of detail:** sufficient for bridge retrofit **Special attributes:**
Import from: AASHTOWare BrD, LEAP Bridge, CSiBridge, LARSA 4D **Export to:** AASHTOWare BrM
EM.IE/I-SE, Prior Inspection Model EM.IE/I-LR-SE, Structural Deterioration Model

18. [EM.MM/SE-RP] GIS Model
31-50 20 31 Maintenance and Management
(33-21 31 14) Structural Engineering (33-21 31 11) Routing and Permitting
Purpose: **Major elements:** **Level of detail:** **Special attributes:**
Import from: AASHTOWare BrR **Export to:** LARS, Superload
N/A

Appendix B - Updated Exchange Models (Chipman et al. 2016)

Survey Model

Phase	Initiation
Creator	Surveyor
Users	Transportation Engineer
Purpose	This exchange captures terrain elevations and soil conditions, which may be produced by a surveyor and delivered to an engineer.
Major Elements	Geographic location and surveying boundaries, Soil layers at drill points, with classification and associated structural properties

Utility Model

Phase	Initiation
Creator	Utility Manager
Users	Transportation Engineer
Purpose	This exchange identifies locations of utilities as recorded by the controlling jurisdiction. The accuracy of such information is intended to assist a utility locator service in marking utilities on-site; it is not to be relied upon by itself.
Major Elements	Geographic location and utility survey boundaries, Distribution systems, classifications, and authorities, Pipes or cables assigned to each system, with locations, axis paths, and profiles

Preliminary Roadway Geometry Model

Phase	Preliminary Design
Creator	Transportation Engineer
Users	Structural Engineer
Purpose	This model provides minimum safe geometrics for the bridge project.
Major Elements	The content of this model includes but is not limited to 1) bridge roadway, 2) facility widths, and 3) vertical under clearances, 4) vertical profile of all roads, 5) horizontal alignment data.
Level of Detail	Preliminary
Special Attributes	Vertical clearance
Exporting Tools	InRoads, MicroStation
Importing Tools	LEAP Geomath

Preliminary Aesthetic Design Model

Phase	Preliminary Design
Creator	Planning Engineer
Users	Structural Engineering
Purpose	The model contains aesthetic design data
Major Elements	Major elements: The content of this model includes but is not limited to 1) location and surroundings, 2) horizontal and vertical geometry, 3) superstructure type and shape, 4) pier shape and placement, 5) abutment shape and placement, 6) appurtenance details, 7) colors, 8) textures, and 9) ornamentation.
Level of Detail	Preliminary
Special Attributes	Slenderness ratios
Exporting Tools	MicroStation
Importing Tools	LEAP Bridge, AASHTOWare BrD

Initial Structural Model

Phase	Preliminary Design
Creator	Structural Engineer
Users	Estimator, Planning Engineer
Purpose	This model is created to help structural engineer select the most appropriate alternative to be advanced.
Major Elements	Major elements: the content of this model includes but is not limited to 1) substructure location, 2) span length, 3) full transverse section, 4) boring locations, etc.
Level of Detail	preliminary
Special Attributes	Initial component sections
Exporting Tools	LEAP Bridge, CSiBridge, AASHTOWare BrD
Importing Tools	Estimating Link, Microsoft Excel

Final Roadway Geometry Model

Phase	Final Design
Creator	Transportation Engineer
Users	Structural Engineer
Purpose	This model contains updated roadway geometry data.
Major Elements	Major elements: the content of this model includes but is not limited to 1) bridge roadway, 2) facility widths, and 3) vertical under clearances.
Level of Detail	Sufficient for final Plans, Specifications, and Estimate
Special Attributes	stations, grades, azimuth
Exporting Tools	MicroStation, InRoads, LEAP Geomath
Importing Tools	LEAP Bridge, AASHTOWare BrD, CSiBridge

Final Aesthetic Design Model

Phase	Final Design
Creator	Planning, Aesthetics and Landscaping
Users	Structural Engineering
Purpose	The model contains updated aesthetic design data.
Major Elements	the content of this model includes but is not limited to 1) location and surroundings, 2) horizontal and vertical geometry, 3) superstructure type and shape, 4) pier shape and placement, 5) abutment shape and placement, 6) appurtenance details, 7) colors, 8) textures, and 9) ornamentation.
Level of Detail	sufficient for final Plans, Specifications, and Estimate
Special Attributes	overhang details
Exporting Tools	MicroStation
Importing Tools	LEAP Bridge, AASHTOWare BrD, CSiBridge

Advance Structural Model

Phase	Final Design
Creator	Structural Engineer
Users	Transportation Engineer, Planning Engineer
Purpose	this model is used for an independent technical progress review, and then used to finalize completed contract plans and specifications.
Major Elements	this model contains 80% of the final structural plan and specification data, including typical bridge section, bridge plan, girder section, etc.
Level of Detail	80% of final PS&E
Special Attributes	bridge components, reinforcement
Exporting Tools	MicroStation
Importing Tools	Tekla, ProStructures

Final Structural Model

Phase	Final Design
Creator	Structural Engineer
Users	Estimator, Load Rating Engineer
Purpose	This model is used to develop detailed cost estimate and assemble a contract package to enable the bridge owner to advertise, let, and award.
Major Elements	Final structural model contains the data of the final structural plans and specifications including completed general notes, bearing tables, camber tables, etc.
Level of Detail	Sufficient for final cost estimate and contract package
Special Attributes	reinforcing bar list
Exporting Tools	Tekla, ProStructures
Importing Tools	Microsoft Excel, Estimating Link

Construction Contract Model

Phase	Bidding
Creator	Structural Engineer
Users	Contractor
Purpose	for contractors to develop contractor's cost estimate, construction planning and detailing.
Major Elements	contract package containing final contract plans, specifications and cost estimate.
Level of Detail	sufficient for contractors to understand the project
Special Attributes	
Exporting Tools	MicroStation, LEAP Bridge, AASHTOWare
Importing Tools	Microsoft Project, Estimating Link, Tekla, ProStructures, UT Bridge

Advance Detailing Model

Phase	Construction Planning
Creator	Contractor
Users	Fabricator, Structural Engineer
Purpose	bridge detailing for bridge owner and designer to review.
Major Elements	typical sections of components, shear key details, reinforcement layout, rebar list, welding detail, bolt locations, etc.
Level of Detail	fabrication detailing – some components
Exporting Tools	Tekla, ProStructures
Importing Tools	MicroStation

Erection Analysis Model

Phase	Construction Planning
Creator	Contractor
Users	Fabricator
Purpose	this model is used for development of a construction schedule
Major Elements	information used for erection including erection calculation, procedure, method, crane types
Level of Detail	as required by contractor and erector
Special Attributes	erection plan, rigging details
Exporting Tools	UT Bridge
Importing Tools	Microsoft Project, LARSA 4D

Final Detailing Model

Phase	Fabrication
Creator	Fabricator
Users	Fabricator, Structural Engineer
Purpose	provide steel components and/or reinforcing concrete components detail layout, with all members defined and rebar placed, for fabrication.
Major Elements	typical sections of components, shear key details, reinforcement layout, rebar list, welding detail, bolt locations
Level of Detail	fabrication detailing – all components
Special Attributes	welding, splice, prestressing strand pattern
Exporting Tools	Tekla, ProStructures
Importing Tools	CNC Software

As-Built Model

Phase	Construction
Creator	Contractor
Users	Structural Engineer, Load Rating Engineer
Purpose	this model is used by structural engineers to calculate load rating factors and by an inspector for bridge inspection.
Major Elements	final PS&E with modifications due to change in bridge construction.
Level of Detail	sufficient for creating as-built drawings
Exporting Tools	Microsoft Project
Importing Tools	MicroStation, Estimating Link, AASHTOWare BrR

Structural Deterioration Model

Phase	Inspection
Creator	Inspector
Users	Structural Engineer, Load Rating Engineer
Purpose	The model is used for structural engineers to make load rating calculation, and for bridge owner to permit and route vehicles.
Major Elements	bridge deterioration data including section loss, strand loss, crack
Level of Detail	sufficient for load rating
Exporting Tools	InspectTech
Importing Tools	AASHTOWare BrR, LEAP Bridge, CSiBridge, LARS

Retrofit Model

Phase	Maintenance
Creator	Structural Engineer
Users	Asset manager
Purpose	This model is used for development of a bridge retrofit /rehabilitation program
Level of Detail	sufficient for bridge retrofit
Exporting Tools	AASHTOWare BrD, LEAP Bridge, CSiBridge, LARSA 4D
Importing Tools	AASHTOWare BrM

GIS Model

Phase	Maintenance
Creator	Structural Engineer
Users	Permit Engineer
Purpose	This model is used for development of a bridge GIS model.
Exporting Tools	AASHTOWare BrR
Importing Tools	LARS, Superload

Appendix 9 Base MVD Recommendation Memo

Memo

Project:	TPF-5(372) BIM for Bridges and Structures
Date:	04/20/2020
To:	COBS T-19/Pooled Fund
From:	Connor Christian
Subject:	Base Model View Definition Recommendation

This Pooled Fund study has always included the objective of creating a Model View Definition (MVD). When starting from nothing, creating an MVD is a standardized procedure that can be followed step by step. However, on this project there was a significant amount of work that was performed by multiple parties prior to the project start. As a result our MVD process we will need to deviate from the typical procedure and pick up at a point where previous work left off. This means that the most important decision that we can make to achieve our goal is to choose the correct starting point for our MVD development moving forward.

Background

Part of HDR's scope of work in year one of the project was to investigate other efforts to ensure that previous work will not be duplicated and that our efforts are in line with other projects to date. Our investigation showed that previous MVD efforts consisted of the following:

- FHWA – Bridge Information Modeling Standardization Project
    - Design to Construction Information Exchange
- buildingSMART International (bSi) IFC-Bridge Project
    - Bridge Reference View (Bridge RV)
    - Alignment-based Bridge Reference View (Bridge ARV)
    - Bridge Design Transfer View (Bridge DTV)
    - Bridge Asset Management Handover View (Bridge AMV)

As our team's original scope of work was to begin with the Design to Construction Information Exchange, we coordinated a meeting with the team that built that MVD (NIBS and Constructivity) in late July of 2019. The purpose of that meeting was to determine the best starting point for our work in the Pooled Fund. In this meeting we were informed that the Design to Construction Information Exchange had been given to bSi and was used as the basis for the creation of their MVDs. Based on the understanding of NIBS and Constructivity, the best starting point for our work was the Bridge DTV because it incorporated their work and was updated to the most recent schema.

Following our meeting with NIBS and Constructivity, the HDR team communicated the idea that we should be using the Bridge DTV as our starting point. After some discussions with AASHTO COBS T-

19/Pooled Fund, it was decided that this was a good way to proceed. The HDR team took the next step of reaching out to the bSi Executive team to discuss the possibility of working with the draft MVDs published by the IFC-Bridge Project. In late January of 2020, we received the approval of the bSi executives to open up discussions with the IFC-Bridge Project regarding how our project might best work with them on updating and testing the Bridge DTV MVD. In late February of 2020 at the COBS meeting in San Diego, we discussed possible methods of how we might interface with the IFC-Bridge Project and communicated our intent to initiate discussions with this group.

In late March of 2020, we arranged a call with the leadership team of the bSi IFC-Bridge Project to discuss how we might begin our work on updating one of the IFC-Bridge MVDs. The IFC-Bridge team, led by André Borrmann, informed our team of some key information. The most important information was that the work done by NIBS and Constructivity was used to create both the Bridge DTV and the Bridge ARV. It was the opinion of the IFC-Bridge Group, given our goal of a Design to Construction MVD, that the Bridge ARV would be a more suitable choice than the Bridge DTV. The specific reason for this suggestion was that the Bridge ARV is more closely aligned with the original Design to Construction Information Exchange MVD, and furthermore, as a Reference View, it does not require compliance with "full model logic" in order to be used.

We were also informed by the IFC-Bridge Project that their project was closed at buildingSMART International. This information is relevant to our ongoing communications with bSi. As discussed at the meeting in San Diego, our original plan was to either interface with the IFC-Bridge Project directly during MVD development to minimize delays in international implementation or complete MVD development without coordination with bSi to minimize delays in MVD creation. The news that the IFC-Bridge group has closed leaves us with only the option of developing the MVD without coordination with bSi. However, André Borrmann did agree to regular reviews with us as we move forward to keep as closely aligned with bSi as possible.

Reference View vs Transfer View

The major difference between a Reference View and Transfer View is the incorporation of "full model logic". This means that the model after being transferred would remain fully modifiable including all model parametric information, constraints, and dependencies. Essentially the model would move from one system into another and be able to be used in the new system as if it were created there.

This is a major difference, and it results in Transfer Views taking significantly longer to create than Reference Views. It also is much more difficult to convince software vendors to support Transfer Views. In a recent IFC Roads meeting, the Software Vendors involved specifically stated that they would not support MVDs with "full model logic" because they see it as detrimental to their business operations.

It is important to note that most BIM-related workflows would not be affected by not having the ability to support full model logic. Attached to this Memo is the Requirements Analysis Report published by the IFC-Bridge Project, which explains in more detail the capabilities of the different MVDs.

Conclusion and Next Steps

The HDR Project Team recommends that the base starting point for the Design to Construction MVD moving forward should be the bSi Bridge ARV. This recommendation is based on the most current information about the existing resources. The initial recommendation from NIBS and Constructivity appears to be in conflict with the recommendation from the IFC-Bridge Project team. However, recent conversations have brought to light that after the work was contributed by NIBS and Constructivity, their limited involvement may have distanced them from an understanding of the content of all four draft MVDs. It is also recognized that a Transfer View would not be supported by the Software Vendor community, and it would take extensive time and resources to create. It is for these reasons that our team is in support of analyzing and further developing the current draft bSi Bridge ARV.

As next steps our team would:

1. Evaluate the readiness of the bSi Bridge ARV MVD for testing
2. Update the MVD as required by our initial evaluation
3. Generate Testing Files necessary for Software Vendors to test the MVD
4. Provide MVD for preliminary testing to Software Vendors
5. Create an IDM representative of the US Bridge Industry and evaluate it against the MVD
6. Make final updates to the MVD based on IDM comparison and Software Vendor feedback
7. Submit the final updates to bSi

All of these tasks are in line with the scope of work submitted for year two (2020) and the scope planned for future years of the Pooled Fund study.

The HDR team will continue to coordinate the efforts of the disparate entities that have created the MVD content to date. It is important moving forward that duplicate efforts are not started or published as this will only cause delay of US input for inclusion in the ISO Standard. This is particularly true as we will be working with the soon to be released IFC4.3 Candidate Standard on Roads and Rail as well the newly started Harmonization Project that may result in some updates to the MVD.

IFC-Bridge Fast Track Project

Report WP1: Requirements analysis

Status: FINAL
Date: 2018-05-17

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Content

1 Overview and methodology

The IFC-Bridge project aims at extending the IFC data model in order to allow the exact description of bridge semantics and geometry. It was initiated by the bSI Infra Room as a fast track project with a project duration of two years.

WP1 intended to define the scope of the project and the requirements of the IFC-Bridge extension. Given the restricted project duration, it was necessary to focus on common and widespread bridge types and to include only those use cases that provide a high value to the end users and require reasonable efforts for defining and validating the necessary IFC extensions.

As a basis for defining the IFC-Bridge extensions, the international project team identified the most important uses cases of the data exchange processes in infrastructure projects. The point of departure for this process had been provided by the outcomes of the IFC-Infra overall architecture process.

The defined list of use cases is not intended to be exhaustive. Instead, the most important use cases have been selected from interviews with experts having practical experience in bridge projects. In addition, the input from several national initiatives was taken into account:

- China: CRBIM project
- France: MIN^{n}D project
- Germany: IFC-Bridge Expert Group
- Nordic Chapter: IFC-Bridge Expert Group
- USA: FHWA project

The basic requirements for the IFC-Bridge extension have been derived from the identified use cases, by focusing on geometry representations and semantic descriptions. They have been distilled into three proposed Model View Definitions (MVDs) which are going to be developed throughout the project.

2 Bridge types covered

The following bridge types, based on their structural system, have been identified as the most common and widespread across the world. These bridge types are considered to be in-scope of this project. The developed IFC-Bridge extensions will be validated using examples of these bridge types.

- Slab Bridge
- Girder Bridge
- Slab-Girder Bridge
- Box-girder bridge
- Frame Bridge
- Rigid Frame Bridge
- Culvert

The following bridges types are also expected to be covered by IFC and the IFC-Bridge extension, however they will not be subject to validation tests:

- Truss bridge
- Arch bridge
- Cantilever bridge
- Cable-stayed bridge
- Suspension bridge

From a material viewpoint, the following bridge types are covered:

- Reinforced Concrete bridges
- Prestressed Concrete bridges
- Steel/Concrete Composite bridges
- Steel girder bridges
- Steel bridges

Particular emphasis will be placed on realizing the necessary data structures for modeling prestressing systems.

3 Use cases

The following IFC-Bridge use cases have been identified by the project team by analyzing the outcomes of the national bridge projects and through discussions with the international expert panel. The table shows the priority of each use case and the complexity involved with defining the necessary data structures. This analysis formed the basis for subsequent decisions regarding the scope of the project; indicated by the color of the first column: green is in scope and red is out of scope.

No	**Use case**	**Description**	**Purpose**	**IFC exchange scenario**	**Required geometry representation**	**Required semantic information**	**Priority**	**Complex ity**	**MVD**
1	Initial State Modeling	initial data (terrain, soil, existing structures etc.) from various sources (including GIS) are brought into BIM space and exchanged using IFC	GIS (and other) data provides the basis for the design task	GIS & other sources to design application	Faceted BRep, Sweep Geometry where suitable (Deck, Rebar, Boring Piles etc),	Major design parameters, Material (soil classification), accuracy and reliability of initial data	high	low	Bridge Reference View
2	Import of alignment and major road / railway parameters	alignment information is imported from roadway/railway design tool into bridge modeler	Alignment provides the basis for bridge design	From roadway / railway design system into bridge modeling system	Alignment and cross-sections	Maximum Speeds, Loads etc.	high	low	Alignment-based Bridge Reference View
3	Technical Visualization	3D technical visualization of the bridge project	Communication of design solutions to third parties, including the public	Design application to Visualization app.	Triangulated Face Sets	Bridge Breakdown Structure Object Types Material (opt) Colors (opt) Relationships between entities (IfcRelConnects...)	high	low	Bridge Reference View

No	Use case	Description	Purpose	IFC exchange scenario	Required geometry representation	Required semantic information	Priority	Complexity	MVD
4	Coordination / Collision detection	Coordination of domain-specific sub-models	Transfer and combine models to detect interferences (clashes)	Design application to Design application	Faceted BRep, Sweep Geometry where suitable (Deck, Rebar, Boring Piles etc)	Component types Classification Relationships between entities (IfcRelConnects...)	high	low	Bridge Reference View
5	4D Construction Sequence Modeling	4D technical visualization of the construction phases	Organization of construction site and construction activities	Design application to 4D scheduling application	Faceted BRep, Sweep Geometry where suitable (Deck, Rebar, Boring Piles etc)	Temporal information	high	low	Bridge Reference View
6	Quantity Take-Off	Determine quantities (volumes and surfaces) from the model	Basis for cost estimation and cost calculation	Design application to QTO application	Faceted BRep, Sweep Geometry where suitable (Deck, Rebar, Boring Piles etc)	Material, Classifications Relationships between entities (IfcRelConnects...)	high	low	Bridge Reference View
7	Progress Monitoring	Transfer information about the progress of the construction project	Track and document the progress of the construction project	Surveying application to visualization application	Faceted BRep, Sweep Geometry where suitable (Deck, Rebar, Boring Piles etc)	Temporal information	high	low	Bridge Reference View
8	As-built vs. as-planned comparison	Compare the built structure against the as-planned model (Geometric Control)	Check the quality of the construction (on site)	Design application to field application	Faceted BRep, Sweep Geometry where suitable (Deck, Rebar, Boring Piles etc)	Classification Tolerance values Relationships between entities (IfcRelConnects...)	high	low	Bridge Reference View

No	Use case	Description	Purpose	IFC exchange scenario	Required geometry representation	Required semantic information	Priority	Complexity	MVD
9	Handover to asset management	use the model to support operation and maintenance of the bridge,	use the model for inspection, damage detection, condition rating, condition prediction, maintenance planning	Design application to asset management system	Faceted BRep, Sweep Geometry where suitable (Deck, Rebar, Boring Piles etc)	Classification Material Maintenance information	high	medium	Bridge Asset Management View
10	Handover to GIS for spatial analysis	Handover the bridge design to GIS for environmental analysis and/or asset mgmt.	GIS systems provide functionality for environmental analysis and can be used for asset management	Design application to GIS system	Faceted BRep, Sweep Geometry where suitable (Deck, Rebar, Boring Piles etc), potentially based on alignment	Major design attributes	high	low	Alignment-based Bridge Reference View
11	Design to Design (reference model)	Use bridge model from early design phase as a reference for creating a more detailed bridge model in the detailed design ohase, limited modifiability required	Models are exchanged across different design phases, model from earlier phase is used us background / reference model for next phase	Design application to design application	Faceted BRep, Sweep Geometry where suitable (Deck, Rebar, Boring Piles etc), potentially based on alignment	Classification Material Component types Relationships between entities (IfcRelConnects...)	high	medium	Alignment-based Bridge Reference View

No	Use case	Description	Purpose	IFC exchange scenario	Required geometry representation	Required semantic information	Priority	Complexity	MVD
12	Design-to-Design (full model logic)	Exchange of fully parametric description of bridge between two distinct design applications	within the same design phase, design models are exchanged between different design applications, model remains fully modifiable, all model logic is transferred	Design application to design application	Advanced BRep (NURBS), Fully parametric model information containing model logic, constraints and dependencies	All information entered in the design application	medium	high	Bridge Design Transfer View
13	Design-to-Construction	Handover from Design Phase to Construction Phase	Bridge Model is handed over from designer to Contractor for bidding and for actual construction	Design application to Tendering application and/or Review application	Faceted BRep, Sweep Geometry where suitable (Deck, Rebar, Boring Piles etc), potentially based on alignment	Material information Product information etc.	high	medium	Alignment-based Bridge Reference View
14	Structural Analysis incl. Structural Dynamics, Fluid-Structure Interaction, etc.	Structural analysis of bridges, tunnels, retaining walls	Ensure stability of the structures	Design application to structural analysis application	Procedural Description (Sweep and CSG) and/or Analytical Model	Loads, Material properties	medium	medium - high	Bridge Structural View

No	Use case	Description	Purpose	IFC exchange scenario	Required geometry representation	Required semantic information	Priority	Complexity	MVD
15	Code Compliance Checking	Check design of bridge for compliance with local codes and regulations	Compliance checking conducted by regulation authorities	Design application to checking application	Procedural description (Alignment, Sweep Geometry, CSG, BRep)	Information regarding the applying regulations (dimensions, distances, materials, etc.)	medium	high	?
16	Drawing generation and exchange	Exchange technical drawings derived from the model	Submission to owner / regulation authorities	Design application to Submission	2D representation	All information relevant for drawing representation (line styles, symbolic representations, etc.)	low	high	?
17	Prefabrication and manufacturing	Usage of model information for control / steering of prefabrication machines.	Partially automated construction of bridge components	Design application to machine	Procedural description (Alignment, Sweep Geometry, CSG, Advanced BRep)	(specific)	low	medium	?

Table 1In and out of scope use cases for the IFC-Bridge project

4 In-scope / Out-of-scope decisions

Based on a careful analysis of the benefits of the individual uses cases and the complexity and effort involved with defining the necessary data structures, the project team decided to prioritize the following use cases for explicit consideration when designing the IFC-Bridge extension:

- Initial State Modeling
- Import of major road / railway parameters
- Technical Visualization
- Coordination / Collision Detection
- 4D Construction Sequence Modeling
- Quantity Take-Off
- Progress Monitoring
- As-built vs. as-planned comparison
- Handover to asset management
- Handover to GIS for spatial analysis
- Design to design (reference model)
- Design to Construction

Due to their overly high complexity, the following use cases are out of scope of this fast-track project:

- Design to Design (Full model logic)
- Structural analysis
- Code Compliance Checking
- Drawing generation and exchange
- Prefabrication and manufacturing

It is emphasized that the exclusion from the fast-track project does not mean that these use cases cannot be covered by future extensions of IFC-Bridge.

It has to be noted in particular, that the full design-to-design use case which incorporates the model's design logic, is excluded here as it would require software vendors to adapt modeling functionality, which is not deemed practical for reasons of competitive advantage, compatibility, and cost/benefit. Currently, there is no well-defined industry need that would justify this effort.

5 Geometry

As can be seen in Figure 1, the in scope use cases require a limited amount of geometry representations. These geometry representations should sufficiently describe how to build components of bridges, including explicit geometry based on boundary representation (B-Rep) and/or implicit geometry based on swept solids. Tessellated geometry is also supported for components and uses that do not involve construction. The IFC-Bridge development can therefore focus on a limited set of geometry representations.

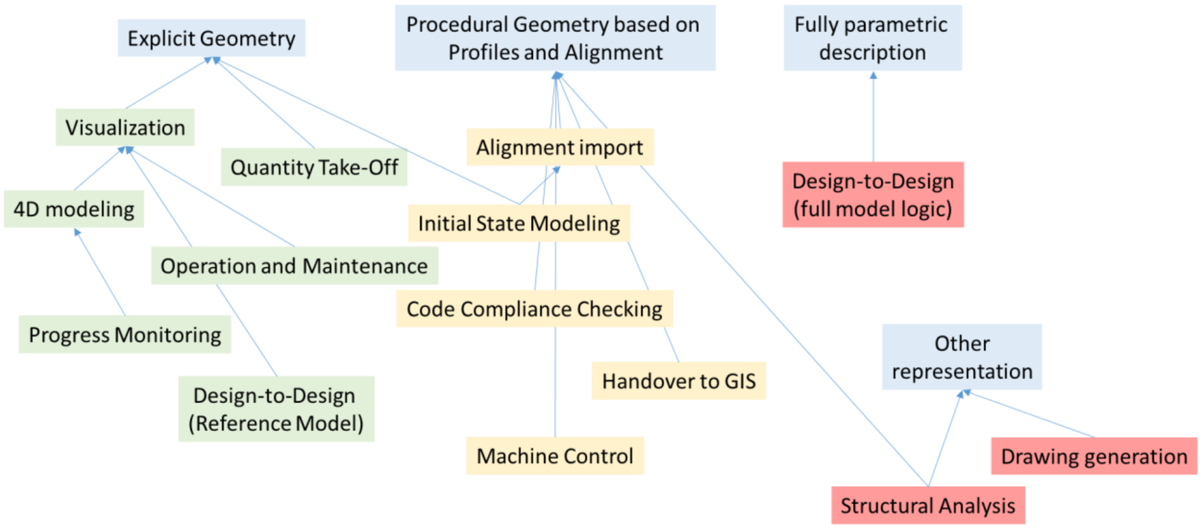

Figure 1 Dependencies between use cases based on required geometry representations.

Many of the required use cases demand the usage of sweeps for representing the superstructure elements, rebar and the prestressing systems. It has been well agreed by the project team that the usage of triangulated face sets is not appropriate for these elements, due to the loss in accuracy and the excessive increase in data size (see Table 1 for more information). The use of swept solids is a strong demand for realizing a number of exchange scenarios (see Figure 2).

The entity *IfcSectionedSolidHorizontal,* introduced in IFC 4.1 by the IFC Alignment and IFC Infra Overall Architecture projects, plays an important role in these exchanges. The entity allows for sweeping along an alignment with potentially varying cross sections, where the cross-section's y-vector is kept pointing in the global z direction. This action cannot be accomplished with other *IfcSweptAreaSolid* subtypes. *IfcSectionedSolidHorizontal* has been introduced for modeling elements of infrastructure facilities, such as roadway layers and bridge decks, using parameters consistent with representations typically used in construction plans. *IfcSectionedSolidHorizontal* will be applied in this sense in the IFC-Bridge extensions and will be included in the Bridge Model View Definitions (see Chapter 8).

Depending on how the element is built, both *IfcSweptAreaSolid* and *IfcSectionedSolid-Horizontal* are needed to define alignment-based geometry. In the case of casting in place, the global z direction can easily be defined on site. However, if the element is precast in a plant, in a horizontal formwork, a profile perpendicular to the sweeping path is required.

6 Requirements resulting from Asset Management

The buildingSMART International InfraRoom has conducted a project on Infrastructure Asset Managers BIM Requirements. The results have been published in report TR1010 which is available on the bSI website[1].

The IFC-Bridge project team took the outcomes into consideration when defining the requirements for the IFC-Bridge extension. The following table lists the individual requirements and how the IFC-Bridge extension is able to meet them.

Requirement from Infra Asset Managers BIM Requirements report	**IFC Bridge fulfilment of requirements**
Unique identification	Each IFC-Bridge model will be able to carry a unique identifier represented by the attribute name of an IfcBridge entity.
Network, geospatial, linear location	IFC provides capabilities for geospatial referencing, a local coordinate system can be used for the BIM model IfcAlignment provides means for linear placement Support for the network perspective has to be provided by IfcRoad and IfcRailways
Functional Requirement	IfcBridge will provide attributes and properties for capturing functional requirements
Dimensions	IFC-Bridge explicitly describes dimensions in terms such as height, width etc. explained in relation to respective object type.
System breakdown into Deck, Superstructure, Substructure	IFC-Bridge will provide a flexible spatial breakdown structure
Support of local/national/regional classification schemes	The IFC data model allows individual elements of a BIM model to be associated with any given classification (see Overall Architecture Report)
Support of local/national/regional Object Type Libraries	The IFC data model allows to connect any given Object Type Libraries with individual elements of a BIM model. To this end Linked Data approaches can be applied (see Overall Architecture Report).
Support of local/national/regional or project-specific property sets	The IFC data model allows to add user-defined property sets in an flexible manner.
Simple 3D geometry for Bridge Asset Management	The Bridge Asset Management Handover MVD will demand explicit geometry (excluding NURBS) allowing primarily visualization and management.
Support of inspection activities	The IFC-Bridge extension will support adding photographs and inspection results to individual components of a bridge model.
Support of sensor data	The IFC model allows to represent sensors and integrate their values by referring to external data sets.

Table 2 Fulfilment of Infra Asset Managers BIM requirements by the IFC Bridge project

[1] Infra Asset Managers BIM Requirements report available here: https://buildingsmart-1xbd3ajdayi.netdna-ssl.com/wp-content/uploads/2018/01/18-01-09-AM-TR1010.pdf

7 Process Map and Exchange Scenarios

In order to identify the exchange requirements and associate them with dedicated data exchange scenarios the following process map has been defined (according to the IDM standard). Due to the large variety in national project setups and contractual models, the process map can only be seen as an example. Nevertheless, the defined exchange scenarios have a generic character and have, therefore, been a basis for the IFC-Bridge development.

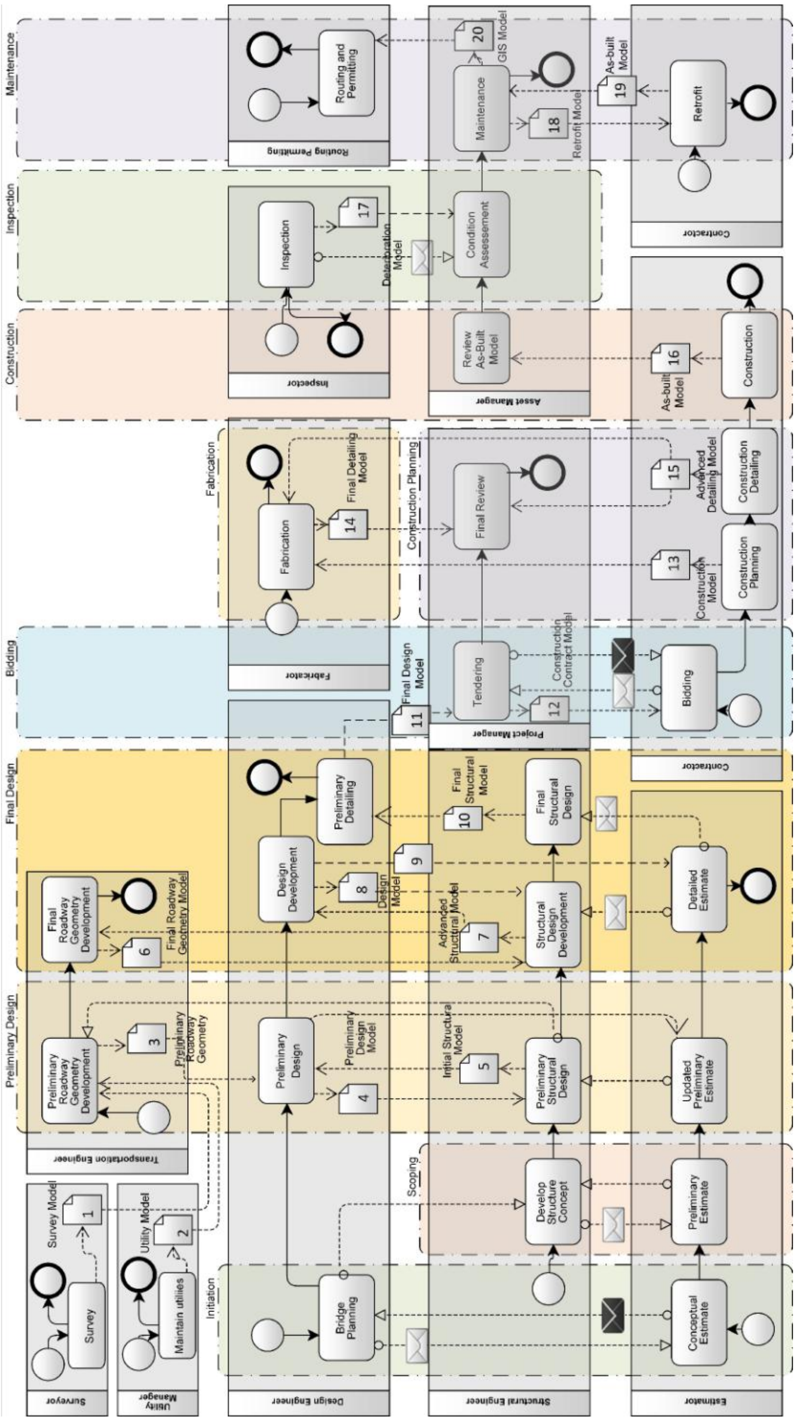

Figure 2: Process Map based on the US FHWA BrIM project process map

Exchange Scenario	Description	IFC-Bridge Use Case (Section 3)	MVD
1	Survey Model: Handover to Preliminary Design	Use Case 1: Initial State Modeling	ARV
2	Utility Model: Handover to Preliminary Roadway Design	Out of scope → IFC-Road	-
3	Preliminary Roadway Model: Handover to Preliminary Design	Use Case 2: Import of alignment and road parameters	DTV
4	Preliminary Design Model: Handover to Preliminary Structural Design	Use Case 11: Design-to-design (reference model)	DTV
5	Initial Structural Model: Handover to design development	Use 14: Structural analyis → Out of scope	-
6	Final Roadway Geometry Model: Handover to (Structural) Deisgn Devlopment	Use Case 2: Import of alignment and road parameters	ARV
7	Advanced Structural Model: Handover to Design Development	Use 14: Structural analyis → out of scope	-
8	Final Design Model: Handover to Structural Design Development	Use Case 11: Design-to-design (reference model)	DTV
9	Final Design Model: Handover to Detailed Estimate	Use case 6: Quantity Take-off	RV
10	Final Structural Model: Handover to Preliminary detailing	Use Case 11/12: Design-to-design	RV/DTV
11	Final Design Model: Handover to Tendering	Use case 6: Quantity Take-off Use Case 13: Design-to-construction	RV/ARV
12	Construction Contract Model Handover to Bidding	Use case 6: Quantity Take-off	RV/ARV
13	Construction Model: Handover to Fabrication	Use Case 13: Design-to-construction Use case 17: Prefabrication	DTV
14	Final Detailing Model Handover to Final Review	Use case 3: Technical Vizualization Use case 4: Coordination	RV/ARV
15	Advanced Detailing Model: Handover to Final Review / Fabrication	Use Case 13: Design-to-construction Use case 17: Prefabrication	ARV/DTV
16	As-built model: Handover to Asset Manager	Use Case 9: Handover to asset management	AMV
17	Deterioration Model: Handover to Condition Assessment	Use case 9: Handover to asset management	AMV
18	Retrofit Model: Handover to constructor	Use Case 13: Design-to-construction	DTV
19	Updated As-built Model: Handover to Asset Mangement	Use Case 9: Handover to asset management	AMV
20	Operation Model Handover to GIS system	Use Case 10: Handover to GIS	ARV

Table 3 Corresponding IFC Bridge use cases and proposed MVD per exchange scenario

8 Model View Definitions

In order to reduce the complexity of the data model developments, the use cases were mapped to the following basic Model View Definitions (see Table 2 and Table 3 for more information):

- Bridge Reference View (Bridge RV)
- Alignment-based Bridge Reference View (Bridge ARV)
- Bridge Design Transfer View (Bridge DTV)
- Bridge Asset Management Handover View (Bridge AMV)

The decision was taken to align both the Bridge Reference View and the Bridge Design Transfer View with the existing views in IFC4, but extend them where necessary to capture the specifics of bridges.

Figure 3, depicted on the next page, lists the differences in terms of the geometry representations supported between the IFC4 Reference view (IFC4 RV), the IFC4 Design Transfer View (IFC4 DTV., the Bridge Reference View (Bridge RV), the Bridge Alignment-based Reference View (Bridge ARV) and the Bridge Design Transfer View (Bridge DTV).

The basic differentiation between RV and DTV is also applied to the Bridge MVDs, the most important differences are:

- *IfcCSGSolid* (Constructive Solid Geometry = Boolean Operations on Solids) is not supported by the Bridge RV, but by the Bridge DTV.
- the support of *IfcFacetedBrep* and *IfcAdvancedBrep* is only realized in the Bridge DTV.
- *IfcPolygonalFaceSet* representation must be used for representing BRep geometry in RV.
- Curved surfaces (NURBS) are not supported by RV.

The Alignment-based Reference View (Bridge ARV) extends the IFC4 Reference View by supporting *IfcAlignment* and *IfcSectionedSolidHorizontal* for positioning and geometry creation. The reason for introducing the additional MVD lies in the importance of alignment for linear infrastructure. Standard IFC viewers typically do not support alignment, but should still be able to visualize bridge models. Therefore, the basic Bridge RV will not demand *IfcAlignment* be supported, but will rely on explicit geometry and on Cartesian coordinates for positioning.

Following is still under development and still requires further investigation in the next project phases:

- development of geometric and semantic aspects may bring forward other differences between Bridge RV, Bridge ARV and Bridge DTV.
- details of the Bridge Asset Management Handover View are still to be decided.

	IFC4 RV	Bridge RV	Bridge ARV	IFC 4 DTV	Bridge DTV
IfcSolidModel	x	x	x	x	x
IfcCsgSolid				x	x
IfcManifoldSolidBrep				x	x
IfcAdvancedBRep				x	x
IfcAdvancedBRepWithVoids					
IfcFacetedBrep				x	x
IfcFacetedBrepWithVoids					
IfcSweptAreaSolid	x	x	x	x	x
IfcExtrudedAraSolid	x	x	x	x	x
IfcExtrudedAreaSolidTapered				x	x
IfcFixedReferenceSweptAreaSolid				x	x
IfcRevolvedAreaSolid	x	x	x	x	x
IfcRevolvedAreaSolidTapered				x	x
IfcCurveSweptAreaSolid				x	x
IfcSweptDiskSolid	x	x	x	x	x
IfcSweptDiskSolidPolygonal					
IfcSectionedSolid			**x**		**x**
IfcSectionedSolidHorizontal			**x**		**x**
IfcTesselatedItem	x	x	x	x	x
IfcTesselatedFaceSet	x	x	x	x	x
IfcTriangulatedFaceSet	x	x	x	x	x
IfcPolygonalFaceSet	x	x	x	x	x
IfcCurve	x	x	x	x	x
IfcBoundedCurve	x	x	x	x	x
IfcAlignmentCurve			**x**		**x**
IfcOffsetCurve					**x**
IfcOffsetCurveByDistances					**x**
IfcDistanceExpression			**x**		**x**
IfcOrientationExpression			**x**		**x**
IfcLinearPlacement			**x**		**x**
IfcPositioningElement	x	x	x	x	x
IfcAlignment			**x**		x
IfcAlignment2DHorizontal			**x**		x
IfcAlignment2DVertical			**x**		x
IfcAlignment2DSegment			**x**		x
IfcAlignment2DVerticalSegment			**x**		x
IfcAlignment2DHorizonalSegment			**x**		x

Figure 3: Comparison of the geometry supported by the IFC4 Model View for Bridges and the proposed Bridge MVDs[2]

[2] full list of the IFC 4 MVDs: http://www.buildingsmart-tech.org/specifications/ifc-view-definition/ifc4-reference-view/comparison-rv-dtv

9 Next Steps

In the next Work Package (WP2), the project team will identify the object types and attributes that are required for describing bridges from a semantic viewpoint in a way that is satisfying the use cases identified in WP1. To this end, a bridge taxonomy is created defining all necessary terms used in the context of bridge engineering. On the basis of the taxonomy, a mapping of the identified concepts to existing or new IFC entities is defined. This allows to specify new data structures (where necessary) as well as the Model View Definitions as discussed above.

Annex 1: Data Requirements

Data requirements have been defined for components of a bridge to reflect parameters required for supported use cases. Representative bridge projects have been used as input, where data found in these representative examples is captured as requirements, using parameters in the same form. For example, if a component (e.g. a pier) is described in construction plans for a representative bridge using a radius for a dimension, and referencing repetitive structures multiple times, then it is expected that the digital representation would follow suit. Similarly, if required material properties are conveyed by referencing an external grade or standard (rather than discrete engineering values such as compressive strength, etc.), then the digital representation would also follow suit.

In the sections that follow, data requirements are shown in tables indicating the field name, proposed mapping in the IFC schema, definition of the field, and whether it applies to the Bridge Reference View (R) and/or Bridge Design Transfer View (T).

Color conventions are used to indicate the use of a field as follows:

Color	Meaning
Red	Identifies the data (i.e. primary key)
Orange	References data described in another table (i.e. foreign key)
Yellow	Required data specific to the object.
Green	Optional data specific to the object.

Table 4 Color conventions for field use

It is important to note that such requirements are intended to represent the minimum amount of information needed to sufficiently support the stated use, and such requirements would be enforced by checking and verification tools. Applications may certainly include additional information, and users may also require additional information. For example, the IFC data model provides a field called “Description” for most data types which can capture informal data – this specification doesn’t impose any requirement for this field as the use is not defined in any specific way that would apply to all projects, though software vendors are encouraged to support such additional fields where there is a fit.

This section has been organized into categories of elements:

- as partitioned by regulatory agencies (e.g. US: FHWA MAP-21 which requires explicit distinction of substructure/superstructure/deck for analysis and inventory purposes),
- with subcategories mapping to how elements are typically modelled within software from industry leaders (e.g. US: Autodesk Infraworks, Bentley ProStructures, Trimble Structures),
- and associations (e.g. US: AASHTO).

1 General Conditions

This section refers to the overall context, positioning, and site conditions where a bridge is located.

1.1.1 Project

All data sets shall consist of a single IfcProject instance, which identifies the overall project, provides defaults for units, and holds a graph of references to all data within scope.

Field	Definition	R	T
Name	The name or code identifying the project within the owning agency.	■	■
Length Unit	Default unit for length. For imperial, inches are recommended. SI Meters are the default if not provided.	■	■
Angle Unit	Default unit for angles. Degrees are recommended, and are the default if not provided.	■	■
Mass Unit	Default unit for mass. For imperial, pounds are recommended. SI Kilograms are the default if not provided.	■	■
Temperature Unit	Default unit for temperature. For imperial, fahrenheit is recommended. SI Celcius is the default if not provided.	■	■
Site	Site within project describing geospatial location and project boundaries.	■	■

Table 5 Requirements for Element Project

1.1.2 Site

Data sets shall include at least one site. The site may define existing and proposed terrain within vicinity of the bridge project and contain alignment(s), bridge(s) and potentially other structures such as the road/rail supported by the bridge. Boring points may be included as objects contained within the site.

To capture existing conditions as well as proposed conditions within the same model, a generic mechanism is proposed by assigning “alternate” objects to elements (via the IfcRelAssignsToProduct relationship), such that any construction element may have a final state (as expected by current software), along with optional alternate states which may capture existing, intermediate states, or arbitrary alternatives. It is expected that most software may only be able to capture final state conditions, however such generic assignment mechanism enables other software to fully define objects in other states with full capability of capturing multiple geometry representations and property sets. To identify meanings of specific alternates, the Name attribute of IfcRelAssignsToProduct may be used to qualify such relationship, with “Existing” proposed to mean the existing conditions.

It is anticipated that future elaboration may support specific time phasing using IfcTask relating to construction elements using IfcRelAssignsToProduct, where the start date, end date, and nature of work (e.g. construct, demolish) may be defined.

Field	Definition	R	T
Name	Name of the site for referencing purposes.	■	■
Bridge	Bridge structure(s) within site.	■	■
Elevation	The reference elevation for which all vertical coordinates are relative.	■	■
Surface Proposed	The ground surface of the site indicating final conditions.	■	■
Surface Existing	The ground surface of the site indicating existing conditions.		■
Boring Points	Boring points indicating soil layers and properties at discrete locations.		■

Table 6 Requirements for Element Site

1.1.3 Alignment

Horizontal and vertical alignment curves provide the underlying placement for all components in a bridge plan.

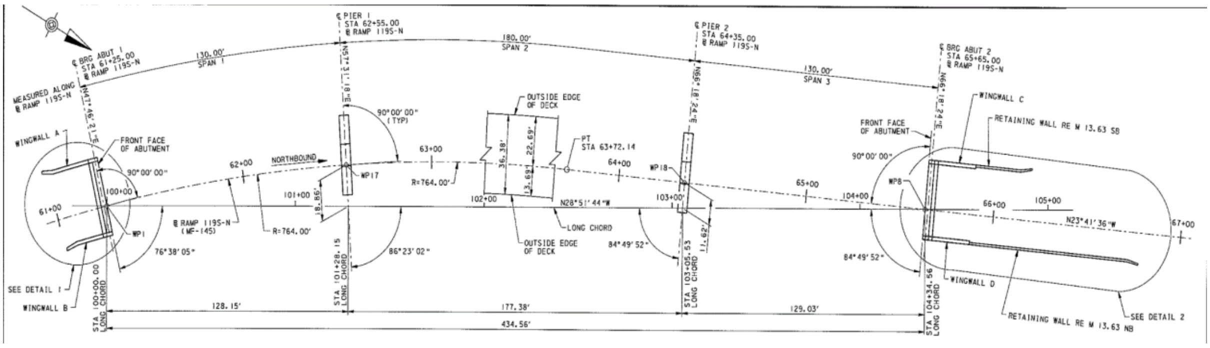

Figure 4 Bridge alignment plans

Field	Definition	R	T
Name	Name of the alignment used for referencing purposes.		■
Axis	Alignment shall define an axis curve, which may consist of a horizontal alignment curve only, a horizontal curve and vertical curve, an offset curve for capturing derivate alignments such as for a girder line, a polyline for capturing existing conditions at approximate intervals, or a line for capturing transverse alignments such as for positioning piers.		■
Containment	Alignment shall be contained within the site.		■
Placement	Alignment shall be placed at the global origin.		■

Table 7 Requirements for Element Alignment

1.1.4 Bridge

Each bridge structure is captured within a definition describing the span location of a bridge relative to an alignment.

The extents of the bridge are defined using an Axis curve, where IfcOffsetCurveByDistances would fit most scenarios – referencing an IfcAlignmentCurve with starting and ending distances along the curve, and typically no laterial or vertical offsets.

Field	Definition	R	T
Name	The name or code identifying the bridge within the owning agency.	■	■
Alignment	Reference to the alignment object used for positioning.	■	■
Axis	Alignment extent of the bridge defined as a sub-span of the overall alignment.	■	■
Components	Components within the bridge, including piers, abutments, girders, and decks. Placement of components is NOT relative to the bridge, but to the underlying alignment.	■	■

Table 8 Requirements for Element Bridge

1.1.5 Bridge Part

Components of bridges may be arbitrary decomposed into spatial parts that may be addressed separately, such as substructure, superstructure, and deck – similar in concept to IfcBuildingStorey, but without any implied sequence or direction.

Note: While bridge parts may also encapsulate phyical objects (e.g. piers), definitions for such physical objects should rely on IfcElement subtypes which provides for templating (IfcElementType subtypes), connectivity (IfcRelConnects subtypes), voiding (IfcRelVoidsElements), and other capabilities only possible with physical elements, for which spatial elements (IfcSpatialElement subtypes) do not support in the current IFC schema.

1.1.6 Soil Boring Point

Site grading is indicated using several geometric structures, for which contour lines or the elevation at any point may be derived. The IfcGeographicElement entity with PredefinedType set to SOILBORING (new) may be used to indicate soil borings at particular points.

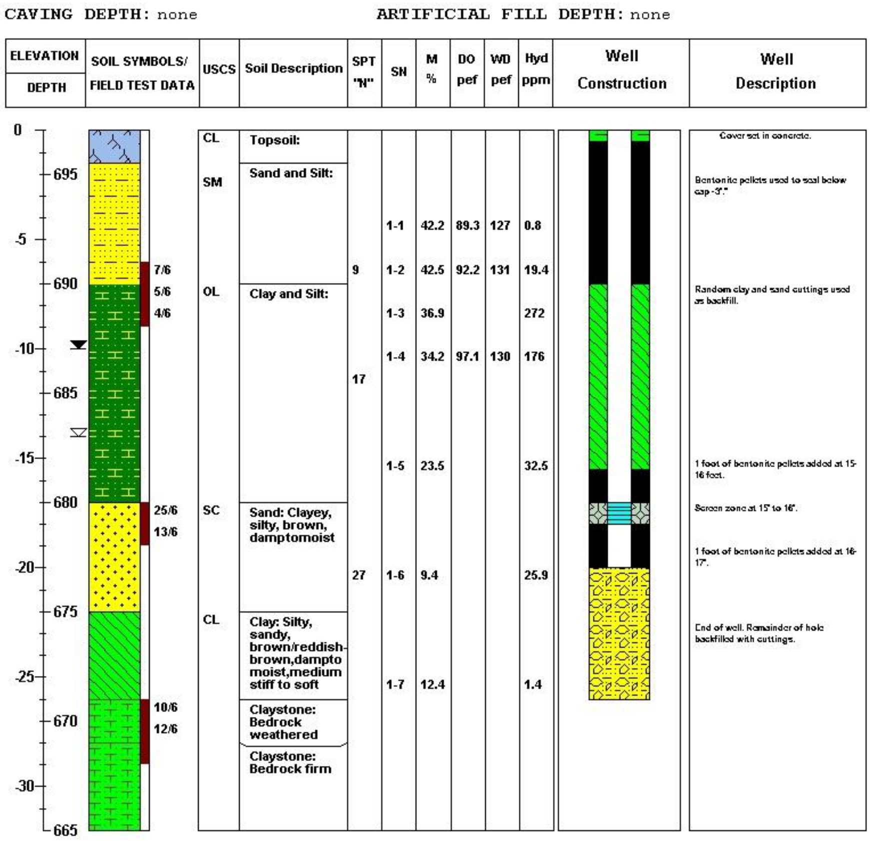

Figure 5 Example of soil boring point representation on plans

Soil boring information indicates the position of the test boring with longitudinal and lateral offsets relative to the alignment curve, and classification of soil between elevations for the specified depth of each boring.

Field	Definition	R	T
Name	Name of boring point for referencing purposes as would be found on construction plans.		■
Location	Location of boring point relative to the site, using linear placement or local placement.		■
Material Layers	Material layers describing soil conditions.		■

1.1.7 Material

Materials are defined on elements to be constructed (e.g. concrete), fabricated (e.g. steel girders), and that exist on site (e.g. soil borings), indicating material category, classification, and structural properties.

Field	Definition	R	T
Name	Material classification according to the respective authority (e.g. ASTM)	■	■
Category	Category of material, where if provided must be one of "Steel", "Concrete", "Wood", "Plastic", "Glass", "Earth".	■	■
Density	Material mass density.		■
Modulus of elasticity	A measure of the Young's modulus of elasticity of the material.		■
Modulus of rigidity	A measure of the shear modulus of elasticity of the material.		■
Thermal expansion coefficient	A measure of the expansion coefficient for warming up the material about one Kelvin.		■
Concrete compressive strength	[If Category="Concrete"] The compressive strength of the concrete.		■
Steel yield strength	[If Category="Steel"] A measure of the yield stress (or characteristic 0.2 percent proof stress) of the material.		■

Table 9 Requirements for Element Material

1.2 Substructure

The substructure of a bridge refers to elements that transfer loads into the ground.

1.2.1 Abutments

Abutments refer to substructures at the ends of a bridge. They may be composed of wing walls (on each side), head wall, stem wall, and cone.

Figure 6 Example of an abutment

1.2.2 Piers

Piers are decomposed into elements according to connectivity, indicating construction joints. Reinforcing may be indicated within inner elements such as footings, columns, members, and walls (see documentation at corresponding elements for usage); such reinforcing should reflect how it is to be placed at time of construction such that rebar connecting between elements is projected out of the element where it is initially placed.

Figure 7 Example of a pier

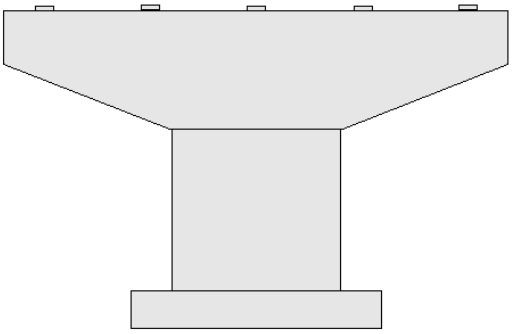

Figure 8 Cross sections of a pier

Abutments and piers are placed relative to the horizontal alignment curve (NOT the vertical alignment curve), with components placed according to Cartesian placement within. This reflects positioning as typically indicated on construction plans, where all dimension lines are based on Cartesian positioning relative to the position and orientation of the station along the horizontal alignment curve.

Field	Definition	R	T
Name	Name of pier for referencing purposes as would be found on construction plans.	■	■
Alignment	Reference to the alignment object used for positioning.	■	■
Location	Location of pier along alignment.	■	■

Pier Cap	Pier cap component, separated according to construction joint.	■	■
Pier Stem	Pier stem component(s), separated according to construction joint.	■	■
Footing	Footings in ground.	■	■
Piles	Piles supporting footings.	■	■

Table 10 Requirements for Element Piers

1.2.3 Pier Stems

Each pier may have one or more stems, separated laterally.

1.2.4 Pier Segments

Each pier stem may have one or more segments, separated by construction joint.

1.2.5 Pier Caps

Each pier may have a top that spans stem(s). If such cap is above a bearing, then it is modelled as part of the superstructure.

1.2.6 Retaining Walls

Retaining walls refer to wall structures for retaining soil.

Figure 9 Example of a retaining wall

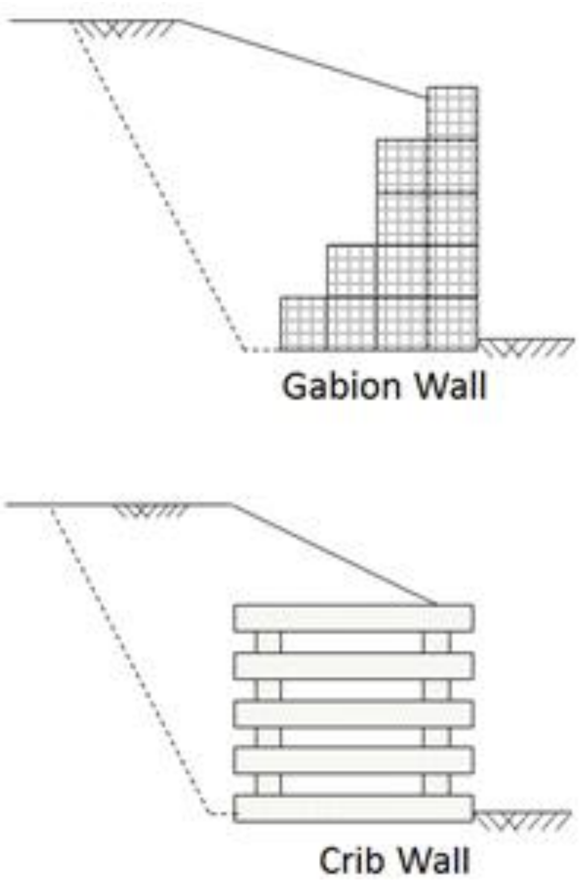

Figure 10 Types of retaining walls on plans

1.2.7 Apron

A bridge apron is a device to protect a river bank or river bed against scour; a shield (source: http://sdrc.lib.uiowa.edu/eng/bridges/WaddellGlossary/GlossA.htm).

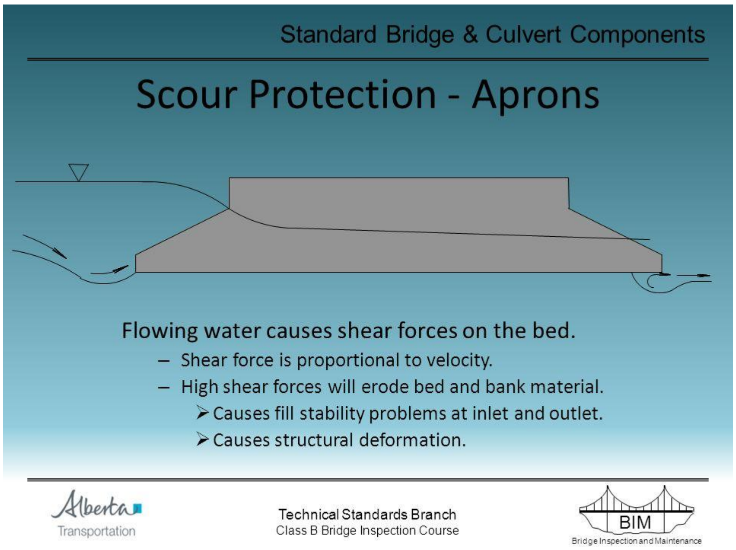

Figure 11 Example of an apron (source: Alberta Transportation)

1.2.8 Arch

An arch refers to a hyperbolic member that supports vertical loads at intervals along its span.

Figure 12 Example of an Arch

A springer refers to the base element supporting an arch.

Figure 13 Example of a springer

1.2.9 Footing

Footings are typically described geometrically by enclosed polygonal areas extruded vertically according to footing depth. For stepped footings, multiple extruded solids may be used, however they must not intersect.

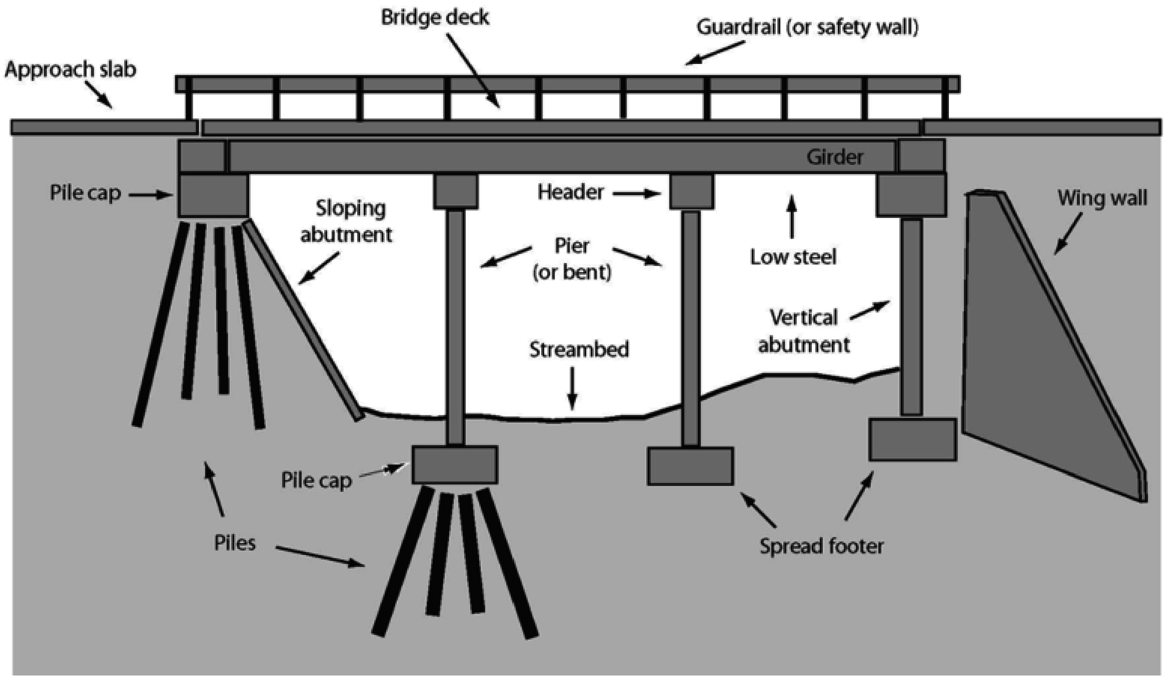

Figure 14 Example of a bridge, including footing

Piles supporting footings are linked according to a connection relationship.

Field	Definition	R	T
Name	Name of the footing for referencing purposes, as would be found on construction plans.		■
Material	Material properties of the footing, indicating concrete strength.		■
Geometry	Geometry of the footing typically described as footprint of polygons with constant height.		■
Piles	Connection to piles supporting footing.		■
Reinforcing	Reinforcing bars within footing.		

Table 11 Requirements for Element Footing

1.2.10 Pile

Piles are typically described geometrically by a circular profile extruded vertically according to pile depth. For multiple piles, mapped representation may be used to efficiently place piles of similar dimensions in multiple locations.

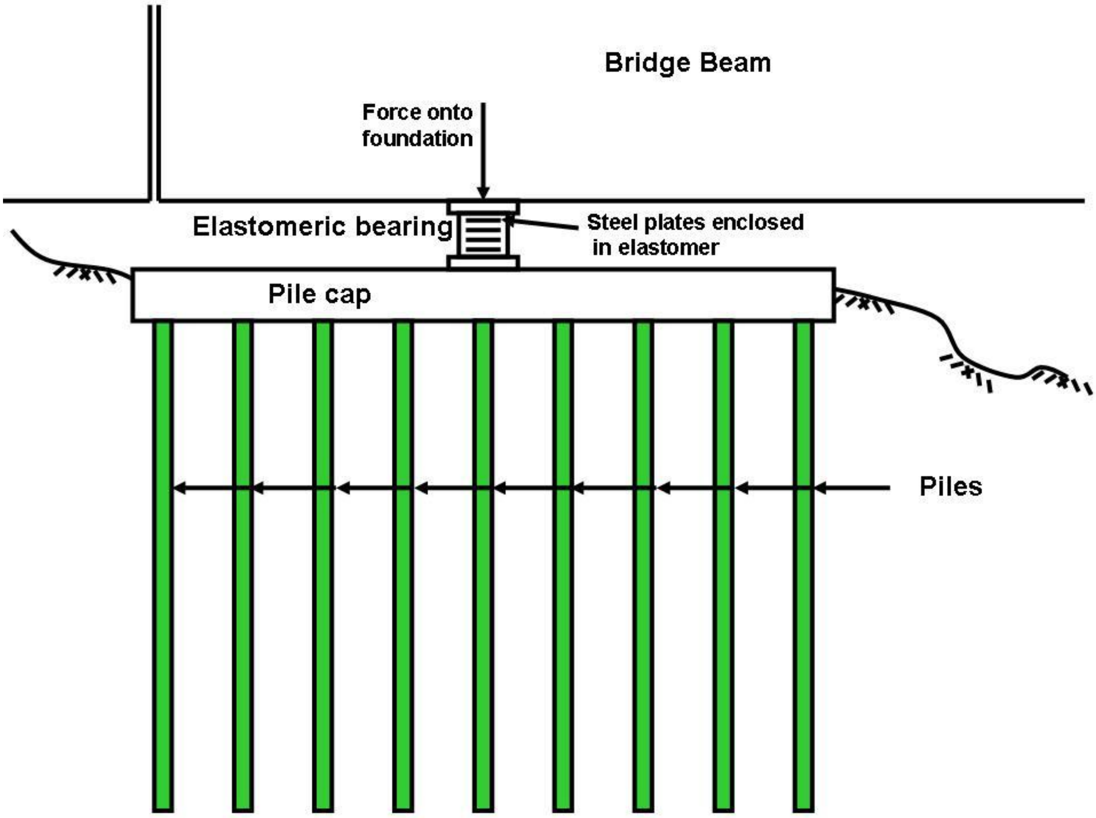

Figure 15 Drawing of Piles

Piles supporting footings are linked according to a connection relationship.

Field	Definition	R	T
Name	Name of pile arrangement for referencing purposes, as found on construction plans.		■
Material	Material of piles.		■
Cross Section	Cross section of piles, typically I-shape or hollow circle.		■
Placement	Cartesian positions of pile occurrences relative to enclosing pier or abutment structure.		■
Batter	Angle of incline indicated as a parameter. In case of inconsistency, the Placement takes precedence.		

Table 12 Requirements for Element Pile

1.2.11 Hat Stone

Hat Stone refers to a top course on an abutment or culvert.

Figure 16 Example of a hat stone

1.3 Superstructure

The superstructure of a bridge refers to those elements than span horizontally to carry loads onto substructures.

Field	Definition	R	T
Name	Name of the superstructure for organizational purposes.	■	■
Alignments	Alignment objects used longitudinally (e.g. for girders) or laterally (e.g. for floor beams).	■	■
Trusses	Truss lines.		
Girders	Girder lines.		■
Cross Frames	Cross frames between girder lines.		
Floor Beams	Floor beams between girder lines.		
Stringers	Stringers between floor beams.		

Table 13 Requirements for Element Superstructure

1.3.1 Girder

Bridge girders refer to horizontal support beams that span along the alignment of a bridge.

Figure 17 Example of bridge girders

For steel girders, this refers to each girder line, decomposed into beam segments.

For concrete box girders, this refers to the overall box girder, typically connected to the bridge deck via a keyed construction joint with adjoining reinforcing.

Field	Definition	R	T
Name	Name of the girder line for referencing purposes as would be found on construction plans.	■	■
Alignment	Reference to the alignment object used to position the girder line.	■	■
Axis	Axis curve defined as a sub-span with offsets relative to the alignment curve.		■
Type	Template defining general construction that may be used across projects.	■	■
Material	Common material that applies to all segments of the girder.		■
Segments	Segmented girders may be decomposed into segments for each continuous section.	■	■
Components	Built-up girders may be decomposed into plates (or members) for web, flanges, cover plates, longitudinal stiffeners, and vertical stiffeners.		

Table 14 Requirements for Element Girder

1.3.2 Girder Segment

Girder segments refer to discrete sections along a girder line. They may be modelled as one object that encapsulates the overall cross section (e.g. I-Shape steel, arbitrary precast profile), or as separate objects (e.g. steel flange plates, steel web plate). Each segment may have a constant cross section, a tapered cross section (linearly interpolated from start to end), a variable cross section (linearly interpolated at multiple points between start and end), or free-form geometry.

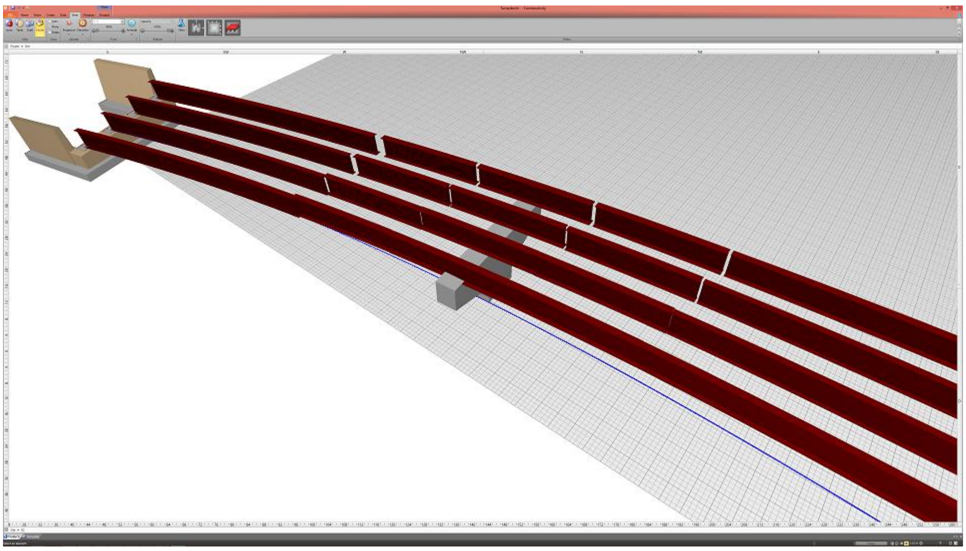

Figure 18 Bridge girder model (source: T. Chipman)

As shown in Figure 18, girders may be split into segments according to defined splices. The gaps in the illustration are exaggerated to show each segment.

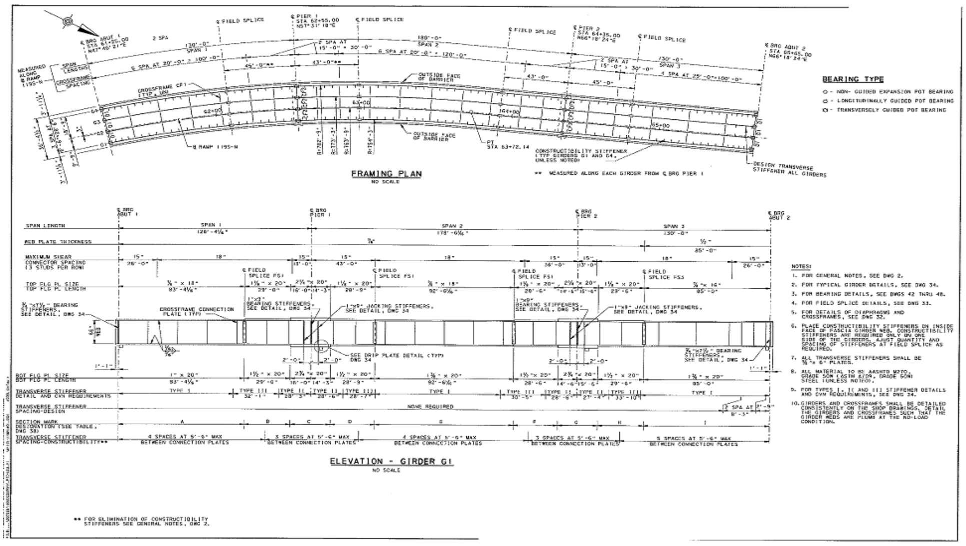

Figure 19 Bridge girder plans

Field	Definition	R	T
Name	Name of the girder segment for referencing purposes as would be found on construction plans.	■	■
Material	Material of the girder segment.	■	■
Solid Geometry	Geometry of the girder segment defined as a cross section that may be constant or variable (linearly or parabolic), swept along the alignment at starting and ending positions.	■	■
Connection Head	Relationship connecting head of girder segment with abutment or another girder segment, where realizing element refers to splice plates.		■
Connection Tail	Relationship connecting tail of girder segment with another girder segment or abutment, where realizing element refers to splice plates.		■
Connection Support	Relationship connecting girder segment to substructure, where realizing element refers to bearing if present.		
Reinforcing	For concrete girders, reinforcing embedded.		■
Tendons	For concrete girders, tendons embedded.		■
Stiffeners	For steel girders, web stiffeners placed at intervals along inside face(s) of web.		■
Shear Studs	For steel girders, shear studs placed at intervals along top flange.		■
Camber	For steel girders, camber ordinates for fabrication.		■

Table 15 Requirements for Element Girder

The connection between beams is represented using IfcRelConnectsWithRealizingElements, where the *RealizingElements* refers to IfcPlate elements for fastening plates on each side, IfcFastener for bolts, and IfcPlate for any flange transition plates. The reason for using this connection relationship specifically (as opposed to just placing the elements) is to be able to derive an IfcStructuralAnalysisModel that captures the beam connectivity.

1.3.3 Cross Frame

Bridge cross frames connect two girders laterally.

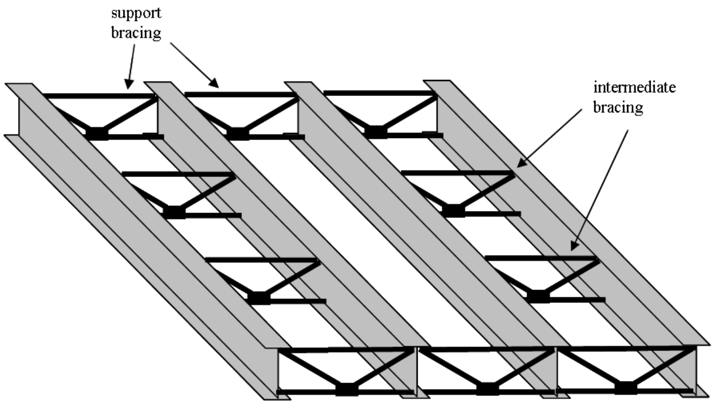

Figure 20 Diagram depicting cross frame

Cross-framing between girders may be described using templates of member configurations. Such cross framing is captured within components, using standard shapes (e.g. AISC in U.S.) where applicable. For curved alignments where girders are placed at different elevations, members must be placed relative to the girders at each side, for which positioning is defined relative to alignment curves.

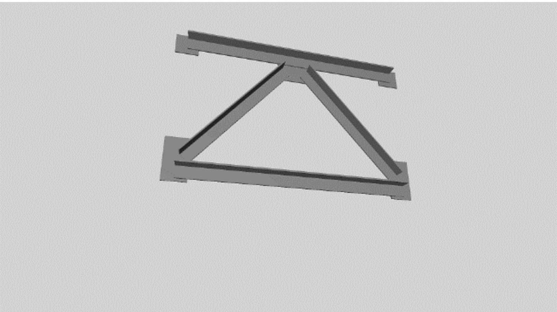

Figure 21 Bridge framing model

Such cross-framing is then instantiated as object occurrences according to repetition intervals, where each occurrence has unique connectivity relationships with corresponding girder segments.

Field	Definition	R	T
Name	Name of cross frame occurrence as would be identified on construction plans.	■	■
Plates	Plates used within cross frame.	■	■
Members	Members used within cross frame.	■	■
Position	Position of cross frame relative to alignment.	■	■
Girder Segment Left	Connection to girder on left as facing direction of alignment.		■
Girder Segment Right	Connection to girder on right as facing direction of alignment.		■

Table 16 Requirements for Element Cross Frame

1.3.4 Diaphragm

Diaphragms refer to sections of bridge girders immediately above supporting structures that provide additional lateral and vertical support.

Diaphragms are modeled similarly as concrete girder segments, except are distinguished according to a predefined type (e.g. IfcBeamTypeEnum.DIAPHRAGM), and have connections to underlying supports.

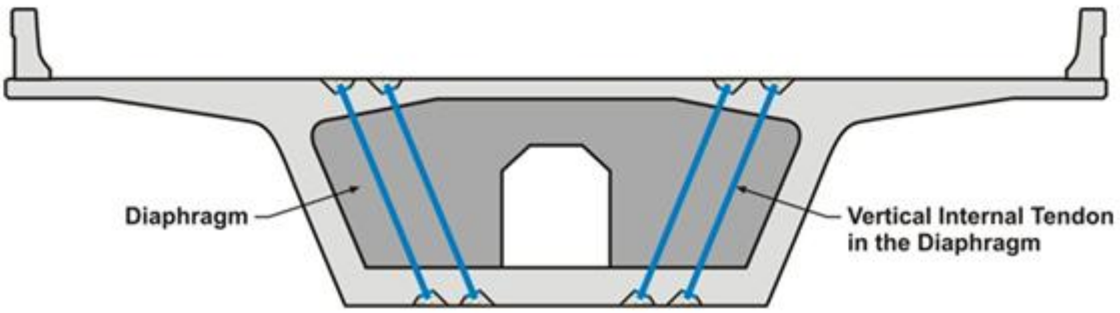

Figure 22 Diaphragm with a vertical internal tendon

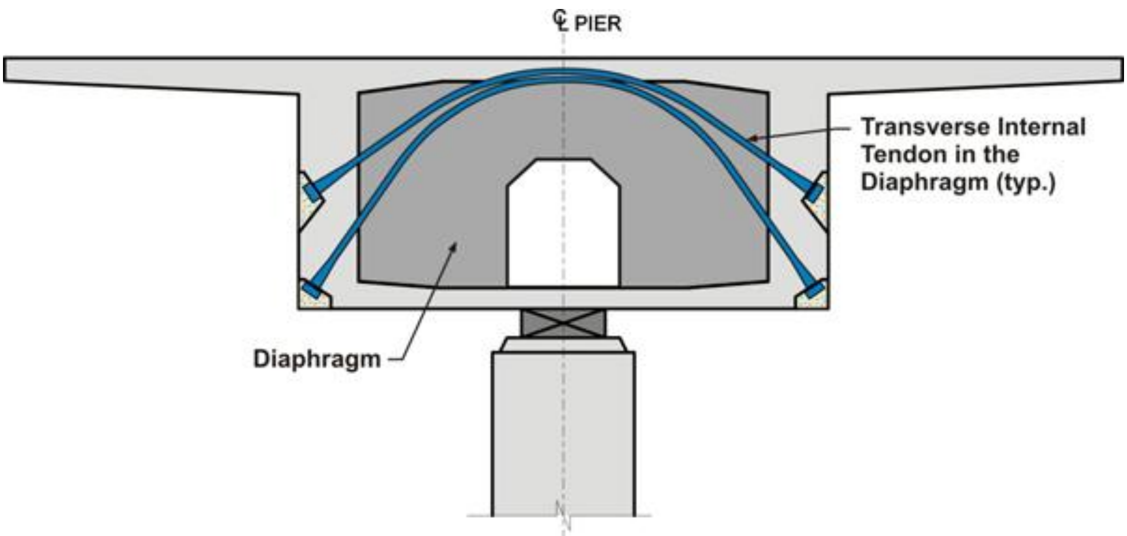

Figure 23 Diaphragm with a transverse internal tendon

Field	Definition	R	T
Name	Name of the diaphragm for referencing purposes as would be found on construction plans.	■	■
Material	Material of the girder segment.	■	■
Solid Geometry	Geometry defined as a cross section that may be constant or variable (linearly or parabolic), swept along the alignment at starting and ending positions.	■	■
Connection Head	Relationship connecting head of diaphragm with a girder segment.		■
Connection Tail	Relationship connecting tail of diaphragm with a girder segment.		■
Connection Support	Relationship connecting diaphragm to substructure, where realizing element refers to bearing if present.		
Reinforcing	For concrete diaphragms, reinforcing embedded.		■
Tendons	For concrete diaphragms, tendons embedded.		■

Table 17 Requirements for Element Diaphragm

1.3.5 Truss

Trusses refer to a framework of linear structural elements in tension and compression for supporting the span of a bridge superstructure.

Figure 24 Example of a truss

Within a truss, struts refer to compression elements, and ties refer to tension elements.

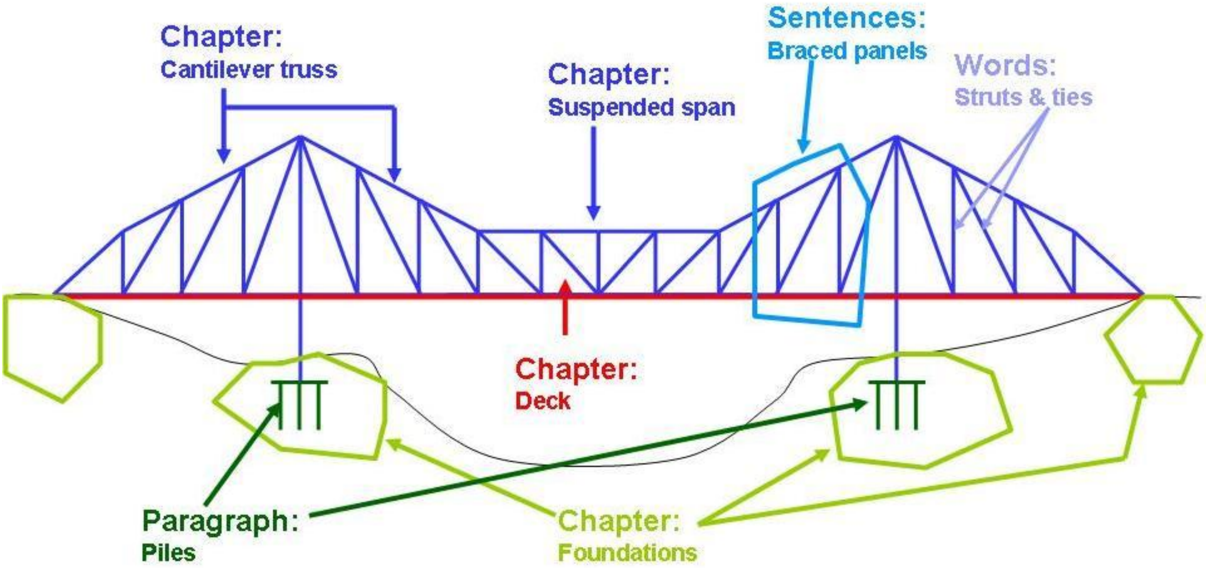

Figure 25 Struts and ties in a truss

Field	Definition	R	T
Name	1.3.5.1 Name of the truss for referencing purposes as would be found on construction plans.	■	■
Members	Members within truss, each having connections to gusset plates.		■
Gusset Plates	Gusset plates connecting truss memers		■
Connections	Relationships connecting truss to other superstructure elements		■

Table 18 Requirements for Element Truss

1.4 Deck

A bridge deck is comprised of those elements used for conveying traffic but do not perform structural functions of the superstructure.

1.4.1 Deck Span

Bridge deck spans represent the surface of a bridge. They may be decomposed into segments and components.

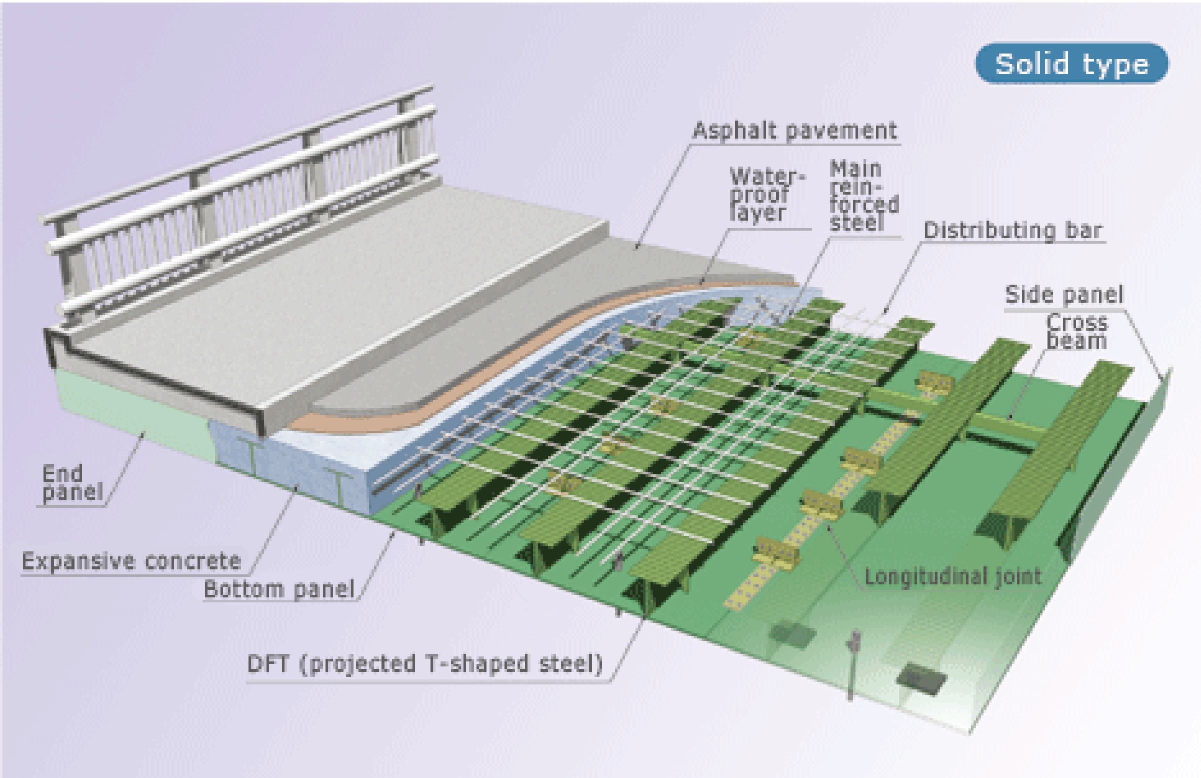

Figure 26 Example of a decomposed deck span

Field	Definition	R	T
Name	Name of the deck sequence.	■	■
Type	Template defining general construction that may be used across projects.	■	■
Material	Common material that applies to all segments of the bridge deck		■

Table 19 Requirements for Element Deck span

1.4.2 Deck Segment

This entity may be used to model segments of a bridge deck, separated by construction or expansion joint. Geometry for bridge decks is typically represented using IfcSectionedSolidHorizontal for defining a cross section that may potentially vary along an alignment.

Field	Definition	R	T
Name	Name of the deck segment for referencing purposes as would be found on construction plans.	■	■
Surface	For reference, surface geometry is only needed for visualization purposes.	■	■
Material	Material of the deck segment.		■
Solid Geometry	Geometry of the deck segment, including any haunches, defined as a cross section that may be constant or variable (linearly or parabolic), swept along the alignment at starting and ending positions.		■
Connection Head	Relationship connecting head of deck segment with abutment or another deck segment.		■
Connection Tail	Relationship connecting tail of deck segment with another deck segment or abutment.		■
Connection Girders	Relationship connecting deck segment to supporting girder(s).		■
Reinforcing	Reinforcing embedded within deck.		■
Drainage	Waste terminals embedded within deck.		■

Table 20 Requirements for Element Deck Segment

1.4.3 Parapet

This entity may be used to model barriers of constant cross-section, or architectural railings.

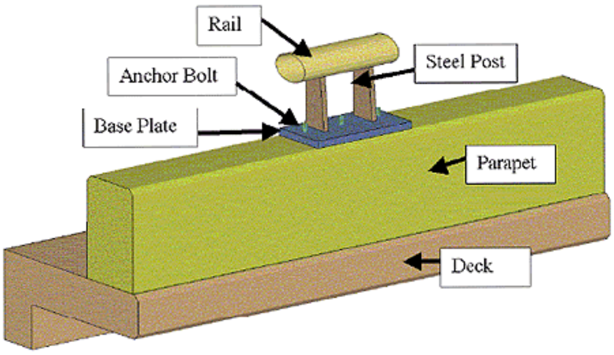

Figure 27 Example of a railing

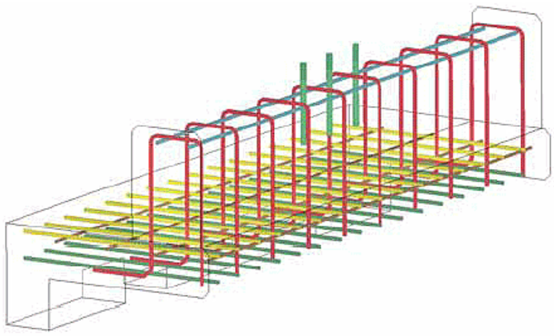

Figure 28 Example of a barrier constant cross-section

Barriers may be defined as a constant cross-section placed along the alignment at either edge of a bridge deck or anywhere in between.

Field	Definition	R	T
Name	Name of the parapet segment for referencing purposes as would be found on construction plans.	■	■
Material	Material of the parapet.	■	■
Solid Geometry	Geometry of the parapet segment defined as a cross section that may be constant or variable, swept along the alignment at starting and ending positions.	■	■
Connection Head	Relationship connecting head of parapet segment with abutment or another parapet segment.		■
Connection Tail	Relationship connecting tail of parapet segment with another parapet segment or abutment.		■
Deck	Relationship connecting parapet segment to supporting bridge deck.		■
Reinforcing	Reinforcing embedded within parapet.		■
Conduit	Conduit embedded within parapet.		■

Table 21Requirements for Element Parapet

1.4.4 Approach Slab

An approach slab refers to a slab providing transition between a bridge and road pavement, where an expansion joint allows for differential settlement, temperature changes, and freeze/thaw effects.

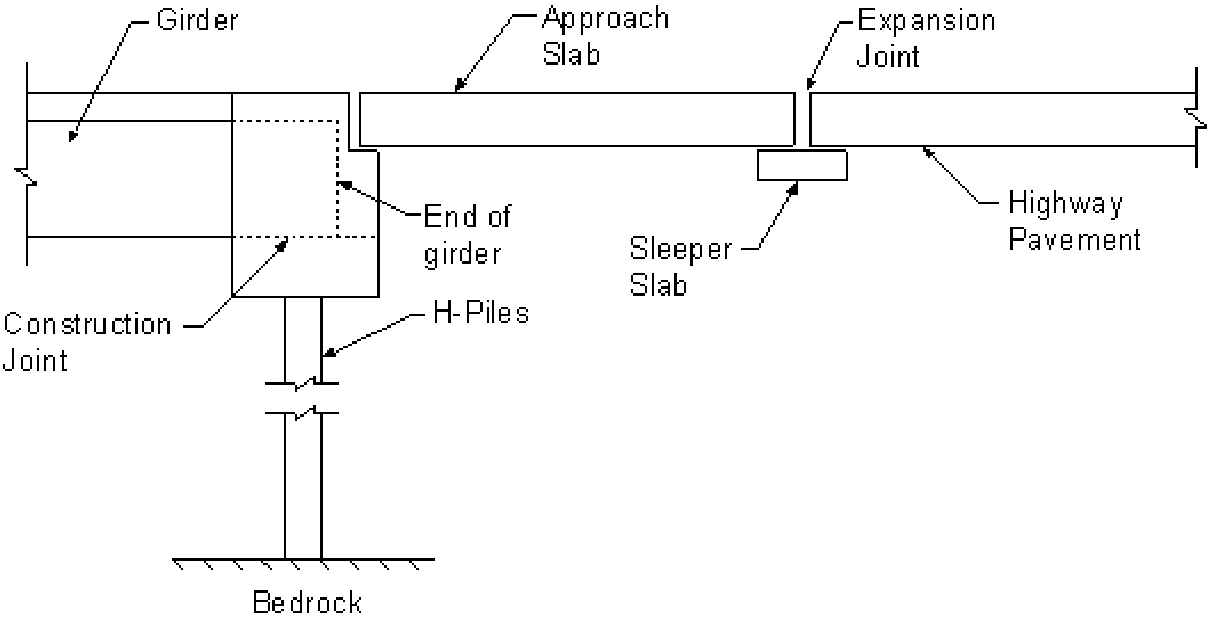

Figure 29 Example of an approach slab in plans

1.4.5 Cornice

A cornice is construction eveloping the sides of a bridge protecting the deck.

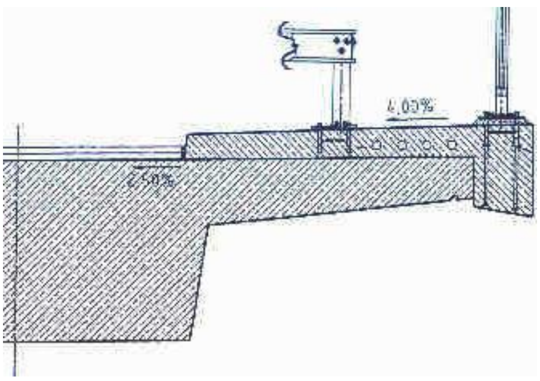

Figure 30 Example of a cornice in plans

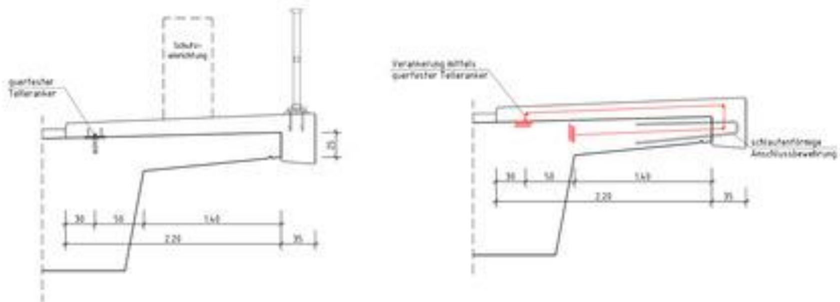

Figure 31 Example of a cornice in plans

1.4.6 Waterproofing

Waterproofing membranes are applied on top of deck segments.

Figure 32 Example of a waterproofing membrane

1.4.7 Roadway Surfaces

Roadway surface elements include pavement overlays and pavement treatments (e.g. rumble strips), and lane striping.

Figure 33 Example of a roadway surface

1.5 Mechanical Connections

Mechanical connections refer to elements providing connectivity with fixed or variable degrees of freedom.

1.5.1 Bearing

Bearings refer to elements connecting substructure elements to superstructure elements where movement is allowed along one or more degrees of freedom.

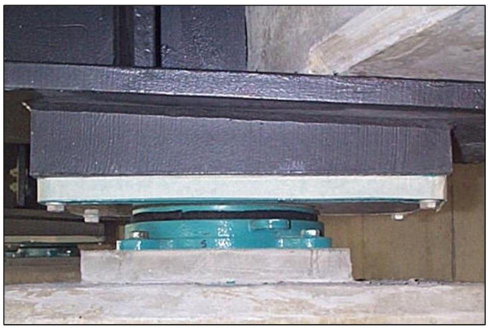

Figure 34 Example of a bearing

Figure 35 Example of a bearing

NOTE: a new entity will likely be introduced in the next phase of this project.

Field	Definition	R	T
Name	Name of bearing for referencing purposes as would be found on construction plans.	■	■
Type	Type of bearing, where common geometry and properties may be defined.	■	■
Mechanical Constraint	Indicates mechanical behavior of bearing for each degree of freedom with optional spring constant.	■	■
Connecting Support	Connection to abutment or pier supporting the bearing.	■	■
Connecting Girder	Connection to girder segment or diaphragm supported by the bearing.	■	■

Table 22 Requirements for Element Bearing

1.5.2 Joint

An expansion joint is an assembly connection between construction elements to allow for thermal differential expansions.

Figure 36 Example of expansion joints

A seam joint is a joint that joins two materials.

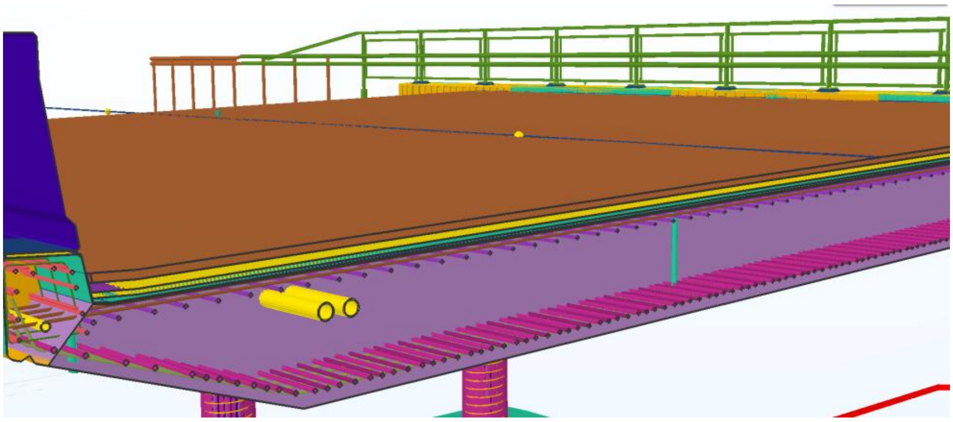

Figure 37 Model depicting a seam joint

A construction joint is one where fresh concrete has to be placed on or against concrete that has already hardened.[3]

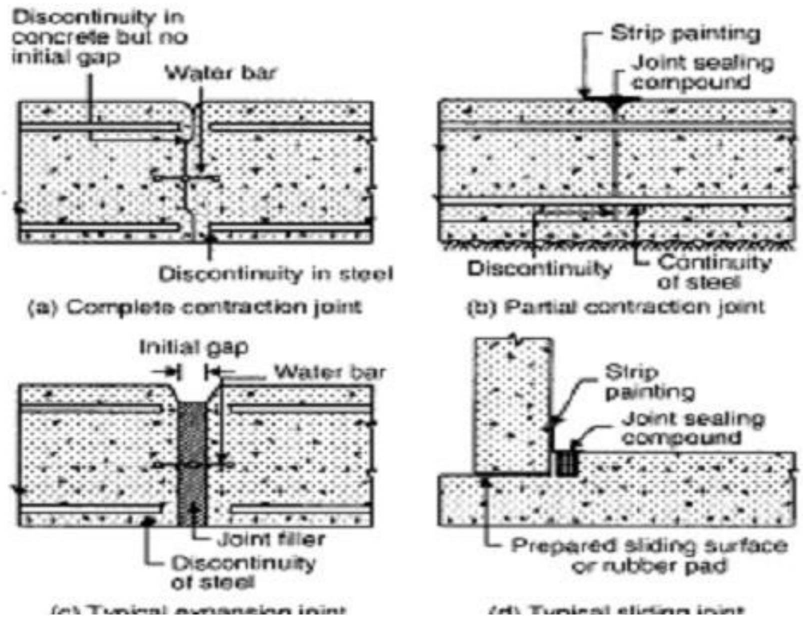

Figure 38 Example of construction joints on plans

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[3] source: https://addyst.blogspot.de/2015/02/construction-and-expansion-joints.html

Field	Definition	R	T
Name	2 Name of joint for referencing purposes as would be found on construction plans.	■	■
Type	Type of joint, where common geometry and properties may be defined.	■	■
Expansion Extent	Indicates the length available for expansion.	■	■
Connection Head	Reference to deck segment or pavement at head	■	■
Connection Tail	Reference to deck segment or pavement at tail	■	■

Table 23 Requirements for Element Joint

2.1.1 Shock Absorber

A shock absorber is a device designed to absorb shock impulses such as from earthquakes.

Figure 39 Example of a shock absorber (source: http://img.archiexpo.com/images_ae/photo-g/126411-6507243.jpg)

Figure 40 Example of a shock absorber

2.1.2 Beam Falling Prevention Device

Figure 41 Example of a beam falling prevention device (source: CRBIM)

2.2 Reinforcement and Prestressing

2.2.1 Rebar Array

Rebar is typically represented with one object instance corresponding to a set of rebar of the same dimensions, spaced at regular or irregular intervals.

Figure 42 Example of a rebar array

Field	Definition	R	T
Name	Name of rebar set for referencing purposes as would be found on construction plans.		■
Type	Type of rebar indicating common bar diameter and bending parameters.		■
Placement	Reference position of rebar within embedding element.		■
Pattern	Cover, spacing, and repetition along one or more axes.		
Geometry	Geometry of rebar indicated as mapped items.		

Table 24 Requirements for Element Rebar Array

2.2.2 Rebar Shape

This entity may be used to capture rebar sizes and bending shapes either parametrically or of fixed dimension.

For parametric definitions, the rebar size and/or material may be specified using a material profile set. If no material profile set is provided, then such information may be configurable by downstream usage of the definition (either a derived definition or an occurrence).

For bending shapes such as for stirrups or ties, the geometry may be defined using a polygonal swept disk, where a polyline indicates the transition points, and a fillet radius indicates how the rebar is to be bent at each transition point.The IFC4 Reference View uses an indexed poly curve (IfcIndexedPolyCurve) to represent the sequence of lines and arcs. For the purpose of representing spirals a polyline parameterized on a cylinder shall be used. IfcPcurve provides the required functinality.

For implicit parametric definitions of bending parameters, the BendingShapeCode and BendingParameters may be provided, where applications rely on their own database (e.g. ACI 318 in the United States) to interpret the code and parameters.

For explicit parametric definitions, constraints may be used to link the shape geometry of the swept disk solid to input parameters.

Field	Definition	R	T
Name	Name of rebar type for referencing purposes as would be found within rebar schedules in construction plans.		■
Material	Material properties of rebar.		■
Geometry	Bar shape defined by swept disc solid with bending radius, after applying all parameters.		■
Bar Diameter	Nominal diameter of rebar according to default units - for example, #7 would be 0.875 inches or 22.225 millimeters.		■
Bar Length	Length of rebar according to default units.		■
Bending Shape Code	Shape code per a standard (e.g. ACI 315 in U.S., ISO 3766, or a similar standard).		■
Bending Parameters	Bending shape parameters. Their meaning is defined by the bending shape code and the respective standard.		■
Bending Radius	The fillet that is equally applied to all transitions between the segments of the IfcPolyline, providing the geometric representation for *the Directrix*. If omited, no fillet is applied to the segments.		■

Table 25 Requirements for Element Rebar Shape

2.2.3 Prestressing system

Prestressing systems are used to strengthen bridge concrete structures and includes several entities.

The key one entity is an extrapolation of **IfcTendon**. The associated geometry has to be able to face bridge alignment. It may be defined as a constant cross-section placed along a polyline.

A bridge tendon can be located into the concrete structure (internal tendon), or located along the concrete structure (external tendon) and then connected to the concrete structure by **deviators**, or even, could be partly in the concrete and partly along the concrete structure.

At each end, the tendon is connected to the concrete structure through a **tendon anchor.** It is at the anchor that a jack is connected to tension de tendon. A tendon can be tensioned by one jack or by both, according to the tension losses along the cable, losses with are depending on the length and the geometry of the tendon.

A bridge tendon could be used to strengthen a given beam or to connect and strengthen the connection between two or more deck segments.

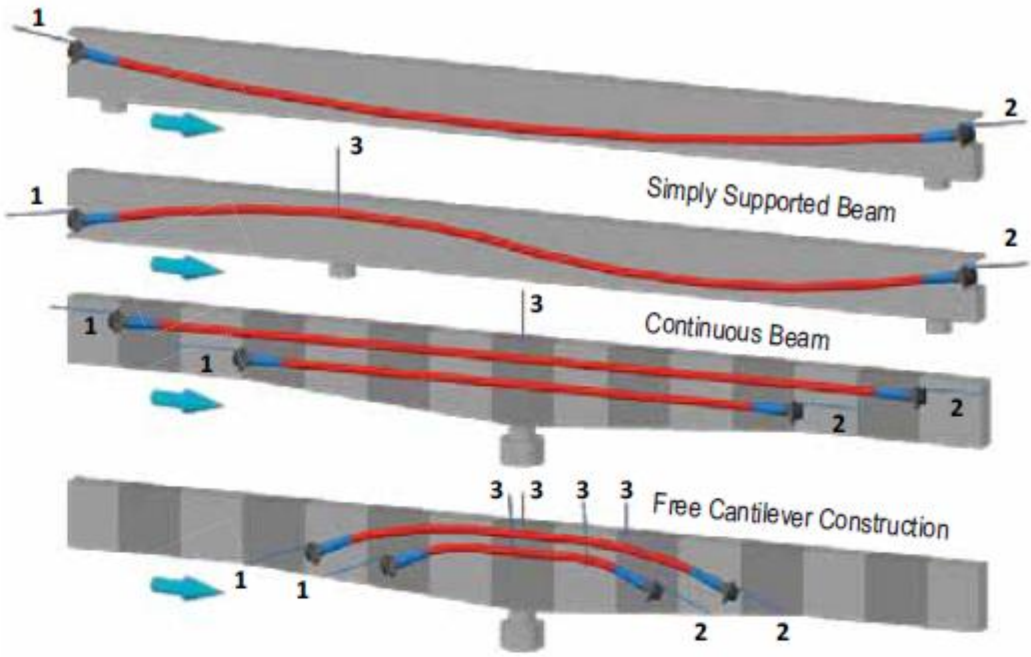

Figure 43 Tensioning system (source: VSL-strand-tensioning-systems.pdf)

2.2.4 Tendons

Prestressing systems include tensioning, anchorage, tendon, threading, and duct systems.

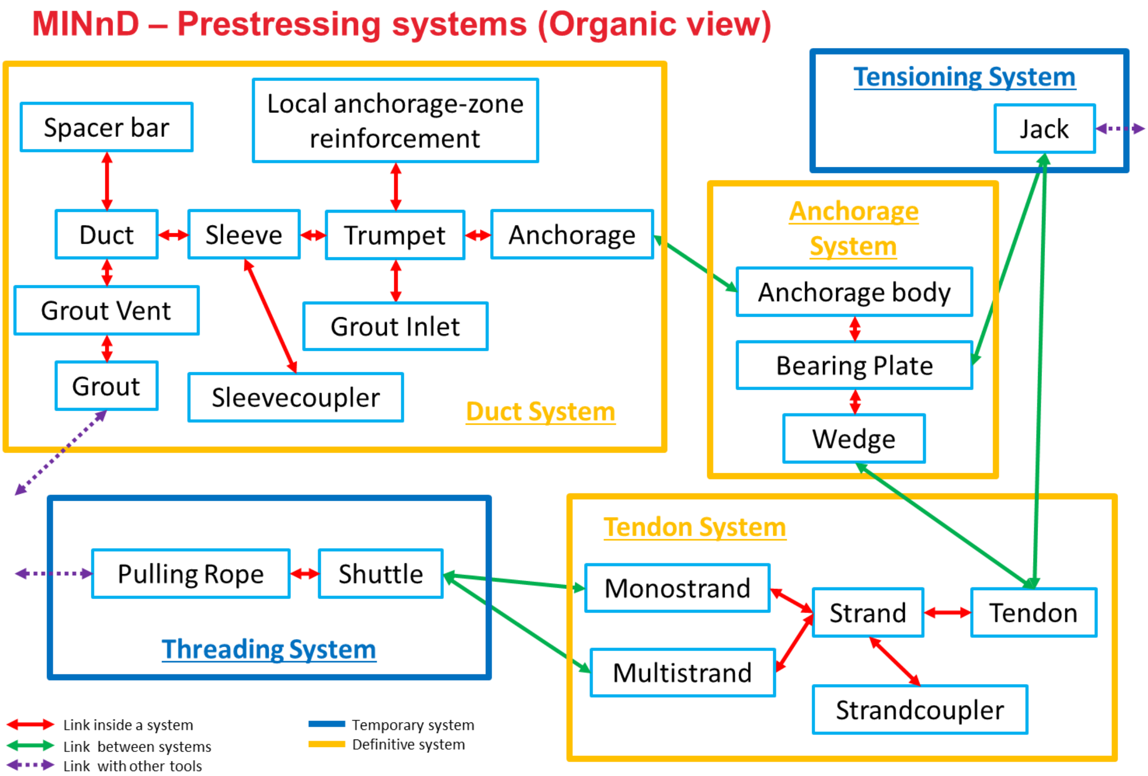

Figure 44 Diagram depicting an organic view of a prestressing system (source: MINnD project)

An anchor refers to an anchoring element for prestressing tendons.

Figure 45 Example of an anchor

Field	Definition	R	T
Name	Name of anchor for referencing purposes.		■
Geometry	Tendon anchor shape.		■
Connection Duct	Reference to tendon duct.		■
Connection Tendon	Reference to tendon strand.		■

Table 26 Requirements for Element Tendon anchor

A tendon refers to a tensioned element producing compression in prestressed concrete.

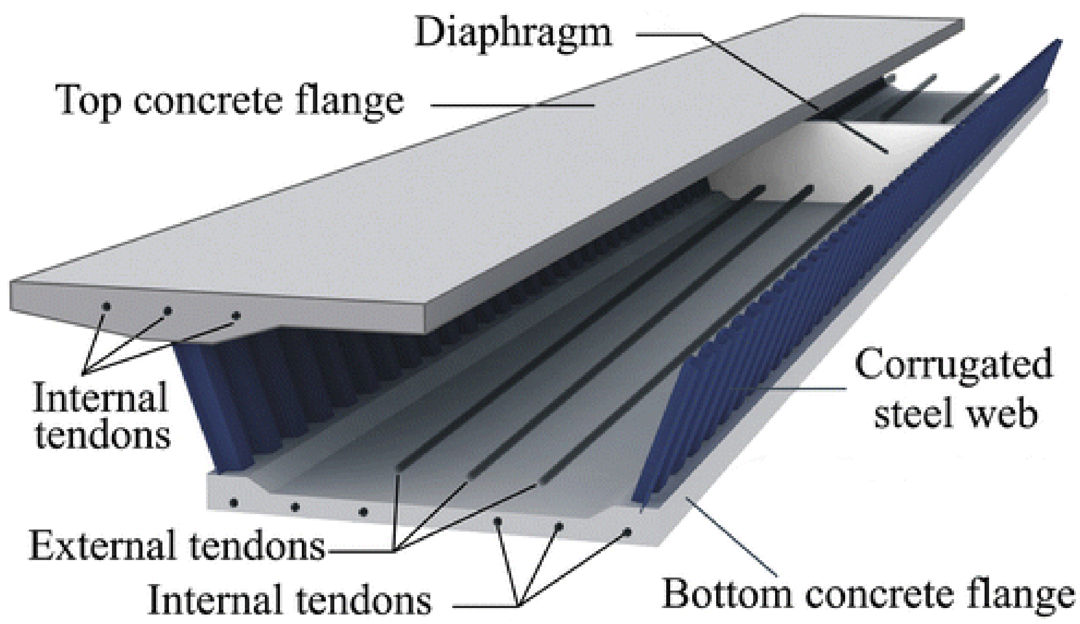

Figure 46 Diagram depicting tendons in concrete

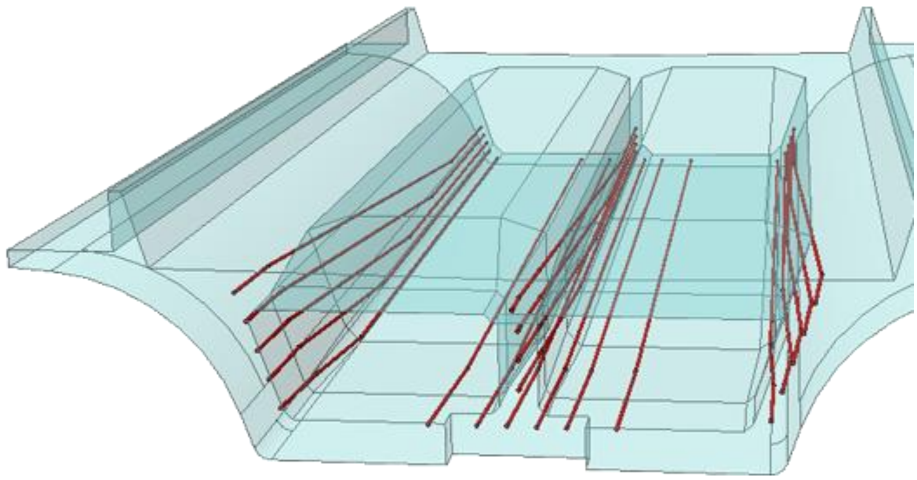

Figure 47 Model depicting tendons in concrete

Field	Definition	R	T
Name	Name of tendon for referencing purposes.		■
Material	Material properties of tendon.		■
Geometry	Tendon shape defined by swept disc solid.		■
Connection Head	Reference to tendon anchor at head.		■
Connection Tail	Reference to tendon anchor at tail.		■

Table 27 Requirements for Element Tendon strands

A deviator refers to a prestressed tendon redirection structure.

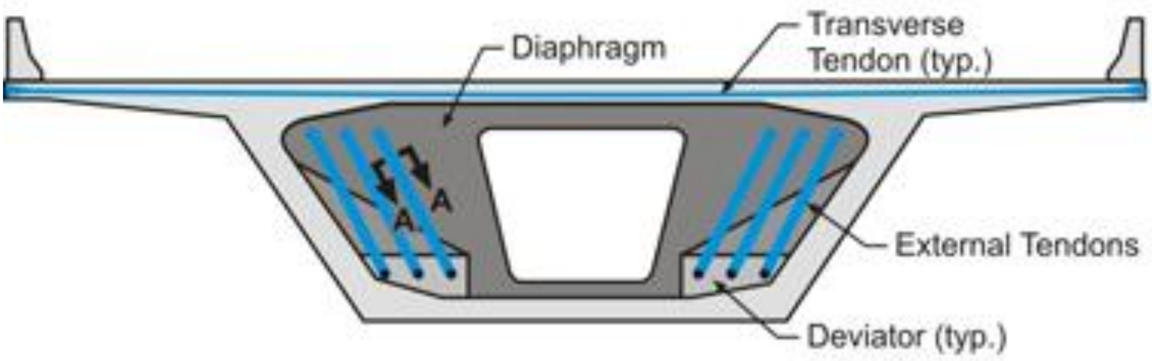

Figure 48 Diagram of a deviator

Figure 49 Example of a deviator

A blister refers to part of concrete where the anchor for prestressing can be embedded.

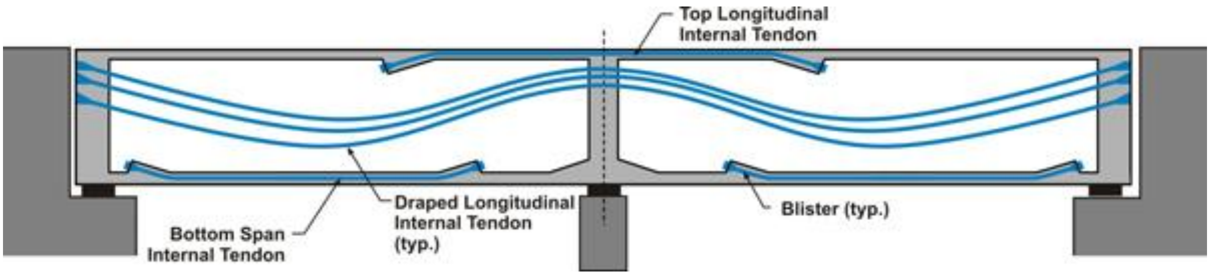

Figure 50 Diagram depicting the element blister

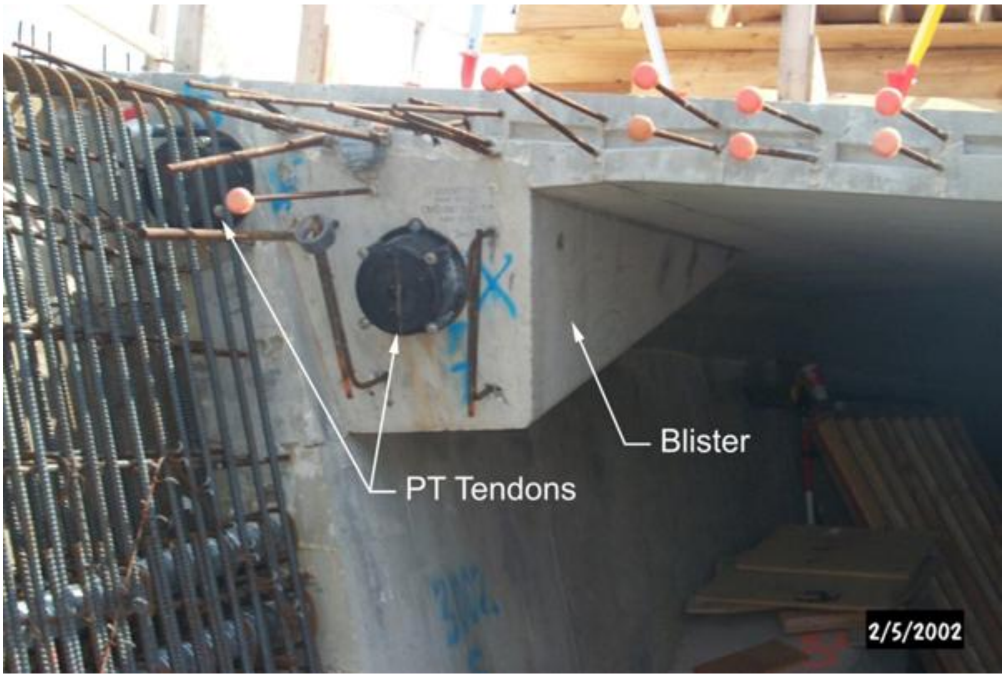

Figure 51 Example of a blister

Field	Definition	R	T
Name	Name for referencing purposes.		■
Material	Material properties of concrete.		■
Geometry	Shape typically defined by sectioned solid with variable cross section.		■
Containing Element	Reference to girder segment or diaphgram hosting the deviator/blister, where the connection indicates a continuous concrete pour.		■
Tendon Ducts	Reference to tendon ducts embedded within deviator/blister.		■

Table 28 Requirements for Elements Deviator and Blisters

Conduit refers to a channel for housing prestressing tendons.

Figure 52 Example of a conduit

Field	Definition	R	T
Name	Name of tendon duct for referencing purposes.		■
Material	Material properties of duct.		■
Axis	Axis curve of tendon duct, which may leverage parabolic shapes using vertical alignment curves.		■
Geometry	Duct shape defined by swept disk solid following axis.		■
Connection Head	Reference to deviator anchoring tendon head.		■
Connection Tail	Reference to deviator anchoring tendon tail.		■
Connection Axis	Reference to deviator(s) anchoring tendon duct along span.		■
Tendons	Reference to tendons within duct.		■

Table 29 Requirements for Element Tendon ducts

2.2.5 Vents

Vents allow air to move between compartments within box girders (to avoid pressure difference with differing temperatures), while potentially protecting infestation from birds and other wildlife.

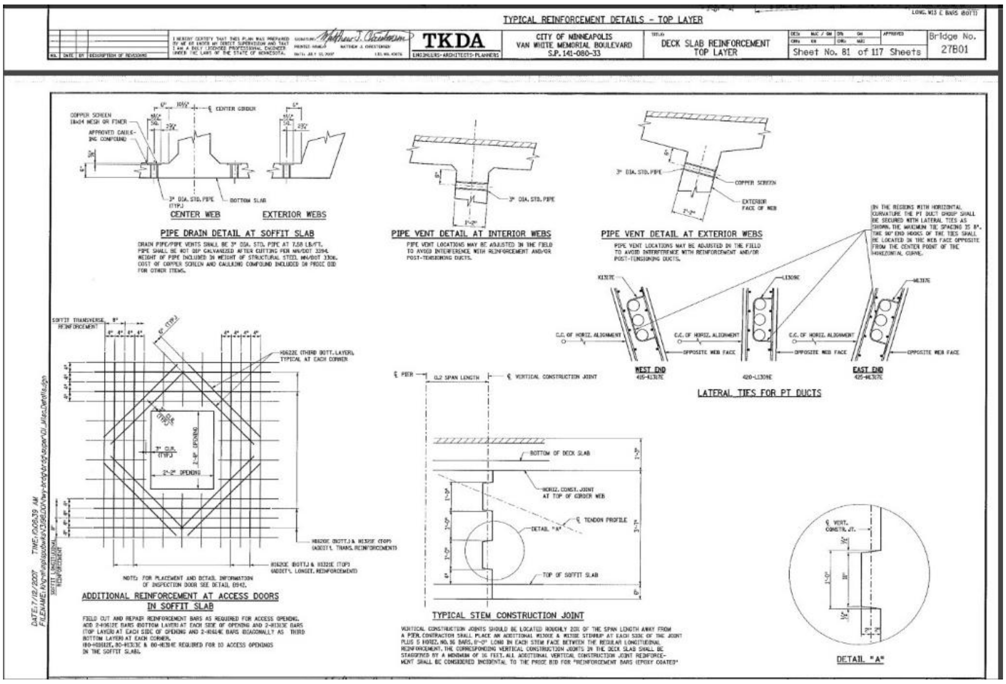

Figure 53 Example of vents on plans (source: TKDA)

Field	Definition	R	T
Name	Name for referencing purposes.		■
Containing Element	Girder segment containing vent.		■
Geometry	Shape of void		■
Screens	Screens attached to inhibit habitation by animals		

Table 30 Requirements for Element Vent

2.2.6 Access Panels

For box girder bridges with enclosed compartments, access panels allow for inspection and maintenance of components, while restricting access from unauthorized persons or wildlife.

Field	Definition	R	T
Name	Name for referencing purposes.		■
Containing Element	Girder segment containing access panel.		■
Geometry	Shape of access panel		■

Table 31 Requirements for Element Access Panel

2.3 Drainage

Drainage elements include all elements used for carrying stormwater away from the bridge structure.

2.3.1 Waste Terminals

Figure 54 Example of a waste terminal

Field	Definition	R	T
Name	Name for referencing purposes.		■
Containing Element	Reference to deck segment containing drain.		■
Connection Tail	Reference to pipe segment connected to drain.		■
Geometry	Shape of waste terminal		■

Table 32 Requirements for Element waste terminal

2.3.2 Pipes

Figure 55 Example of pipes on a bridge

Field	Definition	R	T
Name	Name for referencing purposes.		■
Containing Element	Reference to element containing or anchoring pipe segment.		■
Connection Head	Reference to distribution element at head of pipe segment.		■
Connection Tail	Reference to distribution element at tail of pipe segment.		■
Geometry	Shape of pipe segment in the form of a swept disk solid.		■

Table 33 Requirements for Element Pipe

2.4 Electrical

Electrical elements are comprised of fixtures, wiring, conduit, and junctions that carry electrical power, communications, or other electric signals.

While electrical requirements are often captured separately from bridge structures, embedded elements (e.g. conduit) must be captured for concrete construction.

2.4.1 Junction Box

Field	Definition	R	T
Name	Name of the junction box for referencing purposes as would be found on construction plans.	■	■
Embedding Element	If embedded in concrete, indicates the element containing the junction box.	■	■
Anchoring Element	If attached to a surface, indicates the element anchoring the junction box.	■	■
Body Geometry	Geometry of junction box.	■	■
Conduit	Conduit connected to junction box.		■

Table 34 Requirements for Element Junction Box

2.4.2 Conduit

Conduit is defined as a segment connecting one electrical device (or junction box) to another, following a linear path, and potentially embedded within another element (e.g. parapet wall).

Field	Definition	R	T
Name	Name of the conduit for referencing purposes as would be found on construction plans.	■	■
Embedding Element	If embedded in concrete, indicates the element containing the conduit.	■	■
Anchoring Element	If attached to a surface, indicates the element anchoring the conduit.	■	■
Body Geometry	Geometry of conduit, in the form of a swept disk solid.	■	■
Connection Head	Connection to junction box at head.	■	■
Connection Tail	Connection to junction box at tail.	■	■

Table 35 Requirements for Element Conduit

2.4.3 Lighting

Lighting is defined as placeholder objects without further elaboration.

Figure 56 Example of lighting on a bridge

Field	Definition	R	T
Name	Name of the light fixture for referencing purposes as would be found on construction plans.	■	■
Placement	Placement of light fixture.		
Anchoring Element	Reference to physical element anchoring light fixture, such as a mounting plate.		
Conduit	Reference to conduit for which wiring is connected.		

Table 36 Requirements for Element Lighting

2.5 Traffic Control

2.5.1 Lanes

For bridge design, spaces may be used to designate travel lanes for vehicles, bicycles, pedestrians, or other usage. Such usage may not always be necessary for construction requirements, however may be used for reference purposes to relate actual conditions as observed by humans (e.g. pothole in middle lane) to the physical structure.

Field	Definition	R	T
Name	Name of lane.	■	■
Category	Usage of lane such as "Vehicle", "Bicycle", "Pedestrian", "HOV", according to DOT classification. Specific identifiers are not established in this specification.	■	■
Geometry	Geometry of lane defined as sectioned solid relative to alignment curve, where height indicates required clearance.	■	■
Lane In	Connection to lane(s) converging into this lane.		■
Lane Out	Connection to lane(s) diverging from this lane.		■
Lane Left	Connection to laterally adjacent lane to the left.		■
Lane Right	Connection to laterally adjacent lane to the right.		■

Table 37 Requirements for Element Lane

2.5.2 Signs

Traffic signs include static signage, signals, and displays (using LEDs or video displays). It is anticipated that sign definitions (and “road furniture” in general) provide for placement and dimensions, along with specification of colors, reflective materials, graphics and lettering. Such definition is outside the scope of this project; it is anticipated that the IFC-Road extension will capture such detail.

Figure 57 Example of signs on a bridge

2.6 Temporary Elements

This section refers to elements specifically intended for constructing a bridge. While any physical element may be temporary, including even temporary bridges, elements described herein have specific purpose.

Figure 58 Example of a Launching nose

2.6.1 Launching Gantry

Figure 59 Example of a launching gantry

2.6.2 Staying Mast

Figure 60 Example of a staying mast

2.6.3 Casting Bed

Figure 61 Example of a casting bed

2.6.4 Pulling (Pushing) Jack

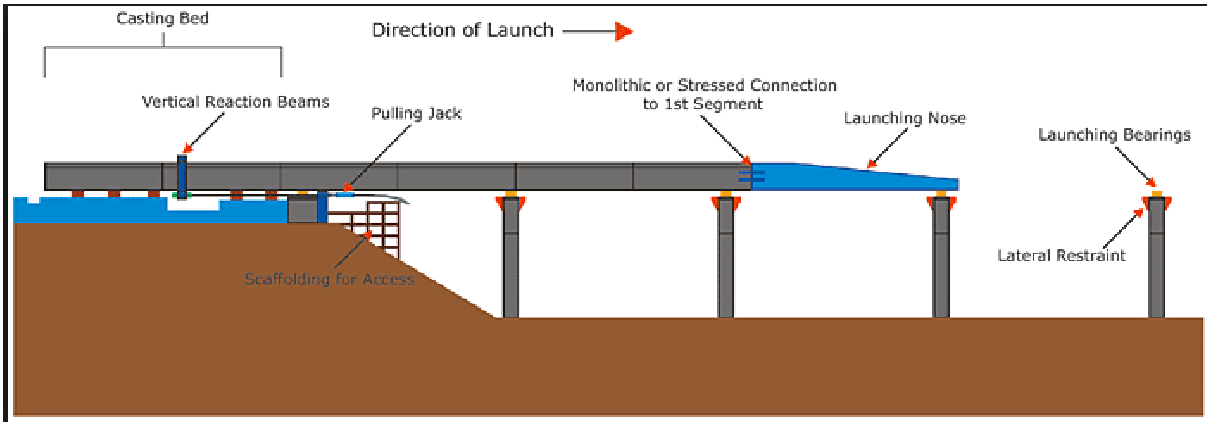

Figure 62 Cross section including a pulling (pushing) jack

2.6.5 Launching Bearings

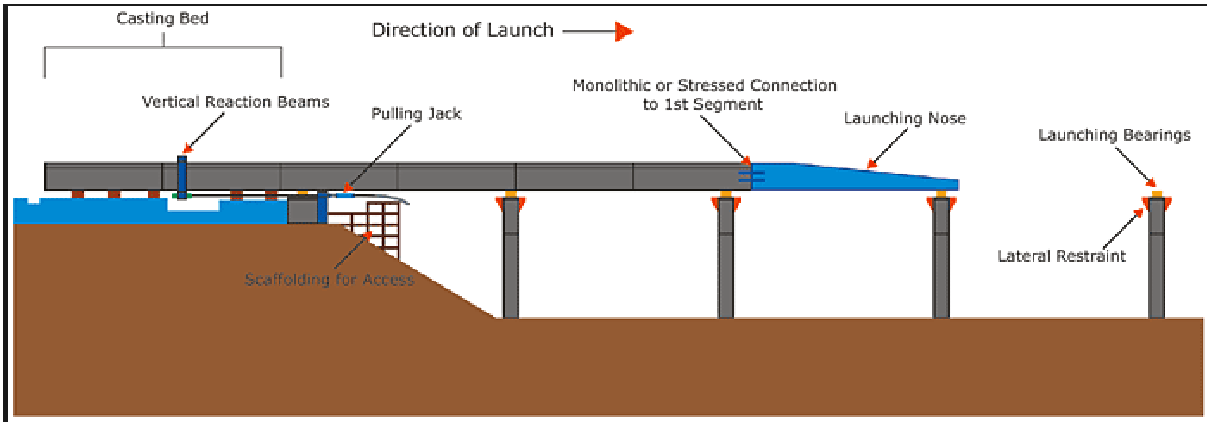

Figure 63 Cross section including launching bearings

Annex 2: List of Figures

Annex 3: List of Tables

Appendix 10: Roadmap Review and Update Recommendations

BIM FOR BRIDGES AND STRUCTURES

TPF-5(372)

Roadmap Review and Update Recommendations

April 2020

Rev 1

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Executive Summary

The TPF-5(372) Roadmap Review and Update Recommendations report is comprised of the following objectives:

- Align the TPF 5(372) scope of work to the current roadmap (Mlynarski & Hu, 2016)
- Revisit the goals in the context of current industry activity, and
- Identify additional goals to pursue to achieve the intended outcomes of the initiative.

This report recommends goals and tasks necessary to provide the AASHTO lead BIM for Bridges and Structures program with the foundational elements needed to successfully move forward. The recommended goals herein have been prioritized based on feedback from the COBS T-19/Pooled Fund. This report concludes with the following recommendations:

Do First

The following tasks are recommended to be added to the current pooled fund due to their high level of urgency and importance.

1. Establish COBS Model Element Breakdown
2. Create Level of Development (LOD) Specification
3. Create Level 1 BIM Execution Plan Template
4. Investigate IFC Testing Tool
5. Establish a MVD Certification Program
6. Contract Language

Schedule Later

The following tasks are recommended to take place within 1-8 years following the conclusion of the TPF-5(372) study. The recommended time to begin the task after the study's end is noted in parenthesis.

1. Establish Standard Governance Body (< 1 year)
2. Conduct ROI Studies for future MVDs (1 to 2 years)
3. Develop a Data Governance Plan to Manage the Data Dictionary (3 to 5 years)
4. Provide Ongoing Education and Support (< 1 year)
5. Investigate Electronic Signing and Sealing Process/Tools (5 to 8 years)
6. Quality Management (< 1 year)

Introduction

Working through the American Association of State Highway Officials (AASHTO), State bridge engineers have pursued the objective of achieveing greater efficiency in bridge project delivery for over a decade. The Committee on Bridges and Structures (COBS) demonstrated a commitment to this goal by passing a resolution that recognized the need for "*Comprehensive Integrated Bridge Project Delivery through Automation."* (Chen & Shirole, 2013) A timeline of the following milestones is shown in Figure 1.

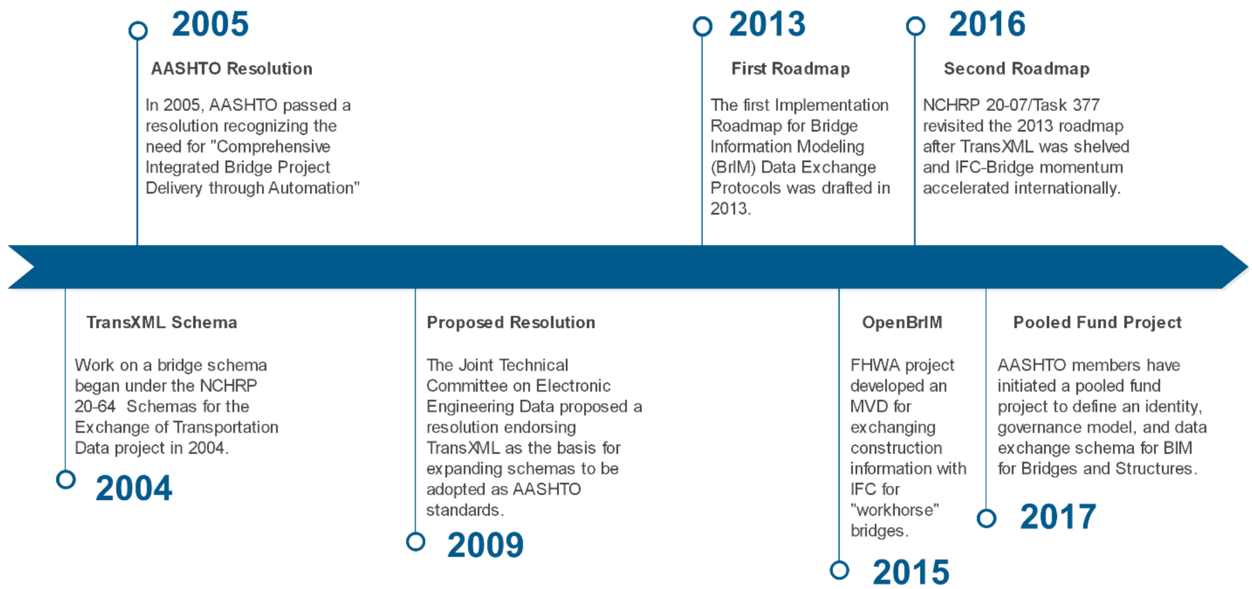

Figure 1: Timeline of Past Bridge Data Standardization Milestones

Early efforts to standardize bridge geometric data were centered on TransXML, which tried to close the data exchange gap for a range of transportation data types. Instead of focusing on the exchange specification of TransXML itself, the next steps were mapping data exchanges, first for design-to-construction and then for the lifecycle. That culminated in the first roadmap for bridge information modeling data standardization in 2013. (Chen & Shirole, 2013)

By then, international efforts had started coalescing around the idea of an Industry Foundation Classes (IFC) standard for bridges. The FHWA funded the Bridge Information Modeling Standardization project in 2015 to develop an IFC Model View Definition (MVD) for "workhorse" bridges, in part to determine the feasibility of IFC for exchanging bridge construction information. (Chipman, et al., 2016) In 2016, a project synthesized data exchange protocols for bridges and evaluated past roadmaps. The report's recommendations established the most recent roadmap for bridge data standardization. (Mlynarski & Hu, 2016)

This report aligns the current roadmap (Mlynarski & Hu, 2016) to the Transportation Pooled Fund Study (TPF-5(372) Study), and recommends additional goals to ensure the success of the bridges and structures data standardization objective. The results of this report will represent the updated roadmap recommendations for COBS moving forward.

Methodology

Objective

The objectives of the roadmap review are to:

- Align the TPF-5(372) scope of work to the current roadmap
- Revisit the goals in the context of current industry activity, and
- Identify additional goals to pursue that will achieve the intended outcomes of the TPF-5(372) study.

Review Baseline

Shortly after the current roadmap was published, a Memorandum of Understanding was signed making the bSi IFC Bridge Project official, supported by the bSi InfraRoom and confirmed by the Standard Committee. (Castaing, et al., 2017) This action resolved uncertainties surrounding the feasibility of IFC emerging as the open data standard for bridges. The roadmap can now be reviewed in the context of the IFC Bridge Project Plan, which establishes the process for developing and governing a US national standard for bridge semantic and geometric information.

Figure 2 illustrates the three tiers of bridge data standards. The bSi IFC Bridge Project advances international standards for bridge semantic and geometric information. The TPF-5(372) study advances US national standards. Once a national standard has been adopted, individual states may wish to develop local standards. For example, all US States need to provide reporting to the Federal Highway Administration (FHWA) for the National Bridge Inventory (NBI). This is a data need that is common to all US states, but is not present outside the US. Thus, NBI data needs are appropriate for a US national standard. Individual states have their own unique information needs for bridge management. These data needs could be defined in a local standard in the future. This review examines the roadmap in the context of developing a US national standard only.

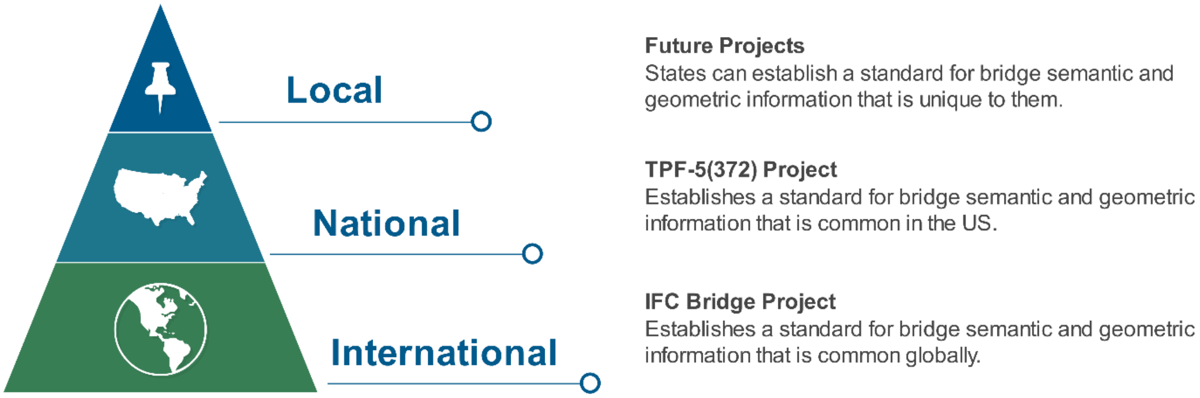

Figure 2: Three Tiers of Bridge Data Standards

Review

Current Roadmap Goals

The current roadmap was summarized as a four-step strategic plan for common modeling formats, as shown in Figure 3.

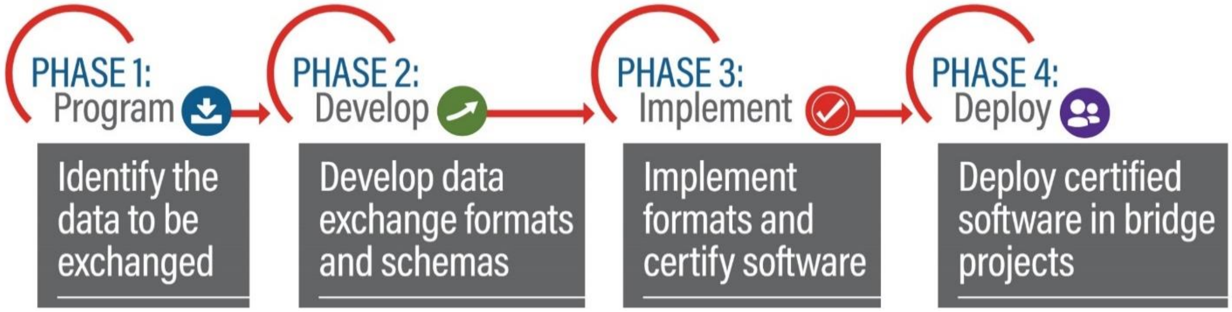

Figure 3: Four-step Strategic Plan for Common Modeling Formats (Mlynarski & Hu, 2016)

The goals of the current roadmap are summarized in Table 1, which also identifies if the goal is included in the scope of work for HDR's TPF-5(372) project.

Table 1: Goals of the Current Roadmap (Mlynarski & Hu, 2016)

Phase	Goal	TPF-5(372) Scope
Phase 1: Program	Create Information Delivery Manuals	Yes
Phase 2: Develop	Create Model View Definitions	Yes
Phase 3: Implement	Create Certification Process	Yes
Phase 3: Implement	Create IFC Testing Tool	No
Phase 3: Implement	Create Method of Electronic Signature	No
Phase 4: Deploy	Conduct an ROI study	Yes
Phase 4: Deploy	Develop Collaboration Forum	Yes
Phase 4: Deploy	Hold Seminars and Workshops	Yes

Alignment to the TPF-5(372) Study

Most of the goals of the current roadmap are incorporated into HDR's scope of work for the TPF-5(372) study. The sections below describe in more detail what is included and what is not included in the TPF-5(372) study. Figure 4 is a timeline indicating when the current roadmap goals will be executed by HDR's TPF-5(372) project.

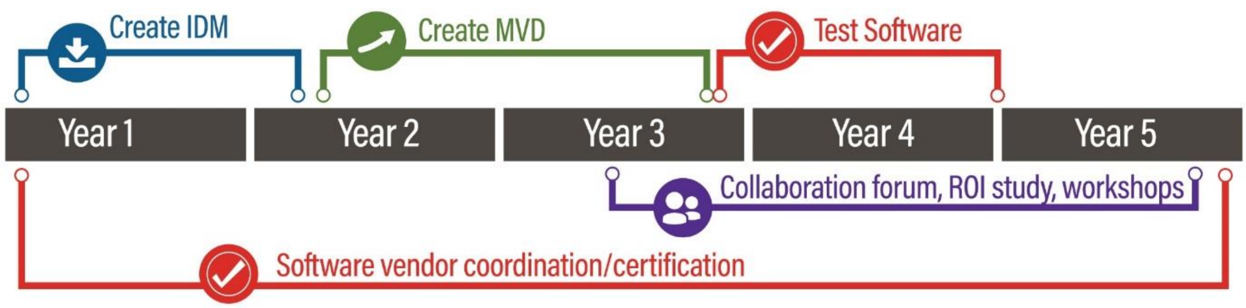

Figure 4: Timeline of the Roadmap Goals Implemented by HDR's TPF-5(372) Study

Phase 1: Program

The primary goal of the first phase of the current roadmap is to develop an Information Delivery Manual (IDM). However, the purpose of the IDM was not specified. The current roadmap lists a series of recommended steps that can be summarized as:

- Update the bridge lifecycle process map developed in a previous FHWA project[1]
- Update the current IDM for different construction procurement models[2]
- Evaluate the current data dictionary[3]
- Evaluate the current Level of Development (LOD) Specification

Task 2.1, of the TPF-5(372) project scope, includes providing recommendations to update and validate the current process map. The project scope also includes an update to the IFC Bridge Design to Construction Information Exchange (U.S.) which should encompass the other three bulleted items.

The data dictionary and the LOD specification are considered to be part of the Model View Definition (MVD) process. Some of this work has already been completed in the Design-to-Construction MVD[4] and

[1] Refer to *Bridge Information Modeling Standardization Volume 1: Information Exchanges* (Chipman, Costin, Yang, Eastman, & Grant, 2016)
[2] Refer to *Bridge Information Modeling Standardization Volume 1: Information Exchanges* (Chipman, Costin, Yang, Eastman, & Grant, 2016)
[3] Refer to *IFC Bridge Design to Construction Information Exchange (U.S.)* (NIBS, 2016)
[4] Refer to *Bridge Information Modeling Standardization* (Chipman, et al., 2016)

more similar work will continue on the proposed Design-to-Fabrication MVD. It is important to note that no LOD specification has been created nor has one been ubiquitously adopted in the transportation industry. The BIMForum LOD specification includes very limited definitions for bridges and highway structures. A framework for a LOD specification for roadway construction was introduced in a previous FHWA project[5] and is being extended by Michigan DOT through their Digital Delivery Working Group. (VanDeventer, Cassar, & Wilkerson, 2018)

Phase 2: Develop

In this section the current roadmap shows the primary goal as mapping the data defined in Phase 1 to existing data exchange schemas. The current roadmap lists a series of recommended steps that can be summarized as:

- Develop a Bridge Taxonomy for naming elements
- Evaluate Proposed Data Structure
- Develop Digital Signature
- Develop Digital Seal

The evaluation of the proposed data structure has occurred in previous projects[6] and this work will continue within the scope of this project as we align the data structure to IFC. Common terms will be collected during Task 1.0 of the current project and will build off of the previous Design to Construction MVD and the IFC4.2 schema which is based on the AASHTO Bridge Element Inspection Manual. The development of a digital signature and a digital seal are not included in the TPF-5(372) study and should remain as goals in the updated roadmap.

Phase 3: Implement

The primary goal in this section of the current roadmap is to create a certification process for software products. The current roadmap lists a series of recommended steps that can be summarized as:

- Convince more software developers to work with the buildingSMART International Implementer Support Group subcommittee.
- Create manuals and guidance to support the software vendors in the certification process.

The TPF-5(372) study scope includes both of these steps.

Phase 4: Deploy

The primary goal in this section of the current roadmap is to deploy certified software for use on bridge projects. The current roadmap lists a series of recommended steps that can be summarized as:

- Create product-specific BIM Guides on how to use the standards
- Conduct an ROI study

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[5] Refer to *Utilizing Digital Design Information in Highway Construction—Case Studies* (Maier, et al., 2017)

[6] Refer to *IFC Bridge Design to Construction Information Exchange (U.S.)* (NIBS, 2016)

- Host seminars, conferences, and workshops to educate on the standards
- Develop a site for the public to provide feedback on the standards

The TPF-5(372) study scope includes all of these steps.

TPF-5(372) Study Outcomes

The scope of work for the TPF-5(372) study drew heavily from the existing roadmap, but was also influenced by subsequent developments such as the initiation of the bSi IFC Bridge Project. The TPF-5(372) study outcomes include an updated Design-to-Construction MVD and a new Design-to-Fabrication MVD that complies with IFC5.0. The TPF-5(372) project will also provide recommendations for a standard governance model.

Current Roadmap Recommendation	Addressed in TPF-5(372)	Comment	Roadmap Update Recommendations
Update Bridge Life Cycle Process Map	Yes	Updated Life Cycle Process Map	none
Update Current IDM for Different Procurement Methods	No	Design to Construction and Fabrication IDMs will be delivered for Design, Bid, Build procurement method	The resulting MVDs should be sufficient for any procurement method. A slight change to LOD requirements could be documented in the future.
Evaluate Current Data Dictionary	Yes	This will be done as part of the MVD process	none
Evaluate Current LOD Requirements	Yes	This will be done as part of the MVD process	none
Develop a Bridge Taxonomy for naming elements	No	There is research being provided on common terms as well as terminology defined as part of the IDM but there is no deliverable of a Bridge Taxonomy	Suggest creation of COBS Model Element Breakdown based on the Manual for Bridge Element Inspection
Evaluate Proposed Data Structure	Yes	This will be done as part of the MVD process	
Develop Digital Signature	No		Add to Future Roadmap
Develop Digital Seal	No		Add to Future Roadmap
Convince Software Vendors to join bSi ISG	Yes	Part of the Software Vendor Engagement Plan	
Create Certification Materials	Yes	Part of the Software Vendor Engagement Plan	
Create BIM Guides	Yes	Part of Education and Training in Year 5	
Conduct ROI Study	Yes	Part of ROI Study	

Hold Workshops, Seminars, and conferences	Yes	Part of Education and Training in Year 5	
Provide Site to public for feedback on the standards	Yes	Collaboration Forum	

Suggested AASHTO Publications and Documents

This is a list of all deliverables that we would recommend be published by AASHTO:

- Design to Construction IDM
- Design to Construction MVD
- Design to Fabrication IDM
- Design to Fabrication MVD
- Bridge Lifecycle Process Map
- Roadmap Review and Recommendations
- IFC Process Cost Benefit Analysis

Future Roadmap Goals

The completion of the TPF-5(372) project will result in a number of standards related resources as well as a governance structure for maintaining all transportation industry MVDs. The following section outlines additional goals that need to be realized in order to succeed with an IFC-based national standard for bridges and structures. The recommended goals listed here are all important possible next steps that will need to be prioritized and scheduled in order to provide an updated Roadmap for Bridges and Structures.

Establish a Standard Governance Body

Part of TPF-5(372) is to recommend a governance structure based off of the original roadmaps recommendations to maintain the standards. The governance structure should provide the governing body with the ability to oversee these standards and develop their review and updating process. The governing body could execute projects to review and/or update the standard, as well as to extend the standard through the creation of future MVDs.

The two MVDs produced by the TPF-5(372) project will be aligned to the international IFC5.0 standard. There needs to be a process to review and update these MVDs as needed. Updates may be needed for a variety of reasons, including:

- changes to the IFC Schema (such as to include more complex bridge types).
- changes to US transportation practice or policy.

Selecting a group that manages these changes may end up being part of the current project. This governing body would help streamline the MVD creation process in the future.

Develop a Data Governance Plan to Manage the Data Dictionary

An outcome from the TPF-5(372) will be a Data Dictionary that describes the contents, format, and structure of the data captured by the MVDs produced by the project. While the IFC schema is carefully managed through bSi, the US data dictionary would be managed by the standard governance body. The data dictionary is a resource for software vendors to map their data models to the IFC standard.

There are many reasons why the data dictionary may need to be changed. For instance, to add an additional parameter, remove a parameter that is no longer necessary, or even to add data that is specific to individual regions. Although the data dictionary can be changed at any time, there is a process for how it can be changed and only by individuals certified by bSi. The data dictionary is open but still controlled to the extent that not just anyone can make changes.

In order to give AASHTO members agency over modifying the Data Dictionary, the standard governance body can develop a Data Governance Plan. The Data Governance Plan would need to identify an individual who is responsible for collecting proposed data dictionary changes, evaluating them, and making changes to the data dictionary.

Establish an MVD Certification Program

Software product certification is a critical step to successfully implement the standard in practice. The current certification process requires software vendors to pay a fee for each MVD instead of for each schema. This process becomes somewhat costly as more and more MVDs become available. This expense could potentially cause software vendors to prioritize MVD certification leaving the industry lacking those MVDs not chosen.

Our recommendation is that AASHTO create a program that supports software developers to certify AASHTO MVDs. Listed below are different options that could be help achieve this goal either individually or combined:

- **Create a proxy certification program**: With a growing number of countries developing MVDs for their national standards, bSi needs to consider a more efficient and cost-effective approach to certifying those MVDs. One approach could be that the standards governance body or the local bSi chapter could certify software products. This could lower the cost for software vendors as well as provide a source of revenue for the standards governance body. Moreover, this would enable the standards governance to maintain control of the certification data and certification criteria. It is possible that AASHTO could work with the local bSi chapter to create this program.
- **Provide certification materials**: Software vendors will need standardized materials (such as testing files and testing criteria) for each MVD in order to support certification. The standards governance body must create a suite of certification data in order to ensure that vendors are certifying against realistic examples of the data the products will handle on projects.

Provide Ongoing Education and Support

The TPF-5(372) project will produce a series of training products and workshops to educate the industry about the standard and how to use it. Despite a large and growing number of participating states, state agencies will, more than likely, adopt the standard at different times. Many agencies will not implement the standard while the TPF-5(372) project is underway. Some States may wait until the MVD's are finalized and deployed. These late adopters will require ongoing support.

This support will include the continued development and support of the initiatives associated with the current ongoing project which includes developing guide contract and specification language for the software agnostic digital contract documents for bridge construction and fabrication. This will help any agency that is trying to change their requirements to include IFC. However, agencies and their consultant, contractor, and fabricator business partners will also need support, guidance, and tools to validate the digital contract documents as well as to sign and seal them.

Conduct ROI studies for future MVDs

As part of TPF-5(372) project an ROI study will be performed to demonstrate the value of the IFC process for the Design to Fabrication model view definition. This will provide the industry with a study demonstrating the tangible benefits on the use of IFC based processes. However with a number of different MVDs to choose from in the future, it is our recommendation that an ROI study be performed on the future MVDs to determine where development resources should be allocated.

Investigate IFC Testing Tool

Once the TPF-5(372) project is complete State Agencies will have the ability to request IFC files as deliverables. Even though software programs will be built to support the MVDs, individuals that are receiving IFC files will not know if the file being delivered meets the MVD and will not know the quality of data supplied. It is our recommendation that IFC testing and validation tools be investigated and/or developed to ease the transition into an IFC based exchange process.

Investigate Electronic Signing and Sealing Process/Tools

It is currently a goal for many State Agencies to sign and seal 3D deliverables in lieu of 2D documents. Some pilot projects such in Utah and Iowa have piloted projects requiring 3D record deliverables but this has not become standard process yet. It is our recommendation that a research project be created to investigate different possible methods of signing and sealing 3D deliverables. It is also our recommendation that the research include investigating the use of distributed ledger technology for this purpose.

Create Level of Detail / Development Specification

There is currently an effort in the AASHTO Joint Technical Committee on Electronic Engineering Standards (JTCEES) to begin a framework for a LOD Specification. As part of TPF-5(372) or future project this LOD Specification should be reviewed for bridge elements so that it aligns with current and future goals of COBS.

Establish COBS Model Element Breakdown

One major component to successful BIM planning on a project is establishing what elements on the project are going to be modeled. A standardized taxonomy of potential model elements not only provides model authors a quick starting point, but it also normalizes the resulting models element classifications. This normalization is key to a comprehensive BIM program. Our recommendation is that an official Model Element Breakdown be established for COBS, utilizing the AASHTO Bridge Element Inspection Manual classifications as a starting point.

Create Level 1 BIM Execution Plan Template

Projects using the BIM process require more planning up front. It has become standard practice to document decisions made about a projects BIM process in a BIM execution plan (BEP). A Level 1 BEP focuses on the overall BIM Process and Level 2 BEP's focus on individual BIM Uses. It is our recommendation that COBS create a Level 1 BEP Template to provide to State Agencies and their contractors so that the higher level BIM planning on projects has a consistent form of documentation that all parties become familiar with both filling out and reading. Standardizing this essential planning document results in a more efficient BIM process across all projects.

Prioritized Goals

Figure 5 - Eisenhower Priority Matrix

Overall there are ten recommended roadmap goals for updating the current roadmap. In order to understand where, on the roadmap, these priorities might fall a workshop was held with COBS T-19/Pooled Fund in San Diego on February 25, 2020. The workshop consisted of rating the recommended roadmap goals based on Importance (how much do you want it) and Urgency (how soon do you need it). Ratings were applied by individuals and then by groups. The average ratings were then charted to represent the final results. The charted results were separated into four quadrants using the Eisenhower method to establish which items should be done first, scheduled later, delegated, and not done. The results of this workshop are described in this section concluding with final recommendations based on the findings.

Results for Prioritization by Individual

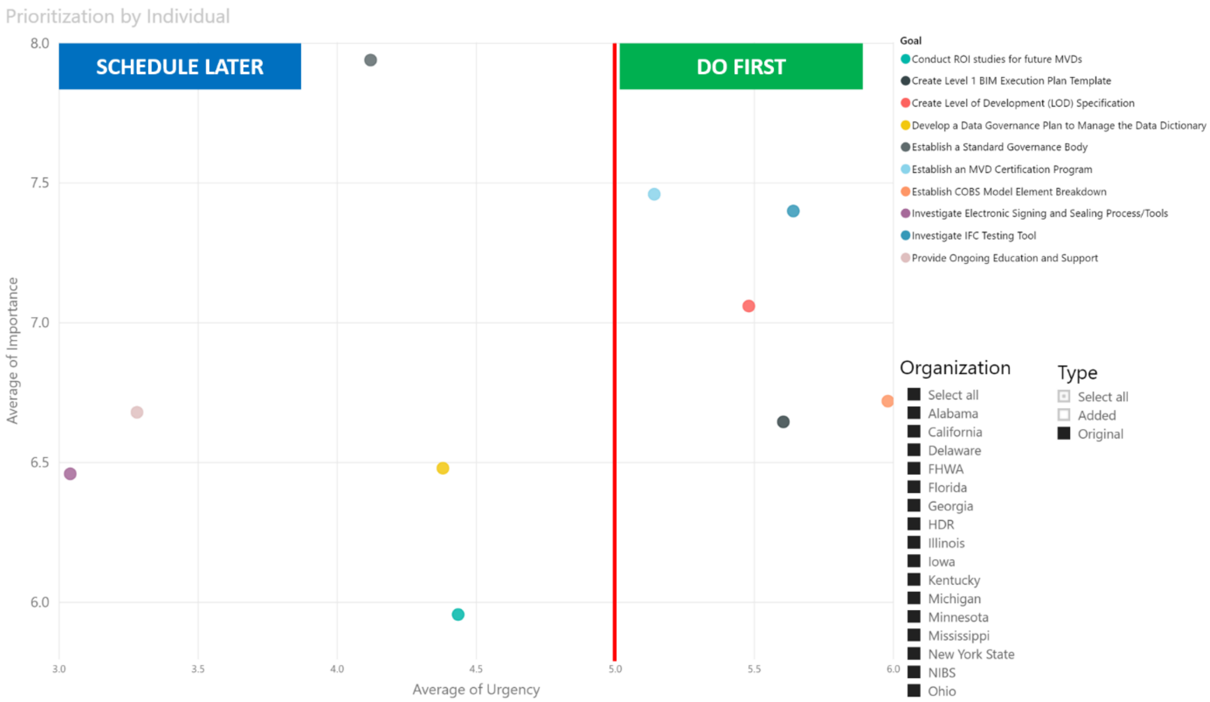

Figure 6 - Matrix by Individual

The results of the individual report showed that all ten recommended goals were ranked as being important enough to require attention. There was an even split of five goals being urgent enough to address first and the other five goals left to schedule at a later time. In each quadrant the points are measured from the bottom left of the quadrant to establish a ranking. The results are as follows:

DO FIRST

1. Investigate IFC Testing Tool
2. Establish a MVD Certification Program
3. Create Level of Development Specification
4. Establish COBS Model Element Breakdown
5. Create Level 01 Execution Plan Template

SCHEDULE LATER

1. Establish a Standard Governance Body
2. Develop a Data Governance Plan to Manage the Data Dictionary
3. Conduct ROI Studies for future MVDs
4. Provide Ongoing Education and Support
5. Investigate Electronic Signing and Sealing Process/Tools

Results for Added Goals by Individual

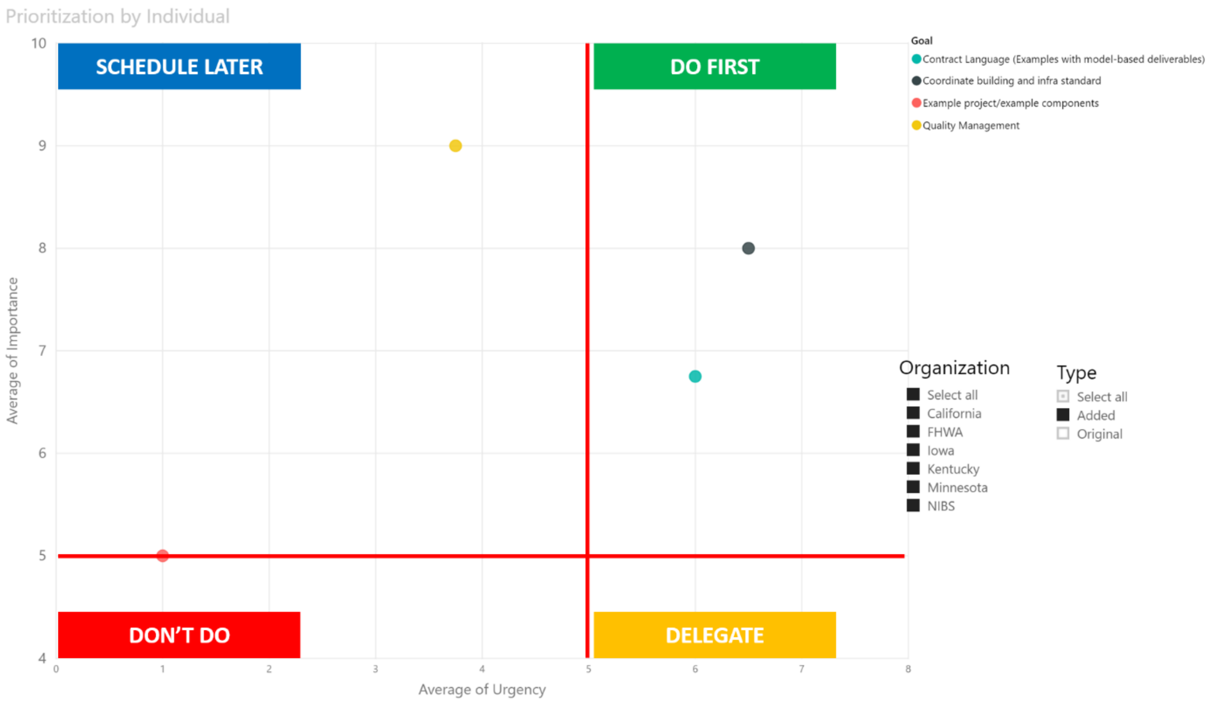

Figure 7 - Additional Goals by Individual

Reviewing the results of the added goals it was found that two of the goals fell in the DO FIRST, one in the SCHEDULE LATER, and one in the DON'T DO quadrant. The results are as follows:

DO FIRST

1. Coordinate Building and Infrastructure Standards
2. Contract Language

SCHEDULE LATER

1. Quality Management

DON'T DO

1. Example Projects / Example Components

Results for Prioritization by Group

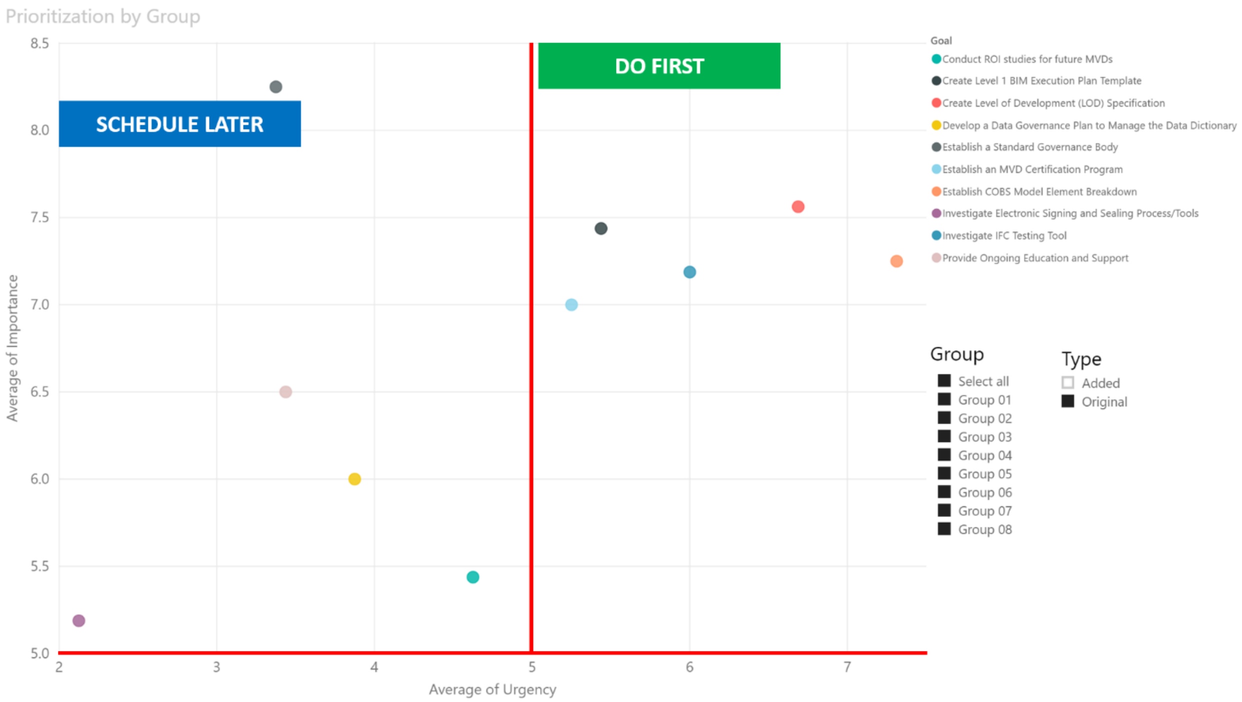

Figure 8 - Matrix by Group

Similar to the individual results, the results of the group report showed that all ten recommended goals were ranked as being important enough to require attention. There was an even split of five goals being urgent enough to address first and the other five goals left to schedule at a later time. In each quadrant the points are measured from the bottom left of the quadrant to establish a ranking. The results are as follows:

DO FIRST

1. Establish COBS Model Element Breakdown
2. Create Level of Development (LOD) Specification
3. Create Level 1 BIM Execution Plan Template
4. Investigate IFC Testing Tool
5. Establish a MVD Certification Program

SCHEDULE LATER

1. Establish Standard Governance Body
2. Conduct ROI Studies for future MVDs
3. Develop a Data Governance Plan to Manage the Data Dictionary
4. Provide Ongoing Education and Support
5. Investigate Electronic Signing and Sealing Process/Tools

Results for Added Goals by Group

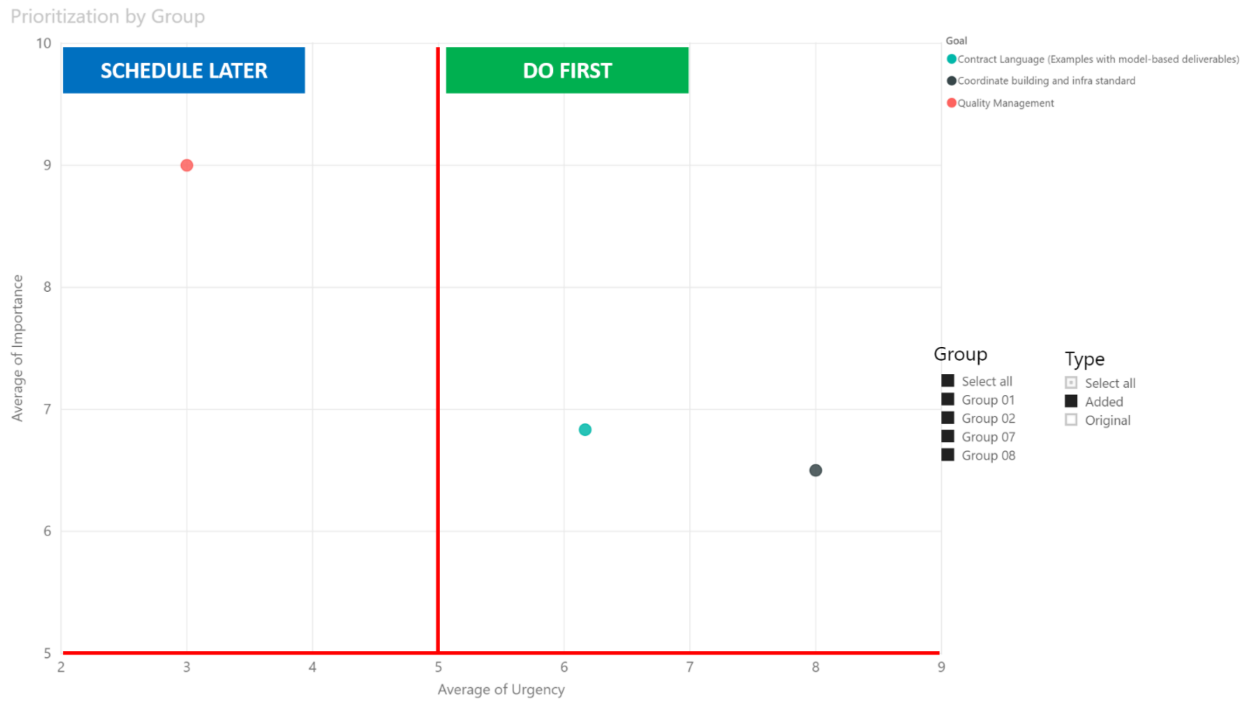

Figure 9 - Additional Goals by Group

These goals are the same as the added goals from the individual session although the Example Projects / Example Components did not get added to the groups. Reviewing the results of the added goals it was found that two of the goals fell in the DO FIRST, one in the SCHEDULE LATER. The results are as follows:

DO FIRST

1. Coordinate Building and Infrastructure Standards
2. Contract Language

SCHEDULE LATER

1. Quality Management

Roadmap Recommendations

After reviewing the results of the prioritization workshop there was some further considerations made resulting in the following recommendations. Having one worksheet filled out by individuals first and a second by groups was a two-step process for a reason. The process was meant to allow users to become familiar with the process and then allow them to discuss with their peers to refine their priorities.

The results from the tests proved to be in line with this idea. The future goals ended up being listed in the same quadrants in both cases but the order of prioritization was slightly different. This represents the refinement through group discussion. For this reason the recommendations are going to focus on the group results over the individual results.

The added goals had similar results in both the individual and group workshops so there is no difference to consider. Of the added goals however there were two goals that were added by only one organization. One of those goals was given a low priority and was listed as DO NOT DO. The other goal was given a very high priority. This goal will be addressed with an individual recommendation.

All recommendations are as follows:

DO FIRST

1. Establish COBS Model Element Breakdown
2. Create Level of Development (LOD) Specification
3. Create Level 1 BIM Execution Plan Template
4. Investigate IFC Testing Tool
5. Establish a MVD Certification Program
6. Contract Language

These goals were identified as having the highest priority. All were identified as being both urgent and important. As a result it is the recommendation of the team that these goals be addressed as soon as possible. The fastest way to address these items is to incorporate them into the work of the current pooled fund.

For items 1-3 it is suggested that they are incorporated into the content that is being generated for the collaboration site. These items could also be part of the trainings and workshops that will be taking place in year five of the project. It is important to note that HDR is currently working on all of these items in separate efforts for the AASHTO Joint Technical Subcommittee on Electronic Engineering Standards and as part of a project for Utah DOT. It would be our recommendation that any progress made in external efforts be considered if these items are established as deliverables for the project.

IFC Testing is part of the project. It is recommended that along with testing IFC’s an investigation of commercially available IFC testing tools also be performed and provided as a deliverable to the pooled fund. This investigation would produce a list of commercially available products highlighting their capabilities as well as comparing them with our teams IFC testing results.

Establishing MVD Certification procedures is currently part of the Pooled Fund. It is recommended that after certification procedures are established, the consulting team scope be expanded to generate necessary certification materials that will need to be provided to software vendors. Working with T-19 the consulting team can also create a way to interact with software vendors (through AASHTO or the Collaboration Forum) to ensure easy access and communication. The end goal will be a one-stop solution for software vendors that would like to become certified on AASHTO adopted MVD's.

Suggested **Contract Language** for model-based deliverables is not currently part of the project. Fair Cape Consulting has provided suggested Contract Language as part of a separate contract with the FHWA. This contract language is currently under final review for publication. In the event that this contract language is not published, it is suggested that a similar effort be added as a deliverable for content to be added to the collaboration site similar to items 1-3.

SCHEDULE LATER

1. Establish Standard Governance Body
2. Conduct ROI Studies for future MVDs
3. Develop a Data Governance Plan to Manage the Data Dictionary
4. Provide Ongoing Education and Support
5. Investigate Electronic Signing and Sealing Process/Tools
6. Quality Management

These goals were listed as having high importance, but low urgency. As a result it is our recommendation that these items be scheduled to be handled after the current scope of TPF-5(372) is complete.

Establishing a Standard Governance Body is a necessary next step for maintaining the MVD's created as a part of this project. The HDR team will be providing a recommendation on how a Governance Body should be formed as part of the project. There is a possibility that a Governance Body may come into formation organically before the project has concluded. There is currently an effort within AASHTO to create a Governance Body for working with IFC. In the event that such a group does not exist at the end of TPF-5(372) study, our recommendation is that work to create this group should begin at that time.

As part of TPF-5(372) project, an ROI study will be conducted on the MVD's that are being created as part of the project. This will be a key part of communicating the value of implementing this particular MVD**. Conducting ROI studies for future MVDs** before funding the MVD development would be important to choosing where to apply resources for future development. This will not be an immediate need but should not be delayed for too long. For this reason it is our recommendation to begin this work within 1-2 years following TPF-5(372).

The **Data Dictionary** will be the most important part of the standard that will need to be regularly curated in the long term. The understanding of what needs to change will not take place until the standard has been in use for a few years. For this reason it is our recommendation that the Data Governance Plan be developed within the 3-5 years following the conclusion of TPF-5(372).

Ongoing Education and Support is part of TPF-5(372) and will be beneficial for all early adopters. When the project has concluded and other organizations wish to get started, the mechanism for continued support will need to be established. It is our recommendation that this work begin immediately following the conclusion of TPF-5(372).

The **Investigation of Electronic Signing and Sealing Tools and Processes** is going to become necessary for any organization that begins using model based deliverables. The need to validate that models being used are the signed and sealed model will be critical at some point in the future. Considering the current tools are unable to support this and the low levels of adoption, this critical point is still a number years off. It is our recommendation that this task begin between 5-8 years after the conclusion of TPF-5(372).

When TPF-5(372) concludes, it is expected that commercial software products will be capable of generating IFC deliverables. This means that it is likely that IFC deliverables will begin to show up on projects relatively soon after. **Quality Management** will be required during the creation of models and for model based deliverables. It is our recommendation that to support the use of IFC based workflows, Quality Management workflows be investigated immediately following the conclusion of TPF-5(372).

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Appendix 11: Roadmap Infographic

BIM FOR BRIDGES AND STRUCTURES TPF-5(372) ROADMAP

BACKGROUND

The desired outcome of the work under the TPF-5(372) Project was to establish a standard for bridge semantic and geometric information that is common in the United States, which was a continuation of a previous effort known as the IFC Bridge project to create international standards. The resulting products from the TPF-5(372) may be used by States as a baseline for future projects to further refine standards at the local level. The work under this project was conducted in a series of activities in a five-year timeline to accomplish four major goals:

OUTCOME 1: Development of Information Delivery Manual (IDM)

OUTCOME 2: Creation of a US Bridge Data Dictionary

OUTCOME 3: Creation of Information Delivery Specification (IDS)

OUTCOME 4: Development of Software Certification Materials

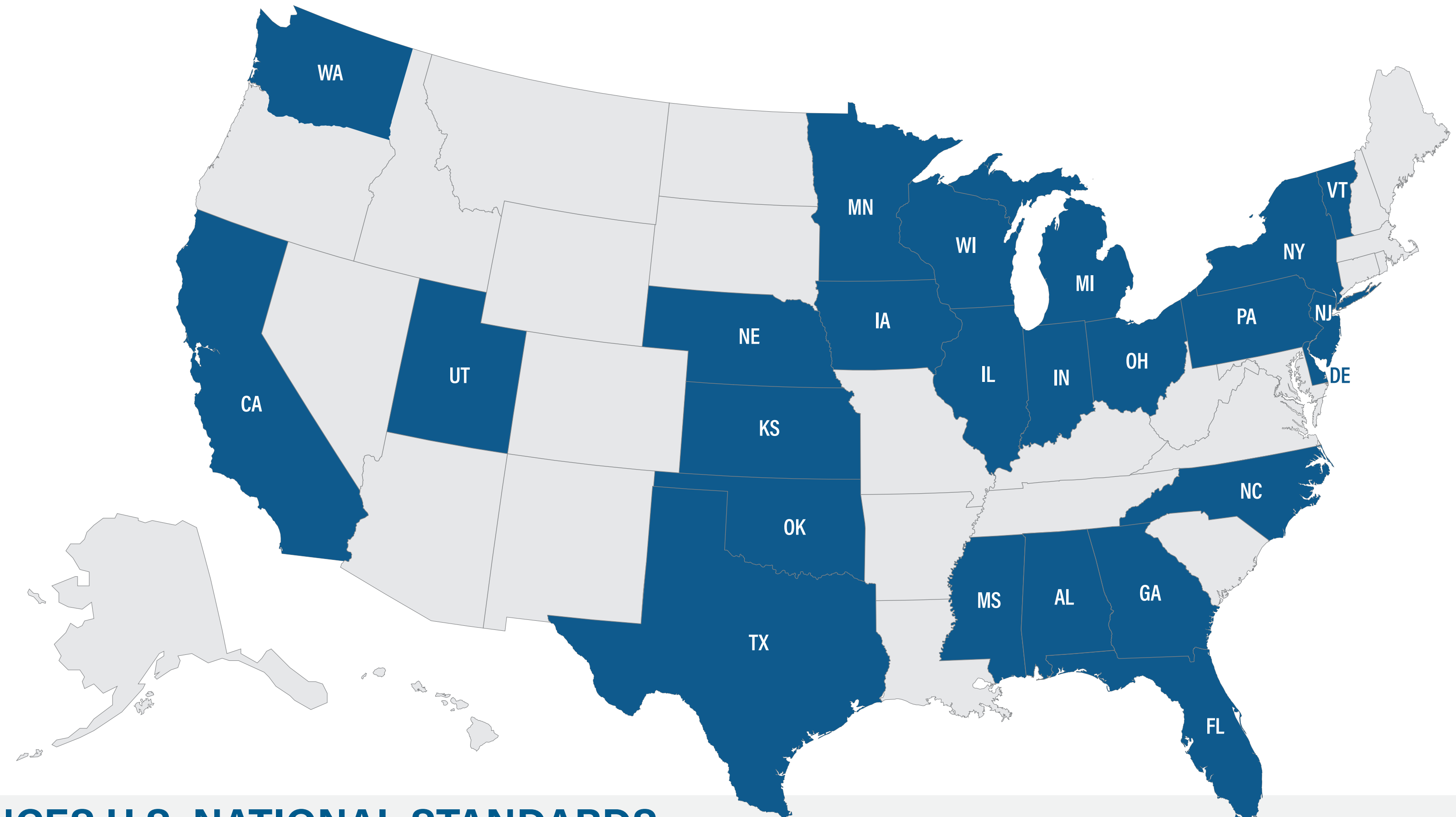
PROJECT SPONSORS

Total Commitments Received: $2,595,000.00*

*As of December 2023

https://www.pooledfund.org/Details/Study/624

https://www.BIMforBridgesUS.com

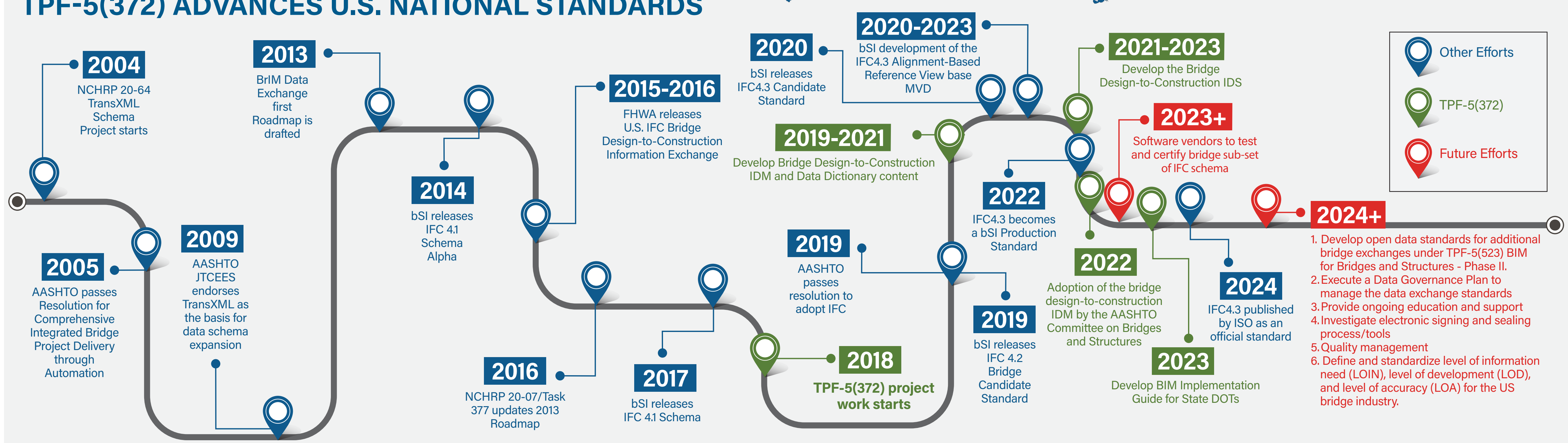


24 PARTICIPATING STATES PLUS FHWA*

AASHTO Publication

Information Delivery Manual (IDM) for the Design to Construction Data Exchange for Highway Bridges, 1st Edition (2023)

TPF-5(372) ADVANCES U.S. NATIONAL STANDARDS



Key Activities to Create IDM

- Validate FHWA Bridge Lifecycle Process Map
- Develop Bridge Lifecycle Management Overview Map* and Bridge Construction Process Map**
- Research common terms for bridge taxonomy
- Develop IDM narrative and exchange requirements
- Ballot and publish the IDM through AASHTO

* Based on earlier work by FHWA
**With contributions from NSBA Task Group 15

Key Activities to Create US Bridge Data Dictionary

- Standardize terminology, definitions, and properties
- Classify data into bridge entity and property groups
- Assign the metadata to describe the technical usage
- Identify and assign related IFC terminology
- Encode the data into the buildingSMART Data Dictionary

Key Activities to Create IDS

- Identify model-based properties
- Enrich its definition by data types and units
- Add mapping to IFC for elements and properties
- Consider further constraints on values
- Generate IDS XML file

Key Activities to Develop Software Certification Materials

- Create a software vendor engagement plan
- Create unit test instructions for IFC 4.3 certification (to be performed by others)
- Utilize project IDS for certification
- Create technical documentation of required IFC mappings and custom properties

Appendix 12: Stakeholder Engagement Plan

BIM FOR BRIDGES AND STRUCTURES

TPF-5(372)

Stakeholder Engagement Plan

April 2020

Version 1.1

BIM FOR BRIDGES AND STRUCTURES
TPF-5(372)

Contents

Overview

Background Information

The TPF-5(372) study is a transportation pooled fund project. The effort emerged from an American Association of State and Highway and Transportation Official (AASHTO) resolution in 2015 that acknowledged the importance of *Comprehensive Integrated Bridge Project Delivery through Automation*. The *Building Information Modeling (BIM) for Bridges and Structures* effort is aimed at enabling the 21st century workforce to exchange information and leverage the potential of tomorrow's technology.

Engagement Plan Goals

Successful engagement begins with a strategic plan that provides a guide for engagement activities. Informative, timely, and concise communication is essential for building trust and relationships among industry stakeholders. This Plan is tailored to provide direction on the design and implementation of engagement tools and tactics. The primary goals of this Plan are to:

- identify key stakeholder audiences and users,
- assess engagement and communication preferences, and
- offer strategies that will maximize engagement opportunities
- foster adoption of common approach to BIM for Bridges by states.

Our engagement approach integrates project needs with stakeholder preferences regarding outreach and engagement. Additionally, this Plan is designed to:

- bolster confidence in AASHTO's BIM for Bridges and Structures efforts,
- build trust and confidence for end users, and
- inspire engagement, learning and future BIM for Bridges and Structures use.

The Plan offers multiple opportunities for meaningful engagement among stakeholder groups. The tools and tactics programmed are designed to provide easy, convenient access to information and learning, as well as opportunities for meaningful dialogue among stakeholders. The aim of this Plan is to provide an engagement approach that reflects TPF-5 (372) member guidance and industry needs for education and engagement opportunity throughout the evolution of this effort. The plan is designed to be flexible in nature to best adapt to funding availability and member/industry needs.

Stakeholder Identification

Team Subject Matter Experts (SMEs) provided early stakeholder identification by pooling professional network contacts. This initial list of nearly 400 stakeholders is comprised of state DOT employees, local agencies, developers and vendors, SMEs, and COBS T-19/pooled fund members. An initial campaign to encourage participation will be developed and deployed when appropriate to engage all stakeholders.

Target Audience Analysis

The target audience comprises individuals at a range of public and private organization types identified in Table 1.

Table 1: Target Audience by Organization Type

Organization Type	Example Organization	Example Job Titles
Federal Government	Federal Highway Administration, DoD	Senior Bridge Engineer, Research Engineer, Project Engineer
State Government	State Departments of Transportation, especially TPF-5(372) member states	Chief Engineer, Deputy Chief Engineer, Chief Information/Technology Officer, State Bridge Engineer, Region Manager, State Research Engineer, State Construction Engineer, State Maintenance Engineer, Bridge Maintenance Engineer, Senior Bridge Engineer, Bridge/Construction Inspector
Industry Association	AASHTO COBS, buildingSmart International, NSBA, PCI, TRB, NIBS	Executive Director, Committee Chair, Committee Member, Committee Friend
Consultants	Members of ACEC	Chief Information/Technology Officer, Area Manager, Engineering Manager, Principal Engineer, Bridge Engineer, Inspector
Contractors and Fabricators	Members of AGC, ARTBA, NSBA, PCI	Chief Information/Technology Officer, Area Manager, Technology Manager, Preconstruction Manager, Project Engineer
Software Vendors	Members of the software advisory group	Product Manager, Program Manager, Software Architect, Application Developer, Industry Strategist

Table 2 identifies the roles of the target audience organizations' leadership and technical staff.

Table 2: Target Audience Roles

Organization Type	Leadership Roles	Technical Roles
Federal Government	Fund research and development (R&D) and technology deployment (e.g. via Every Day Counts program)	Facilitate technical peer exchange to identify notable practices and disseminate these to States.
State Government	Fund implementation	Implement
Industry Association	Coordinate national initiative	Elevate best practices, build/expand support
Consultants	Fund implementation	Implement
Contractors	Fund implementation	Implement
Software Vendors	Prioritize implementation	Implement

The target audience has two primary needs. Firstly, leadership needs a business case to justify the investment necessary to fund development and implementation of BIM standards. Secondly, SMEs need technical information in order to implement these standards.

Baseline Level of Awareness

The level of knowledge varies, but is generally low with small pockets of subject matter expertise. Highlights (as of January 2020) of notable levels of awareness are:

- **Federal**: FHWA has supported research since 2013 and continues to fund incremental progress towards standardization.
- **State**: Twenty (20) states have joined the TPF-5(372) study with active participants in working groups. [https://www.pooledfund.org/Details/Study/624 as of 01/09/2020]
- **State**: Two (2) states have piloted model-based bridge construction contract documents.
- **Industry**: NSBA has a committee developing a data dictionary for steel bridge fabrication.
- **Industry**: The AASHTO Council on Highways and Streets passed a resolution to adopt IFC and engage with bSI. The resolution was passed in October 2019.
- **Consultants**: Consultants conduct research and design pilot projects in many states.
- **Contractors**: Contractors execute pilot projects in many states.
- **Software**: Twenty (20) software vendors participate in the software advisory group.

In general, practitioners lack awareness of how to apply BIM to bridge project development. There needs to be widespread investment across industry to develop requirements, guidelines, standards, manuals, and software workspaces to support BIM-based bridge project delivery. This investment requires demonstration and justification with a business case.

Engagement Outcomes

This engagement plan is designed to achieve the following measurable outcomes.

- Continued investment in research and implementation support
- Five (5) software vendors participating in MVD testing
- AASHTOWare support to test the MVDs
- Increase the number of states piloting BIM-based bridge project delivery to ten (10) by 2023

Engagement Strategies and Tools Matrix

The BIM for Bridges and Structures effort will employ a variety of communication tools to achieve the overall goals. The following matrix of tools and tactics is designed to identify the tool, target audience, and year of deployment. To create continuity and streamline message delivery, the team will use a mix of the following tools to communicate with the public:

TOOL/TACTIC	DESCRIPTION	DEPLOYMENT
INITIAL ENGAGEMENT CAMPAIGN **Target Audiences:** • **State DOT officials** • **Local agencies** • **Software Vendors** • **COBS T19/Pooled Fund Members** • **SMEs**	A communications campaign will launch the engagement efforts for the TPF-5(372) *BIM for Bridges and Structures* effort. This campaign will encourage industry professionals to register on the Collaboration Forum site and explain desired input and engagement from them. This campaign will be executed through an email service and will drive users to the Collaboration site for registration page. The campaign will also provide an opportunity for users to identify project-related needs that are not being met by current resources.	Early 2021
TOOL/TACTIC	**DESCRIPTION**	**DEPLOYMENT**
COMMUNICATION PREFERENCE ASSESSMENT SURVEY **Target Audiences:** • **State DOT officials** • **Software Vendors** • **COBS T19/Pooled Fund Members** • **SMEs**	At the onset of the stakeholder engagement initiative, a Communications Preference survey will be administered to all identified stakeholders. This will provide insight regarding the most likely method of communication for each stakeholder audience. The Plan will be re-assessed and modified based on this input. While engagement with each stakeholder cannot be guaranteed, an adaptive strategy best allows the team to engage with each stakeholder type. The survey will be developed and deployed using Survey Monkey services. Stakeholders will be asked to complete and share the survey with colleagues to build a more robust stakeholder community database.	Early 2021
TOOL/TACTIC	**DESCRIPTION**	**DEPLOYMENT**
ADVISORY COMMITTEE MEETINGS **Target Audiences:** • **Software Vendors** • **COBS T19/Pooled Fund Members** • **SMEs**	A multi-disciplinary Advisory Committee of software developers and industry professionals will be assembled to inform and refine engagement and implementation efforts. This group will meet online on a quarterly basis or as deemed appropriate.	2022/2023

TOOL/TACTIC	DESCRIPTION	DEPLOYMENT
ONLINE COLLABORATION FORUM **Target Audiences:** • State DOT officials • Local agencies • Software Vendors • COBS T19/Pooled Fund Members • SMEs • All registered users	A customized collaboration forum that provides opportunities for industry and stakeholder engagement. The site will serve as a clearinghouse for reference materials, resources, and engagement tools. The site will offer mechanisms for guided conversations, voting and polling around industry specific topics. A resources library will provide communications and resources that assist with education and instruction. The collaboration site will allow for project information to be presented alongside input measures. The site may include, but would not be limited to: resource library, images, visualizations, FAQs, & videos. URLS: www.BIM4BridgesUS.com, www.BIMforBridgesUS.com	Design and Build – 2019/2020 IFC5 Voting mechanism deployment 2020 Full site deployment – 2021
TOOL/TACTIC	**DESCRIPTION**	**DEPLOYMENT**
E-UPDATES / NEWSLETTERS **Target Audiences:** • State DOT officials • Local agencies • Software Vendors • Software Vendors • COBS T19/Pooled Fund Members • SMEs	Monthly e-Updates will be distributed to all COBS T19/Pooled Fund members to provide regular updates regarding these efforts/activities. Short, electronic newsletters will be published (minimally) each quarter and distributed to all stakeholders included in the database. Newsletters will provide current events/discussion notices, project spotlights, notifications of upcoming events/activities, calls-to-action, etc. The newsletter will help drive engagement on the collaboration forum site.	Monthly Quarterly after launch of Collaboration Site; as needed when appropriate
TOOL/TACTIC	**DESCRIPTION**	**DEPLOYMENT**
DIRECT ENGAGEMENT **Target Audiences:** • FHWA officials • AASHTOWare committee members	Successful national deployment requires broad buy-in to the national standard developed by this project. We will provide resources for pooled fund members to engage directly with FHWA officials and AASHTOWare committee members to advocate for e.g. testing the MVDs in AASHTOWare Bridge software and to further fund R&D and technology deployment efforts such as research projects and Every Day Counts outreach, AID grant opportunities and STIC funding opportunities.	2021-2023

TOOL/TACTIC	DESCRIPTION	DEPLOYMENT
TRAINING MODULE and/or FAQ **Target Audiences:** • **State Bridge Engineers** • **Local agencies** • **Bridge Engineers** • **Project Engineers** • **Technology Managers**	Training materials will be prepared that provide an overview of IFC and manage expectations regarding its use. For example, it would explain what IFC is and the bridge types that are supported by IFC, how to determine if your software supports IFC, how to validate the information when you import an IFC file, and so on. The goal of the training is to provide high-level instruction that helps to manage expectations regarding use of IFC for bridge design/construction/fabrication. Additionally, a modified training module can be developed to help train software vendors on the process to certify.	2023
TOOL/TACTIC	**DESCRIPTION**	**DEPLOYMENT**
EDUCATIONAL VIDEO **Target Audiences:** • **State DOT officials** • **Local agencies** • **Software Vendors** • **COBS T19/Pooled Fund Members** • **SMEs**	A 3-5 minute video to explain what IFC is, what the process of developing an IFC-based national standard for bridges entails, the long-term benefits, and the importance to state DOTs. This video is intended to be promotional/educational.	Produce end of 2021 Launch 2022
TOOL/TACTIC	**DESCRIPTION**	**DEPLOYMENT**
CAPABILITY MATURITY SELF-ASSESSMENT **Target Audiences:** • **CTOs/Tech Managers** • **State Bridge Engineers** • **Local agencies** • **SMEs**	A capability-maturity model is a tool for implementing organizations to assess their organizational readiness for deployment. It defines enabling investments in various categories, such as hardware, software, policy, and training. For each capability investment, there are levels of maturity that an organization can grade against. Capability-maturity models are useful for organizations to strategically plan investments.	Early 2023
TOOL/TACTIC	**DESCRIPTION**	**DEPLOYMENT**
ONGOING TECHNICAL SUPPORT • **Practitioners**	Technical support such as implementation guidance, sample scopes of work, sample contract language and guide specifications. These may be collected and distributed via the Collaboration Forum.	Ongoing as requested/approved

TOOL/TACTIC	DESCRIPTION	DEPLOYMENT
BUSINESS CASE WHITE PAPER AND ROI TOOLKIT • Leadership • State DOT officials • Local agencies	Work on the ROI framework will begin in Contract Year 3 (2021). A short white paper will be developed to provide leadership/decision makers with a tool to help communicate the business case for investment.	2021
TOOL/TACTIC	**DESCRIPTION**	**DEPLOYMENT**
MARKETING MATERIALS • Leadership • Practitioners • Local agencies	Marketing materials such as case studies, podcasts, presentations, infographics, flyers, etc. will be developed and shared with users, primarily via the collaboration forum.	2022-2023
TOOL/TACTIC	**DESCRIPTION**	**DEPLOYMENT**
INDUSTRY PRESENTATIONS • State DOT officials • FHWA officials	We will create conference presentations to inform industry of the project progress, outcomes, and support needs. These presentations may be delivered by project members or by pooled fund members. They would be delivered at events such as the COBS, AASHTOWare and TRB annual meetings.	Ongoing as requested/approved

Measurement and Monitoring

As engagement tools and strategies are developed and implemented, the project team will monitor and assess the effectiveness of engagement platforms. When available, digital tools will be tracked using analytic measurements such as unique visitors, downloads, and views. Tools will be monitored and reported in a quarterly report to Working Group 4.

Additional analytics may include:

- Number of registrants on the collaboration forum, by target audience type. (i.e. are we reaching our target audience)
- Poll participation rates
- Number of downloads from the collaboration forum.
- Number of uploads to the collaboration forum.
- Clicks on the MailChimp and open rates on MailChimp.
- Number registering/completing the training.

BIM FOR BRIDGES AND STRUCTURES TPF-5(372)

Appendix 13: Proposal for the Creation and Governance of a US Data Dictionary and its Relationship to the buildingSMART Data Dictionary

BIM FOR BRIDGES AND STRUCTURES TPF-5(372)

Proposal for the Creation and Governance of a US Data Dictionary and its Relationship to the buildingSMART Data Dictionary

Suggestions on how the Data Dictionary being created by the TPF-5(372) could be governed and connected to broader national and international efforts.

2020-07-17
Version 1.0

Jeffrey W. Ouellette

Table of Contents

Executive Summary

As part of the scope of the TPF-5(372) BIM for Bridges and Structures, a Data Dictionary is being created to address the information (terms, definitions, and relationships) directly related to the open data exchange standards being developed. This content of this Data Dictionary is intended to be linked directly to the buildingSMART Data Dictionary (bSDD), a service provided by buildingSMART International (bSI) to aggregate and link terms and definitions across domains, geographic, political, and language-specific regions. While the TPF-5(372) effort is initially focused on the requirements of the AASHTO members, it has been recognized that input is needed from other related infrastructure industry stakeholder organizations such as FHWA, NSBA/AISC, ACI, PCI, AGC, etc. In order to mitigate potential Intellectual Property Rights (IPR) issues (copyright ownership, usage/licensure, and governance), provide a high level of quality and consistency for national standards usage, and create a robust, reliable connection to the buildingSMART Data Dictionary and its stakeholders, it is proposed that a Data Dictionary Working Group be formed by the new buildingSMART USA (bSUSA) chapter for its maintenance and governance, and that bSUSA should be the Owner and Agency for a United States Data Dictionary (USDD) as it relates to the bSDD. In this manner, the USDD, through the bSUSA, can accommodate the current needs of TPF-5(372), future needs other infrastructure-related BIM standards as they are developed, as well as any other Data Dictionary requirements for other domains and stakeholders throughout the US built asset industry, including the design, procurement, construction, and operations of buildings and infrastructure.

Background

There are a number of concepts, components, and organizations that are relevant to this proposal. This section will provide background information about each and how they relate to the proposal.

TPF-5(372) BIM for Bridges and Structures Data Dictionary

The current Transportation Pooled Fund project, TPF-5(372) BIM for Bridges and Structures, includes a task to develop a bridge-specific data dictionary (DD) per AASHTO requirements, supporting data exchange standards for bridge lifecycles based on IFC. This task is being led by Aaron Costin, Univ. of Florida, and includes input from other related stakeholders (e.g. NSBA, ACI, etc.) through a bi-weekly meeting of the NSBA TG-15. The content of the DD is currently being captured and edited in an Excel spreadsheet format, but ultimately needs some type of database storage for access and consumption by the members and their service providers (designers, engineers, contractors, etc.), as well software vendors to embed the functionality in their respective software for use.

United States Data Dictionary

Ideally, the work being pursued by A. Costin in TPF-5(372) would be the kernel for a more extensive, single, national standard DD for concepts, terms, and definitions related to the entire infrastructure domain (e.g. bridges, roads, tunnels, rail, etc.), a “USDD”. In the future, this data dictionary could either sit alongside a national DD for verticals (buildings) or incorporate that domain into a single one. In any case, the USDD content needs some means of storage and distribution for access by all stakeholders operating in the US infrastructure market (contractors, software vendors, suppliers, owners, designers, etc.), whether located inside or outside US borders.

In addition, this USDD should have some positive, use case-based impact on future IFC and bSDD development, as well as any other bSI standards and technologies that are used as the basis for AASHTO standards.

buildingSMART International Data Dictionary

The buildingSMART International Data Dictionary (bSDD) is being offered to the industry as a service to aggregate, store, and allow public access to information needed to supplement, or enrich, IFC-based BIM workflows. While the official IFC schema captures a great deal of information about a project and its components, it is extensible so users may further capture important information that may be unique to their particular domain, market, or even project. This information includes:

- Custom terms and definitions for additional properties/attributes of objects;
- Mapping of custom terms and definitions to official schemas and across other content sources;
- Mappings of standard classification systems (Uniformat, UniClass, OmniClass, etc.) to objects.

The bSDD, as a service, relies on external content provided by numerous 3rd-parties, such as product manufacturers with product libraries, owners with organizational standards defining classification, data capture, and exchange requirements, industry trade organizations with domain-specific information and requirements, and even buildingSMART chapters who may be overseeing national standards for built asset digitization. These parties are known as “Content Owners” who have complete ownership and control over their respective content but pay a fee to bSI to add that content to the bSDD to store, provide tools to further manage the content, and make the content readily accessible. This fee is meant to offset the cost for hosting the content and providing the access tools at a cost more economical than each Content Owner doing it for themselves. Content Owners designate “Agents”, individuals directly responsible for interacting with the bSDD in adding or editing the Content Owner’s content. An Agent may be a member or employee of a Content Owner organization/company or may be a contracted 3rd-party contractor with expertise in Data Dictionaries.

Currently, the bSDD is undergoing a significant technical upgrade (version 5), with a refactoring of the underlying database structure, web services architecture, web-based interface, and APIs for 3rd-party software. At the end of this revision and extensive testing process, hopefully by October 2020, bSI will launch a new bSDD website, an API for software to access the bSDD from within tools (e.g. SketchUp, Revit, Tekla, ALLPLAN, OpenBridges, etc.), and a pricing system for Content Owners and Agents.

buildingSMART International

buildingSMART International is the organization responsible for the development and maintenance of the open BIM data standards such as Industry Foundation Classes (aka “IFC”, ISO 16739) the open semantic data schema for the built environment, the BIM Collaboration Format (BCF) for communication of IFC model-based issues between IFC-enabled tools, and the buildingSMART Data Dictionary (bSDD) based on the ISO 12006-3:2007 standard “Framework for object-oriented information”. The organization is open and provides a number of ways for participants to engage the standards development and implementation processes.

buildingSMART USA

The US has been closely involved in buildingSMART International, since bSI’s first inception in 1996 as the International Alliance of Interoperability (IAI) with a chapter and active members from across the building industry. Since then, the US chapter has undergone a number of significant governance changes. As of today, the US chapter has reincorporated as an independent, non-profit industry association, known as “buildingSMART USA”. In its initial form, the chapter will be focused on meeting the needs of the infrastructure community, specifically around current AASHTO and FHWA needs and projects. An industry committee, “Roads, Bridges & Tunnels”, has been proposed with representatives from these organizations as well as representation and support from service providers like HDR, WSP, and others. Through the committee and chapter, industry stakeholders can find an open and neutral ground to communicate, participate, and collaborate on the use of open standards during the digitization of the industry.

Issues

In the development of the DD for TPF-5(372), a number of crucial issues have been identified as follows:

1. The TPF-5(372) data dictionary really needs broader input from industry stakeholders beyond AASTHO members and FHWA, including the various other national standard associations such as NSBA/AISC, ACI, and PCI, to name a few, as well as service providers like designers, engineers, contractors, and product suppliers;
2. While the DD is starting with bridges, it will need other related infrastructure data terminology and definitions over time, including roads, tunnels, and more;
3. While initialization of the bridge DD is covered by the current overall scope of the TPF-5(372), ongoing governance of the standard after conclusion of the project still needs prescription;
4. A centralized, coherent, and authoritative ownership and governance model is needed to continue the development and maintenance of the DD into the future, as well as aggregate the input from other industry stakeholders. This ownership and governance model should be seen as an enabler, not an obstacle, to getting the necessary industry-wide input and management of the quality of the content, as well as widespread adoption and implementation by the industry;
5. There is a need to centralize effort, results, and ongoing maintenance in a truly "national" standards effort, across local, state, regional, and national governance structures, where the project DD becomes a "US Infrastructure Data Dictionary" and possibly a comprehensive US-focused "built environment" DD;
6. There is a need to mitigate intellectual property rights (IPR) issues (ownership and governance) regarding all the input (terms and definitions) collected from the different organizations who have a stake in such standards;
7. The data dictionary needs to be readily available to all stakeholders operating in the US infrastructure market (contractors, software vendors, suppliers, owners, designers, etc.), whether located inside or outside US borders. For the most robust and extensive adoption and implementation, providing an online database, with a web browser-based interface for human-readable interaction and an API for software developers and vendors to embed functionality directly in software for use is essential. Utilizing such a centralized, online resource improves the quality of the further management of the DD and ensures consistency across implementations in multiple software platforms. Such DD online infrastructure will require investment/funding for the hardware, software, and human management.
8. Ideally, a neutral 3rd-party, with a low-threshold relationship to bSI, would be the most efficient means of connecting a US-based data dictionary with the bSDD.

Proposal

Based on the background information and identified issues, there is a recommendation to the governance, further development, maintenance, storage, distribution, and access of the data dictionary being initiated by TPF-5(372). The components of that recommendation are as follows:

1. A United States Data Dictionary (USDD) would be an official buildingSMART USA project, creating a national, open standard fully managed by bSUSA and its Technical Committee through a USDD Working Group;
2. The USDD Working Group (WG) would be led initially by Aaron Costin and comprised of industry professionals and academics to aggregate and manage the content of the USDD based on industry needs that may change/grow over time;
3. A Steering Committee of nominated/selected individuals, from the different bSUSA member and industry stakeholder organizations (e.g. AASHTO, FHWA, AISC, ACI, PCI, etc.), would have oversight of the WG, making sure that all aspects and needs of the industry were being addressed based on the charter of the WG and needs of the stakeholders;
4. Within the Working Group, 3-5 persons would be designated as the practical "Agents", by the Steering Committee and bSUSA, to interface directly with the bSDD service in managing the content developed by the WG;
5. The form of the content (terms, definitions, and relationships) aggregated and developed by the Working Group, known as the "USDD", would be copyrighted directly by bSUSA, and contributed to the bSDD, enabling fair use without undue licensing attribution or fee;
6. Content contributed to the bSDD by other organizations would be offered freely under fair use by the individual organizations, retaining their ownership and copyright in the source material, if desired;
7. Being the "owner" of the USDD, the bSUSA chapter would be the primary "Content Owner" from the perspective of the bSDD, as well as "Agency" responsible for editing and maintaining all its content contributed through the USDD;
8. The bSUSA chapter would be responsible for all Content Owner and Agent Fees. Ideally, the fees paid to bSI would be offset by chapter membership fees or designated "USDD sponsors" within the chapter membership. For any Multinational or Standard bSI members who have designated the US chapter as their primary association, the rebate to the US chapter could be designated, in whole or in part, as USDD sponsorship fees, possibly negotiated and indicated on a case-by-case basis.

Appendix 14: Software Vendor Letter of Intent Template

For the sake of confidentiality, the appendix includes only the template for the Software Vendor Letters of Intent.

BIM FOR BRIDGES AND STRUCTURES TPF-5(372)

Letter of Intent

Development of Software to support TPF-5(372)

HDR
Address
Address
Phone
Contact/Agent Name
Contact email

Date: July 01, 2021

Developer Company Name
Address
Address
Phone
Contact/Agent Name
Contact email

RE: Intent to Develop Software

Over the past five years, members of the American Association of State Highway and Transportation Officials (AASHTO) have been learning about the use of building information modeling (BIM) for the design, procurement, construction, and operational management of transportation infrastructure (e.g. roads, bridges, rail, etc.) and piloted several projects to explore the technologies, workflows, and resulting benefits of implementation. Just as the vertical construction (buildings) industry has experienced, one of the key factors to getting the most benefit is the use of open data standards to enable the exchange and use of information across a wide variety of technology platforms and processes. As such, AASHTO has resolved[1] to use buildingSMART International's (bSI) openBIM®[2] data model standard, Industry Foundation Classes (IFC)[3], as the foundation for the use of BIM-based project delivery and operations workflows and data for highways and bridges in the United States. The practical application of IFC and related bSI openBIM standards (such as Model View Definitions [MVDs], the buildingSMART Data Dictionary, and the BIM Collaboration Format [BCF]) requires that commercial software products used throughout the US transportation industry support these standards. This enables the use of many different types of tools, from many different sources, to address the particular

[1] See Administrative Resolution AR-1-19 Adoption of Industry Foundation Classes (IFC) Schema as the Standard Data Schema for the Exchange of Electronic Engineering Data
[2] See https://www.buildingsmart.org/about/openbim/ for the definition of "openBIM"
[3] See https://technical.buildingsmart.org/standards/ifc/ for more information about IFC

needs of various project stakeholders leveraging the data from BIM implementations across the life cycle of projects/assets.

Thus, it is in the mutual interest of commercial software developers and AASHTO members to cooperatively advance the practical application of open data standards and their support in software functionality. This documentation (the "Letter of Intent") to develop functionality in software to support IFC-based BIM workflows represents terms for a good faith agreement that is not legally binding on the undersigned parties.

I. The Developer

_______________________ (the "Developer").

II. The Industry Representative Body

Members of the Project "Transportation Pooled Fund 5(372) BIM for Bridges and Structures" (the "**Industry**") as contractually represented by the Iowa Department of Transportation.

III. Industry Representative Body's Agent

HDR Engineering, Inc. (the "**Agent**"), a consultant to the Iowa Department of Transportation engaged to provide professional services to advance the Transportation Pooled Fund Study 5(372) goals and outcomes.

IV. The Project:

Transportation Pooled Fund 5(372) BIM for Bridges and Structures [aka "**TPF-5(372)**] (the "**Project**") is an effort to develop AASHTO standards enabling BIM-based workflows for the design, delivery, and ongoing operations and maintenance of bridge structures across the United States of America.

V. Scope of Agreement - Developer

In general, the Developer intends to commit resources to supporting IFC-based functionality within their designated software product(s) in the interest of the Project:

The Developer shall provide the following to support the goals of the Project:

1. Functionality within the developer's software to enable ***any single or combination of aspects*** including;

    a. digital modeling of bridges and associated structures;

    b. the assignment or association of model and information semantics as defined by IFC version 4.3 (IFC4.3) in addition to internal, proprietary data schemas;

c. export of digital models and associated data in an IFC4.3 format (.ifc, .ifcxml, .ifczip, .ifcJSON), as defined by one or more Model View Definitions ('MVDs'), via mvdXML files, as supplied by the Agent;

d. import of digital models and associated data in an IFC4.3 format (.ifc, .ifcxml, ifczip, .ifcJSON);

e. association of model data to the proposed United States Data Dictionary (USDD) via the buildingSMART Data Dictionary (bSDD) service;

f. use of the buildingSMART International BIM Collaboration Format (BCF) to enable model-based communication between software products from various companies and other Developers.

2. Not-For-Sale (NFR) versions of software for the Agent to assist independent testing and reporting of issues regarding Developer's support;
3. Certification of software supporting the goals of the Project;
4. Documentation for the Developer's software which supports said functionality;
5. Coordination with Agent to provide training materials;
6. Availability of supporting functionality in 'off the shelf' software for purchase by Industry, Agent, and any service providers to the Industry.

VI. Scope of Agreement – Industry

The Industry has engaged the Agent to provide support and services described below from July 1, 2021 to December 31, 2023, the end of the Project, which may be subject to change.

VII. Scope of Agreement – Agent

The Agent, when instructed by the Industry, shall provide the following direction and support to the Developer:

1. *Specifications for digital modeling and data association requirements, as it applies to bridges and associated structures;*
2. *Technical specifications for IFC4.3 data association, export, and import, as it applies to bridges and associated structures;*
3. *A Unit Test Suite containing instructions for various models and associated data, to be created, exported, and/or imported by the Developer's software;*

4. *Assistance in testing and validating development of modeling and data association, as well as file export and/or import;*
5. *Reviewing software documentation for supporting functionality in the Developer's software;*
6. *Cooperative educational and/or training program of Developer's software regarding specified functionality;*

VIII. Compensation / Benefit

The agreement of Agency between the Industry and the Agent is separate to this Letter of Intent. Neither the Industry nor the Agent shall provide any direct financial compensation to the Developer. Any benefits realized by the Developer, the Industry, or the Agent arising from this Letter of Intent shall be in kind. These in-kind benefits to the Developer for participating in the Project may include the following:

1. *Public acknowledgement of Developer's participation in support of the Project;*
2. *Inclusion of the Developer's company name and logo on the TPF-5(372) website and presentation slides listing the Developer as a strategic partner;*
3. *Use of authorized statements from the Developer on the website, presentation slides, or in written or verbal communications about the Project from the Industry or Agent;*
4. *Opportunities for the Developer to provide introductory, orientation, and/or training presentations to Industry and Industry's service providers regarding Developer's software functionality supporting the Project;*
5. *Public acknowledgement of Developer's software as a Certified Provider should the Developer pursue and attain certification of their product.*

The Developer shall provide consent under separate letter to the Agent to use the Developer's official company name and logo - official electronic versions and usage guidelines provided by the Developer - for the Project's promotional materials and events. In the event of termination of this Agreement, the Agent and Industry will cease using the Developer's official company name and logo on any materials or in any events following termination. The Developer recognizes that material published prior to termination may continue to contain the Developer's name and logo.

IX. Confidentiality and Disclosure

To protect the Developer's intellectual property rights, representatives from the Industry and/or Agent may be required to sign Non-disclosure Agreements (NDAs) before providing the support and/or services identified above. These NDAs would clearly state the disclosure restrictions, which in general would prohibit any proprietary information or material to be disclosed to other Developers participating in the project or to the general public outside the Project.

X. Completion:

The Industry requests that the Developer, unless otherwise stated under the terms of a future agreement between the parties, complete terms of section VI. Scope of Agreement - Developer prior to the end of the Year 5 term of the Project specifications, December 31, 2023, unless otherwise indicated in the future by the Industry or Agent.

Regardless of the Developer's timeline, the Agent's support and/or services will terminate on December 31, 2023, unless otherwise indicated in the future by the Industry or Agent. As such, the Agent will stop accepting new requests for support and/or services on September 30, 2023.

XI. Non-Binding Effect and Severability

This Letter of Intent shall be considered 'Non-Binding', therefore, the parties acknowledge that this Letter of Intent has no enforceable adherence or penalty by any Party and may be terminated without prejudice at any time in the future by any Party. The terms outlined herein are solely for the purposes of reaching a good faith agreement of Project engagement between the parties for the duration of the Project.

Upon termination, the Developer will no longer receive any continuing benefit as defined in the Letter of Intent from the Industry or the Agent, and all parties will surrender any exclusive materials provided to each other. Any public communication regarding termination of the Letter of Intent and pursuit of the Project by the Developer, the Industry, or the Agent shall only indicate that such a termination took place.

XII. Governing Law

This Letter of Intent shall be governed under the laws of Iowa and the federal laws of the United States of America.

XIII. Signatures

DEVELOPER

As the authorized agent of the Developer, I hereby agree to the terms of the Letter of Intent in good faith.

Developer's Signature ________________________ Date ______________

Printed Name ________________________

INDUSTRY

As the authorized agent to the Industry, I hereby agree to the terms of the Letter of Intent in good faith.

Industry Signature ________________________ Date ______________

Printed Name ________________________

AGENT

As the authorized agent to the Agent, I hereby agree to the terms of the Letter of Intent in good faith.

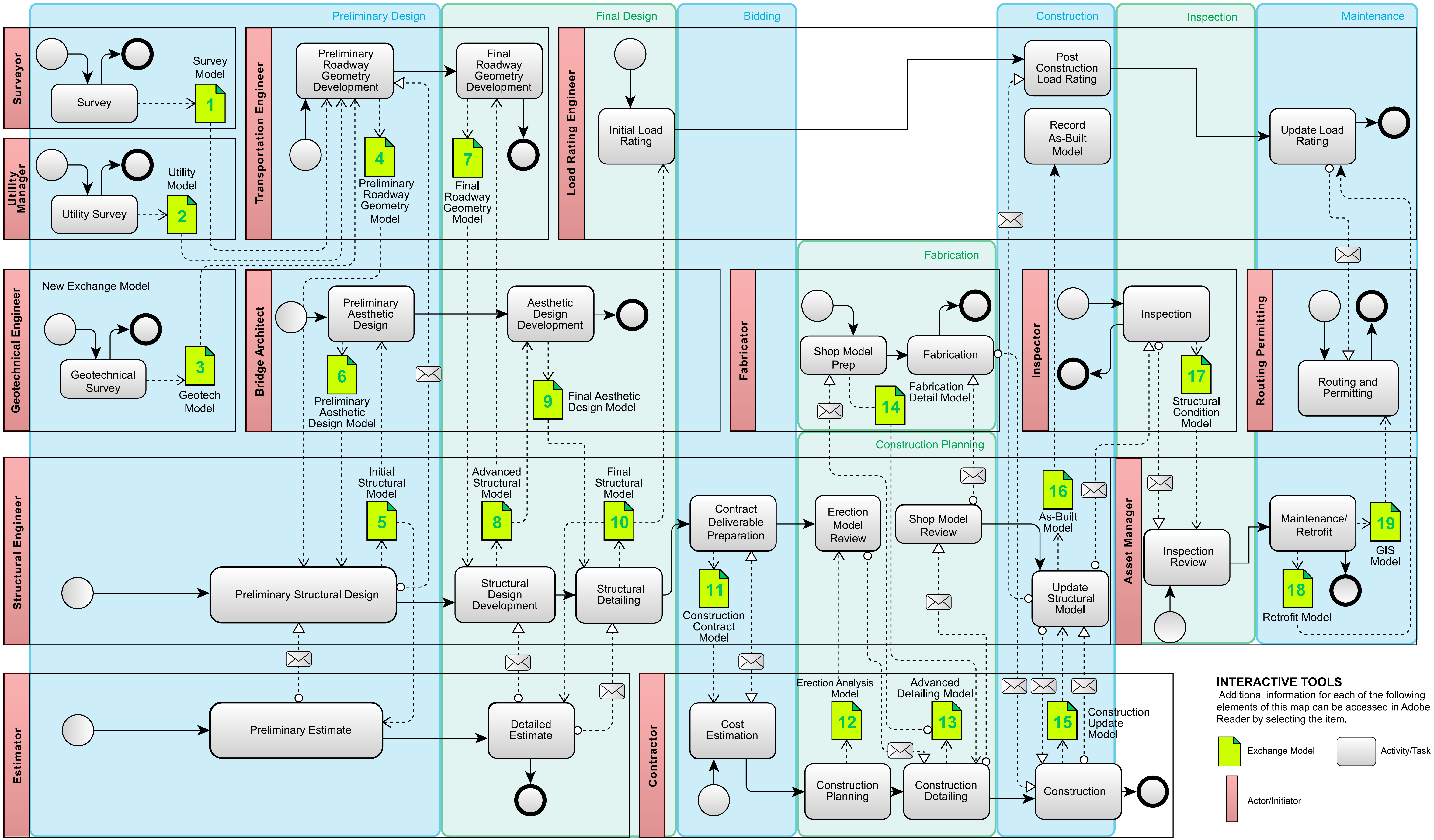
Agent's Signature ________________________ Date ______________

Printed Name ________________________

BIM FOR BRIDGES AND STRUCTURES TPF-5(372)

Appendix 15: Interactive Bridge Lifecycle Management Overview Map

Bridge Lifecycle Management Overview Map



INTERACTIVE TOOLS

Additional information for each of the following elements of this map can be accessed in Adobe Reader by selecting the item.

Exchange Model

Activity/Task

Actor/Initiator

LEGEND

Sequence Flow

Data Association

Message Flow

Message

Start Event

End Event

NOTE: The purpose of this map is to establish the digital model exchanges and the respective parties involved. Any ancillary memos or reports between said parties are assumed to be included in the exchange.

BIM FOR BRIDGES AND STRUCTURES TPF-5(372)

Appendix 16: Return on Investment Analysis: Literature Review

BIM FOR BRIDGES AND STRUCTURES TPF-5(372)

Memo

Project:	TPF-5(372) BIM for Bridges and Structures
Date:	11/16/2022
To:	Working Group 1: Research & ROI
From:	Alexa Mitchell, Francesca Maier, Emily Johnson, Stéphane Gros, Sarah Henly-Thomas
Subject:	Return on Investment Analysis (Task 3) – Literature Review

Introduction

This memo summarizes the literature review undertaken to support the development of a white paper on the benefits and costs of using building information modeling (BIM) for bridges. Over fifty items were collected from a range of sources, including open-access journal articles, state and federally funded research, measurement tools, and international publications.[1] The review covered three main topics: 1) Identification of benefits and costs; 2) Resources for the quantification of benefits, costs, and return on investment (ROI); and 3) Methodological considerations, including the amplification of benefits through interoperability. The findings related to each of these topics are summarized in the rest of this memo. The final section includes a list of references sited in this memo.

Identification of Benefits and Costs

A large number of benefits and costs are identified in the literature. They are typically grouped within broad categories, for analysis and presentation, as discussed below.

Benefit Categories

The benefits of using BIM encompass a large variety of effects, direct or indirect, tangible or intangible, and accruing to different parties (e.g., owners, contractors, asset users). Adding to this complexity is the often noted disconnect between the time a benefit is "enabled" through the use of BIM, and the time it is actually "realized" in the form of productivity gains or project cost savings. Another source of confusion is the distinction between intermediate benefits and end benefits, with the former referring to operational improvements experienced by a BIM practitioner (as a direct result of using BIM), and the latter to beneficial outcomes experienced by an organization, as a result of one or several intermediate benefit(s).[2]

[1] A lot of the initial literature on the benefits and costs of BIM focuses on vertical infrastructure and the building industry, where the practice originated. This review focuses on publications that explore the use of BIM for civil infrastructure, including roads and bridges.

[2] End benefits can also be understood as strategic or fundamental objectives, in contrast to intermediate benefits which are only a means to an end. Examples of intermediate and end benefits include: 1) easier coordination of design and construction (intermediate) and time savings in design (end); 2) improved accuracy in materials

In many publications, the benefits of BIM are presented by asset lifecycle phase. A systematic review of the literature published in 2020 [1] identified dozens of benefit streams (intermediate and final), organized into four main phases: Design, Pre-Construction, Construction and Post-Construction.

A useful approach for assessing and organizing the benefits of BIM is the "impact pathway" methodology set out by PWC for the UK Government in 2018 [2]. In that context, an impact pathway is best understood as a sequence of events leading from an activity to an outcome. As illustrated in the figure below, reproduced from the UK study, each pathway begins with a project-based activity (e.g., stakeholder consultation), connects to a BIM enabler (e.g., 4D virtual design simulations), identifies one or multiple intermediate benefits (e.g., fewer changes during construction), and quantifies the resulting end benefits (e.g., time savings). Importantly, each pathway also identifies the lifecycle phase in which the benefit originates and the phase(s) in which it accrues.

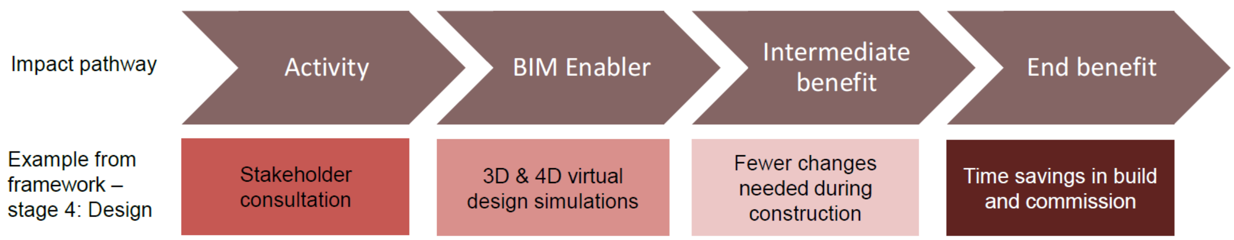


Figure 1: Impact Pathway Definition and Example [2]

The UK study identified a total of 117 impact pathways grouped into 22 high-level "benefit areas" and eight "measurement categories,"[3] namely: time savings, material savings, cost savings,[4] improved health and safety, reduced risk, improved asset utilization, improved asset quality for end-users, and improved reputation.

Another study prepared for the Transportation Research Board (TRB) [3] identified 24 benefit streams organized into four main categories: in-house agency benefits (e.g., cost savings from reduced paper use), project cost savings (e.g., avoided change orders), staff time savings (e.g., avoided RFIs, efficiencies in information retrieval), and benefits to asset users (e.g., time savings from reduced construction road closures). Each of these benefit streams was associated with one or more of 14 BIM use case(s).[5] Use cases

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procurement (intermediate) and environmental benefits from fewer materials used (end); or 3) better understanding of construction operations (intermediate) and improved health and safety in construction (end).

[3] "Measurement categories" and "benefit areas" are the exact terms used in the UK study. Examples of benefit areas within the time savings measurement category include time savings in design, time savings from answering RFIs, or time savings in incident response. The terms can be understood respectively as "categories of benefits" and "benefits," but all the benefits within the same measurement category can be measured using the same general approach (including, in some cases, a common set of assumptions), hence the reference to "measurement" categories; and each "benefit area" can be associated with multiple pathways and intermediate benefits, hence the use of the word "area."

[4] Broader savings across an asset lifecycle where it is difficult to distinguish time and material.

[5] Examples of use cases considered in the TRB study include capturing existing conditions, authoring design models, inspecting assets, creating quantities and cost estimates, or automating equipment guidance. They are the equivalent of the project-based activities and BIM enablers in the impact pathway method.

were grouped within four categories (i.e., project delivery core and extensions, asset management core and extensions), and thus indirectly mapped to an asset lifecycle.

The main benefit streams identified by this literature review are summarized in the table below, using seven of the eight categories defined in the UK study.[6]

Table 1. Overview of BIM Benefits, Core Categories and Examples

Benefit Categories	Examples of Benefit Streams
Time Savings	▪ Staff time savings (e.g., responses to RFI) ▪ Efficiencies in design (e.g., faster document review and approval) and construction (e.g., reduced reliance on manual information management)
Cost Savings	▪ Agency cost savings (e.g., reduced physical storage and office space needs, lower inspection costs from unmanned aerial vehicles) ▪ Project cost savings (e.g., improved schedule management, optimized material use) ▪ Cost avoidance (e.g., avoided change orders, errors, incidents, or claims and/or litigation)
Material Savings	▪ Reduced use and storage of paper ▪ Material savings from more refined designs and construction planning
Environmental Benefits	▪ Reduced emissions from material savings and shorter construction schedules ▪ Improved public engagement
Asset Utilization	▪ Improved utilization of IT assets, data assets, and transportation assets (e.g., shorter lane closures)
Health & Safety	▪ Hazard avoidance and improved risk mitigation through visual construction planning ▪ Reduced workers exposure (e.g., offsite fabrication) and fewer work-zone crashes for users
Other Benefits	▪ Reduced variance (e.g., reduced CAPEX contingency) ▪ Improved agency reputation

Cost Categories

The costs of using BIM were enumerated in fewer studies than the benefits. The 2018 UK study [2], notably, did not consider costs at all. The main categories of costs were direct and indirect, of which only direct costs were typically quantified. Direct costs can occur at the programmatic level, where the costs support the use of BIM across an agency's project development program, or at the project level, where the costs only support one project. Indirect costs occur when participants in the Architecture, Engineering,

[6] The benefits of BIM can be organized and presented in many different ways. The classification developed for the UK study is used here, as it is both comprehensive and logical. In the UK study, however, improved reputation and reduced risk (or variance) are presented as two separate measurement categories.

and Construction (AEC) supply chain pass on their own BIM-related costs to an agency, in the form of higher overhead costs or bid prices.

- Programmatic direct costs include the costs of establishing the IT business systems required to support project development (i.e., hardware, software, and training),[7] as well as the staff or consultant costs needed to establish and support the use of BIM (e.g., process improvements, development of standards and guidelines, customization of workspaces). Some programmatic costs are one-off, representing an initial, upfront investment, while others are recurring. [3] Some recurring costs are cyclical, with different return periods (e.g., hardware replacements, software license agreements), while others are sporadic (e.g., updates following the release of new software versions).
- Project-level direct costs include changes in staff time on BIM vs. non-BIM-based designs (i.e., development and documentation time).[8] For consultant-designed projects, these can be discerned as increases in the average cost of professional services contracts with BIM requirements. [3] On a construction project, the use of BIM may change the means and methods of executing construction work and inspection tasks. These new methods may result in additional costs for data preparation and time savings in executing the work. Agencies may perceive these cost increases indirectly, but the cost of requiring a digital as-built deliverable, for example, can typically be isolated. [3]
- Indirect costs, as noted above, manifest themselves as higher overhead costs or bid prices. Two indirect costs were identified in an ROI analysis of providing 3D models as reference information at the Michigan DOT. They were both increased professional services costs, one for design, and the other for construction engineering and inspection. [4]

Summary: Many intermediate benefits were identified in the literature, which reduced to end benefits that fell into seven categories. Over 80% of benefits fell within three categories: time savings, cost savings, and material savings. Costs were more directly expressed. Direct costs fell into two broad categories: those supporting an agency's program and those occurring only on projects. The most frequently noted costs were: 1) hardware, software, and training investments; 2) model development efforts during the design phase; and 3) consulting costs. Indirect costs are costs accruing to an agency's supply chain partners that are passed on to the agency as increased prices.

Resources for Quantification

Five resources for quantifying the benefits and costs of using BIM were examined as part of this review. They are described in the table below. Key findings on the quantification of benefits and costs, including lessons learned and limitations, are summarized in the sections that follow.

[7] Some of these costs support business functions as a whole and are not specifically related to the use of BIM. Even some BIM-related software costs may not be wholly attributable to BIM adoption, if for instance, the BIM software replaced non-BIM software used to execute the same function (e.g., design authoring and documentation).

[8] In many ROI frameworks, changes in staff time would be reported as a benefit, not a cost. Increases in staff time would be reported as a negative benefit.

Table 2. Overview of Resources and Tools for the Quantification of Benefits and Costs

Resource	Work Products	Objectives, Scope, and Calculations
BIM Level 2 Benefits Measurement Methodology [2]	Detailed guidelines (PDF documents), no tool	▪ Project-level assessment of the benefits of "BIM Level 2",[9] across eight stages of an asset lifecycle. ▪ Also applicable at program or organizational level. ▪ Impact pathway approach, with 117 individual pathways, grouped within 22 high-level benefit areas and 8 measurement categories. ▪ Large set of equations, with only a few suggested values (e.g., UK governmental guidance for monetization) ▪ Costs not considered at all; beneficiaries not identified
Lifecycle BIM for Infrastructure [3]	Research report, benefit-cost analysis (BCA) framework and spreadsheet-based tool	▪ Program-level assessment, based on BCA methodology ▪ Investment Case compared to Base Case, where both can be defined in relation to one of four BIM capability levels ▪ Costs and benefits associated with 14 BIM use cases ▪ 24 benefit categories (6 in-house agency benefits, 5 project cost savings, 9 staff time savings, and 4 user benefits); 15 cost categories (4 initial, 11 ongoing) ▪ Look-up tables with suggested values for benefits and costs, with ability to override with agency-specific data ▪ B/C Ratio calculated over 10 years (default), as Total Benefits over Total Costs, with discounting
Cost-benefit Analysis Model for the Use of BIM in Public Tenders [5]	Methodology handbook and spreadsheet-based tool, including 6 case studies (building & infrastructure)	▪ Ex-ante project-level assessment, relying heavily on preliminary established values ▪ 8 benefit categories (including cost reductions, time savings and emission cost savings); 9 cost categories (including lower productivity and additional efforts required, and BIM-related investment costs allocated to specific project) ▪ Allocation of costs and benefits to one of three project phases: planning and design (up to 5 years), construction (10 years), and operation and maintenance (20 years) ▪ B/C Ratio calculated over a period of up to 35 years, as Total Benefits over Total Costs, with discounting
Addressing the Challenge and the Return on Investment for Paperless Project Delivery [6]	Technical report, spreadsheet-based tool, and one case study	▪ Program-level assessment of ROI to state agencies of implementing e-Construction solutions (e.g., electronic bidding and contract award; digital plans and estimates; digital review of documents; mobile devices; etc.) ▪ 31 benefit categories across 8 applications; up to 14 cost categories (including pre-implementation planning, hardware and software, systems integration, and agency staff time) ▪ Estimates based on size of construction programs (2015) and various assumptions and benchmark data

[9] The definition of BIM Level 2 used in the study is based on Publicly Available Specification (PAS) 1192-2:2013: "a process of managing information throughout the lifecycle of a built asset, with key features including the definition of information requirements by the client; the use of a collaborative Common Data Environment; and the use of 3D modelling in design, capturing both geometric and non-graphical data."

Resource	Work Products	Objectives, Scope, and Calculations
		▪ ROI calculated over 7 years, as Total Benefits over Total Costs, without discounting
3D Highway Design Model Cost Benefit Analysis [4]	Research report and spreadsheet-based template for ROI calculations	▪ Program-level assessment of ROI from investing in 3D engineered models ▪ Quantification of one benefit stream (reduction of change orders due to quantity deviations and errors and omissions) and two cost categories (additional cost to produce 3D models, staff needed for technical support). ▪ Other benefits and costs identified in report, including savings from lower bids (due to low bidder using AMG construction). ▪ ROI calculated over 5 years, as (Total Benefits – Total Costs) / Total Costs

Quantification of Benefits

There is no comprehensive database of BIM adoption experiences and no common baseline for evaluating the impact of BIM implementation. Quantification, therefore, requires a range of approaches and different assumptions that reflect stakeholder perspectives and data from individual projects. [5] Most studies reviewed herein relied on expert panels and/or surveys to develop quantitative estimates of benefits (and costs), with only a few notable exceptions.

The Michigan DOT study [4] quantified some of the benefits of BIM through statistical analysis of agency data. Construction cost savings were estimated across the agency's program by analyzing historical price data for projects with and without 3D models. Two measures of benefits were defined: 1) project award price vs. engineer's estimate; and 2) final project cost vs. award price. Statistically significant savings were identified for projects using BIM.

The European study [5] measured time savings in construction through schedule compression, which can be observed retroactively and analyzed programmatically. The study also noted that more accurate quantity take-off savings are associated with more accurate estimates of the required material and connected activities but did not provide further detail on quantification.

The 2018 UK study [2] provides a sound and detailed approach to benefits quantification, including a large set of impact pathways and associated equations, as well as some suggested values for the monetization of benefits, but its use requires significant data collection and analytical efforts.[10]

[10] As an illustration, the quantification of material savings requires the following data: *"Project cost plan detailing material usage (physical – e.g. in kilograms, m2, m3); design stage bill of quantities (the amount of materials*

The most relevant set of quantifiable benefits were found in the TRB study [3] which produced a spreadsheet-based tool to estimate 24 benefit streams, including equations and lookup tables with suggested values derived from the literature, subject matter experts, and case studies.

The quantification of benefits (and their proper attribution to BIM adoption) requires that the changes in staff time, project costs, etc. be tied to specific BIM enablers or use cases, as it was done in the European study [5] and TRB study [3]. Both of these studies also considered the impact of organizational BIM maturity on the realization of benefits: the more mature the use of BIM is at an agency, the more likely the agency will be familiar with BIM use cases and employ BIM across the asset lifecycle. [3]

Overall, at this stage, the benefits of BIM and the lifecycle use of infrastructure project development data have been largely speculated, as opposed to rigorously analyzed. This is explained in part by the many challenges faced by analysts, including:

- Many benefits are realized through cost avoidance, [3] which is difficult to quantify at the project level (because some agency costs cannot be allocated) and challenging to isolate from other variables at the programmatic level (because of non-BIM-related development work).
- Benefits accrue throughout the supply chain, and those occurring outside an agency are particularly difficult to assess.
- Benefits accumulate throughout the project and asset lifecycle, [5] [3] [2], and the magnitude of benefits can increase over time, as BIM is applied more and as users gain familiarity.
- While enhanced communication and collaboration are the most frequently cited intermediate benefits, there is no credible estimate of these benefits in monetary terms. [5]
- The data needed to quantify benefits to asset users are typically lacking. For example, more compressed construction schedules lead to less traffic congestion, which leads to travel time savings for the public and fewer carbon emissions, but these are all difficult to estimate. [3]
- More generally, agencies have not been tracking/measuring the impacts of BIM on their operations, so there is very little data available for benchmarking and evaluations.

Quantification of Costs

As noted earlier, only the direct costs of BIM adoption are typically measured, including initial investment costs (one-offs) and recurring costs, such as hardware replacement or software subscriptions. Investments in hardware, software, and training are relatively easy to quantify. The costs of process improvements, developing and adopting open standards, and other aspects of BIM maturity (see next section) are a lot more difficult to estimate, and generally not covered in the literature.

A comprehensive European study [5] estimated that the average cost of BIM adoption ranges between $15,000 to $20,000 per person in the first year of adoption, including $2,000 to $3,000 in hardware cost;

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ordered) and the actual final bill of quantities required to deliver the asset; and a value for the cost of materials; as well as an understanding of any change in materials required attributable to BIM."

$8,000 to $10,000 in software licenses (for modeling and verification); and $5,000 to $8,000 in training cost.[11]

The ROI tool developed for the TRB study includes cost data and suggested values for equipment, software, training, and professional support services. These are based on a variety of sources, including online cost research, agency data, case studies, and inputs from a panel of experts.[12] [3]

The Michigan DOT study used direct costs for staff and consultant time for providing programmatic support and software configuration and computed indirect costs using percentages of the design and construction costs. The BIM-related costs for design were estimated as a 10% increase in professional services contract value. The cost of design professional services was estimated at 9% of the construction contract value, rather than measured directly. [4] The BIM-related costs were thus 0.9% of the overall construction contract value across the construction program.

Summary: There are many examples of approaches to quantify benefits, particularly time, cost, and material savings. Most examples for quantifying benefits are at the project level, but there was one example of using statistical analysis of an agency's construction program data to identify statistically significant benefits. Most studies relied on expert panels and/or surveys to quantify some costs and benefits. Labor and technology costs are straightforward to compute, but quantifying the costs of process improvements, open standards, and other aspects of BIM maturity is more challenging.

Methodological Considerations

A number of measurement issues have been highlighted in the literature. In addition to the "convoluted" nature of BIM benefits evaluation [7], a key concern is the need to account for multiple areas of maturity when assessing the extent to which an agency can benefit from the adoption of BIM.

ROI Measurement Issues

The challenges of measuring the ROI of BIM are well documented. They include, but are not limited to, the time lag between the implementation of BIM and the realization of benefits; the difficulties of disentangling the effects of BIM from those of other activities; or the challenges of scaling project-based costs and benefits across an agency's program because of differences in BIM maturity within the supply chain.

In their review of BIM benefits measurement tools available in the UK,[13] the Centre for Digital Built Britain (CDBB) expressed skepticism in the accuracy of the benefits produced by these tools. [7] Reasons for this skepticism included the lack of benchmarking data, the reliance of estimates on the knowledge of users entering the data, the likelihood of double-counting, or the exploration of anecdotal rather than tangible

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[11] Original estimates converted from Euros at current exchange rate (1 Euro ~ 1 USD).

[12] In that tool, software costs can be aligned to specific BIM use cases, and thereby benefits, that the software enables.

[13] The CDBB reviewed three measurement tools: 1) Scottish Futures Trust, *BIM ROI Tool*, https://bimroi.scottishfuturestrust.org.uk; NATSPEC and SBEnrc, *BIM Value*, https://bimvaluetool.natspec.org; and University of Cambridge, BIM Benefits, not publicly available.

benefits. The centre also noted that existing tools are most often used to assess individual organizations and top-tier suppliers (e.g., large contractors or consulting firms) although BIM capabilities and benefits should be assessed along the supply chain as a whole.

Maturity Levels and ROI

In stakeholder interviews across Europe, most agreed that there are only a few or no benefits at the beginning of BIM adoption. Reasons for this included low productivity and additional efforts required initially, the high costs of BIM adoption, a need for specific knowledge and expertise to apply BIM, and interoperability issues. [5] A rigorous ROI analysis, therefore, needs to consider maturity levels, especially if the return period is short. Five critical areas of maturity were identified in the literature. They are described briefly below, along with their implications for the realization of BIM benefits.

Interoperability

Interoperability is critical because many of the benefit streams require the information from BIM to be used many times over the asset lifecycle. It is possible to have interoperability for a limited period of time, such as during the preconstruction and construction phases of a project, by rigidly using products from a single software vendor ecosystem. Creating interoperability through the use of open standards, however, lowers the external costs to the supply chain, which increases participation and competition. Open data also remains accessible over time as software evolves. Interoperability through open standards, therefore, is an important enabler of BIM benefits.

Importantly, interoperability is not just a technical issue, but also an organizational concern. In order for the technical solution for interoperability to succeed, the parties must implicitly value interoperability and must have aligned technological capabilities, protocols, processes, and quality management procedures. Nonetheless, there are three technical factors necessary for successful interoperability [8]: 1) successful implementation of import/export functions in commercial off-the-shelf software (COTS); 2) sending and receiving software support of the internal structure of the file format; and 3) the variety of data object types being shared.

Finally, one paper [9] identified three barriers to BIM adoption: 1) the need for well-defined construction process models; 2) the requirement for computable digital design data; and 3) the need for practical and purposeful exchange and integration of model contents. All three of these barriers are addressed through the IFC-based standards that are being developed by the TPF-5(372) project.[14]

Familiarity with BIM

The TRB and Michigan-based studies [3], [4] considered four levels of maturity, defined as follows:

- Level 0: No BIM.
- Level 1: Object-based modeling, which may include creating 2D information for contract plans, or creating 3D files for contractor use.

[14] The first, through the development of the IDM, and the second and third through the implementation of IFC-based interoperability in commercial software products.

- Level 2: Model-based collaboration, which typically involves sharing federated models within a single shared online area, while relying on file-based collaboration and library management. Level 2 might also include creating 3D object models for all disciplines.
- Level 3: Network-based integration, with fully integrated project models shared via real-time Common Data Environment (CDE), use of standards for interoperable data, and information attributes for all 3D objects.

These levels were derived from the building industry, which had very limited prior use of model-based design. All U.S. transportation agencies currently operate at a minimum maturity level of 1 and have done so for decades. Several other BIM maturity scales are available in the literature, along with multiple maturity assessment tools.[15]

Quality Control Protocols

The productivity gains that occur as a result of BIM adoption depend critically on the consistency and accuracy of the data. [10] Yet, there are no standardized measures of BIM quality, nor automated quality control procedures for BIM. Problems with the existing quality-checking protocols include poorly defined information deliverable requirements, opportunity for errors from manual compliance checks in construction, and lack of clearly established BIM requirements and guidelines. [10] In contrast, the MVD developed by the TPF-5(372) project will enable automated quality checks of IFC files.

Implementation with Process Improvements

Much of the literature looks at BIM at a macro level and neglects the practical, on-the-ground experiences of individual projects. [11] One study looked specifically at this micro level, conducting in-depth interviews with project teams to assess how process improvements affect the realization of BIM benefits. The interviews identified several instances where historical policies and processes were in conflict with BIM and thus prevented BIM benefits from being realized.[16]

BIM Adoption through the Supply Chain

None of the reviewed studies estimated the level of BIM adoption through the supply chain, nor quantified the impacts of broader adoption. Nonetheless, benefit amplification could be assessed from the following impact pathways: 1) open standards enable more flexibility with software choice, which lowers the cost of staff training, increases competition with software vendors, and may lower the cost of software workspace development and maintenance; or 2) the industry becomes less reliant on both 2D plans and selected data extracted from project models, and starts using models directly to access all necessary information.

[15] In a comprehensive review of BIM maturity assessment tools available globally, the Center for Digital Built Britain identified fifteen tools, eleven of which were deemed applicable to infrastructure.

[16] Examples include using old file sharing practices instead of the project's information management conventions, eliminating the efficiencies from using a common data environment; contractual incentives not to use BIM-capable firms (e.g., small business utilization targets); or financial incentives for expediency that create disincentives for capturing accurate asset information.

Summary: For many benefit streams, the realization of BIM benefits depends critically on interoperability. A great deal of attention is paid to technical interoperability, but the criticality of organizational support for interoperability cannot be overstated. Other organizational issues, such as process improvements, quality control protocols, or an agency's familiarity with BIM are notable amplifiers of BIM benefits.

Conclusions

The generic benefits of BIM adoption have been thoroughly explored. Studies often rely on estimating benefits and costs at the project level, regardless of which party incurs the costs and benefits, and extrapolating across an agency's program. There are many examples from the literature of strategies to quantify benefits, but most examples of cost estimation relate to direct costs.

There are also many examples of the beneficial application of BIM on projects, but equally, there are examples where no benefits were realized, in particular when established practices are in conflict with BIM.[11] There was only one study [4] that analyzed the application of BIM (narrowly) across an agency's construction program. But while statistically significant BIM benefits were found, these empirical results did not establish causality.

The maturity and depth of BIM implementation throughout the supply chain is an important determinant of whether benefits realized at the project level can be scaled across an agency's program. The majority of the benefit streams depend upon the application of BIM in an earlier phase, typically the design phase. Benefits realization depends therefore on interoperability, but organizational issues like leadership support for data exchange and process improvement are notable benefit enablers.

The impact pathway methodology of the UK BIM benefits measurement methodology is a worthy approach to isolate benefits that apply equally to buildings and infrastructure, avoid double counting, and incorporate the enabling/amplifying effects of maturity (both for BIM use and interoperability). The UK study found that over 80% of benefits fell into the categories of time, cost, or materials savings. [2] Focusing on these benefit streams and core BIM use cases that would produce benefits over the horizon of the study, rather than the entire asset lifecycle, can provide a manageable boundary on the ROI computation framework.

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BIM FOR BRIDGES AND STRUCTURES TPF-5(372)

Appendix 17: Return on Investment (ROI) Analysis White Paper

BIM FOR BRIDGES AND STRUCTURES
TPF-5(372)

Investigation and Exploration

Task 3 Return on Investment Analysis

White Paper

March 2024

Version 2.0 – Final

BIM FOR BRIDGES AND STRUCTURES TPF-5(372)

Table of Contents

List of Acronyms

AASHTO	American Association of State Highway Transportation Officials
AMG	Automated Machine Guidance
BCA	Benefit-Cost Analysis
BLS	Bureau of Labor Statistics
BIM	Building Information Modeling
CBA	Cost-Benefit Analysis
CDE	Common Data Environment
COTS	Commercial Off-The-Shelf
DOT	Department of Transportation
EC	European Commission
FHWA	Federal Highway Administration
IFC	Industry Foundation Classes
ISO	International Organization for Standardization
IT	Information Technology
OMB	Office of Management and Budget
PV	Present Value
RFI	Request for Information
ROI	Return on Investment
SOC	Social Opportunity Cost
SRTP	Social Rate of Time Preference

Glossary of Terms

Base Case: In the context of a BCA, the scenario or state-of-the-world in which a project or initiative does not happen, and against which an investment case – with the project or initiative – is compared. In this paper, the base case typically assumes no BIM or no new BIM adoption.

Benefit-Cost Ratio: A measure of return on investment (ROI) used in benefit-cost analysis; the present value of total benefits divided by the present value of total costs.

Benefit-Cost Analysis: A conceptual framework that quantifies in monetary terms as many of the costs and benefits of a project or initiative as feasible. BCA helps determine whether and to what extent a project is worth investing in from a societal perspective, as opposed to a private, financial perspective. It is referred to as Cost-Benefit Analysis (CBA) in most countries other than the U.S.

Common Data Environment: The combination of a technical solution and a process that provide a centralized repository for creating, managing, and sharing project and asset information.

Discounting: A method used to convert future costs and benefits into a common year (present value) for comparison.

Discount Rate: The annual percentage change in the present value of a future dollar, or other unit of account. The discount rate used in public sector evaluations is either the Social Rate of Time Preference (SRTP) (the value society attaches to present as opposed to future consumption) or the Social Opportunity Cost (SOC) of capital (a measure of the foregone ROI in the private sector).

Domain: The specific area of practice within the Architecture and Engineering field.

End Benefit: A beneficial outcome experienced by a project or organization (e.g., cost savings) as a result of one or several intermediate benefits experienced directly by users.

Impact Pathway: A sequence of actions that lead to an outcome. Each impact pathway begins with a project-based activity (e.g., design authoring), connects to a BIM enabler (e.g., use of model-based design), identifies any immediate benefits (e.g., better visualization of the design intent) and cumulative end-benefits over the asset lifecycle (e.g., reduced costs in construction).

Intermediate Benefit: An operational improvement experienced by BIM users (e.g., better understanding of the design intent) and typically leading to an end benefit (e.g., project cost saving).

Period of Analysis: In the context of a BCA, the period (number of years) over which the benefits and costs of a project are calculated; also referred to as the appraisal period.

Present Value: The value of future costs or benefits expressed in present terms by means of discounting.

Sensitivity Analysis: A technique used to determine how changes in the value of an input variable affects the value of an output variable.

Executive Summary

The overarching objective of this paper was to support agencies in their efforts to determine whether the returns from adopting BIM for bridges justify its costs. To do so, we have addressed the following questions.

What are the benefits of using BIM? The benefits of using BIM include a large variety of effects. They are typically grouped into broad categories and/or by asset lifecycle phase. Most benefits expected to occur in the design phase are time savings, including those resulting from improved understanding of the design intent, improved communication and cooperation, faster access to information, or the ability to develop and assess design alternatives more efficiently. During construction, time savings, material savings, and other cost savings – as well as environmental, health, and safety benefits – have been documented. These would typically result from earlier access to information, improved communication between stakeholders, enhanced understanding of the project, improved safety conditions, or improved collaboration. In the post-construction phase, time savings, material savings, and other cost savings, along with health and safety benefits, and improved asset utilization are expected, as a result of earlier access to information, improved performance management, or improved asset quality. Importantly, many of the benefits realized in construction are enabled by the use of BIM in design. And while the benefits occurring post-construction are typically expected to be the largest – in part because they would be realized over an extended period of time – they are also the least well-established and documented.

What are the costs of using BIM? From the perspective of a client agency, the costs of BIM implementation are either direct or indirect. Direct costs can occur at the programmatic level, where the costs support the use of BIM across an agency's project development program, or at the project level, where the costs only support one project. Programmatic direct costs include the costs of establishing the IT business systems required to support project development (e.g., hardware, software, Common Data Environment (CDE), and training), as well as the staff or consultant costs needed to establish and support the use of BIM. Project-level direct costs include changes in staff time on BIM vs. non-BIM-based designs (i.e., development and documentation time). Indirect costs occur when participants in the Architecture, Engineering, and Construction supply chain pass on their own BIM-related costs to an agency, in the form of higher professional services costs or bid prices.

What is the ROI of BIM adoption? While many argue that the benefits of BIM during delivery have been demonstrated, this demonstration relies heavily on individual case studies, expert panels, or user surveys – as opposed to more rigorous benefit-measurement techniques (e.g., statistical comparisons of projects with and without BIM and hypotheses testing; measurement of staff time spent on BIM-related tasks). In addition, there is little tangible evidence regarding the returns to owner agencies in the long run (i.e., when considering the potential use of BIM and/or BIM-originated data in the post-construction phase, for operations, maintenance, and asset management). Finally, while case studies and survey findings can help owners appreciate the potential returns of BIM adoption, the magnitude of benefits and costs are expected to vary across projects and organizations.

What are the key determinants of BIM benefits and ROI? The realization of BIM benefits depends, crucially, on five areas of maturity: 1) Interoperability – the ability of two or more systems or organizations to exchange information and to work together towards a common goal; 2) Familiarity with BIM – the extent of BIM implementation and use within an organization (or industry), a combination of BIM capability and experience; 3) Quality Control Protocols – including clearly established BIM requirements and guidelines, standardized measures of BIM quality, and automated quality control procedures; 4) Process Improvements – the extent to which existing policies, processes, and workflows are actually improved when BIM is introduced; and 5) Adoption through the Supply Chain – the extent to which organizations along the supply chain, small or large, have access to the technology and skills required to implement BIM practices and can leverage for their own use and benefit, the information created and shared by others. Within an agency, the ability of practitioners to experience value from the use of BIM also depends on the size and complexity of projects, with larger benefits and returns expected from more complex projects. Finally, as with any other investments, the scale of the investment (e.g., number of BIM-enabling workstations, software licenses, training sessions, etc.) must be commensurate with an agency's expected needs and utilization.

Can the ROI of BIM adoption be easily quantified? Yes and no. Estimation of future, *potential* returns is possible, and relatively easy, with some of the tools reviewed in this paper. The TFRS-02 tool, in particular, produces ex-ante (i.e., prospective or before-the-fact) ROI analyses of investments in BIM and estimates potential returns from future investments based on a "benefit-transfer" approach, whereby the benefits quantified in other contexts (or intuited by subject matter experts) are applied, and scaled, to a specific agency or program. Importantly, the tool was not designed to facilitate ex-post (i.e., retrospective or after-the-fact) evaluations of ROI through the measurement of realized returns (based on observed changes in staff time, agency costs, or other outcomes), but it does provide a framework within which such measurement can be undertaken. At the core of this effort would be the definition of an adequate base case or counterfactual against which the investment case (BIM adoption) can be compared, within all major categories of benefits and costs. For example, spending on change orders for a sample of BIM projects would have to be compared to spending on change orders for a sample of otherwise similar non-BIM projects (or statistical techniques be used to account for other project attributes). In relation to investment costs, it would be critical *not* to assume that all the costs incurred in the investment case, with BIM, are new or incremental to the base case. For example, an agency may purchase software from the same vendor, under the same licensing agreement, whether they use the advanced BIM-enabling features or not.

What data is needed to estimate the ROI of BIM? The TFRS-02 tool offers two broad options for estimating, *prospectively*, the ROI of BIM adoption: 1) Default Analysis, requiring only a few user inputs and based solely on "rule-of-thumb" data, derived from benefit-transfer or expert judgment, and available within a database of suggested values; and 2) Detailed Analysis, allowing users to tailor the ROI assessment to an agency's context, but requiring a lot more user inputs and agency-specific data. In the default analysis, data on the agency program and investment costs are needed, as well as relatively simple specifications of the base case and investment case (e.g., selection of BIM use cases). The data needed to run a fully-detailed analysis are too numerous to list here. They can be grouped within three broad categories, depending on the level of effort expected for their collection : 1) Data that should be readily available from agency records and/or accounting systems (e.g., staff counts and salaries, average design contract value); 2) BIM-related data that will only become available once an agency adopts BIM practices (e.g., spending on BIM-enabling systems, initial training hours, etc.) and that may require modifications to existing data-tracking systems and processes (e.g., keeping track of BIM-related training-hours, documenting the reasons behind change orders, etc.); and 3) Data or transformed data that will only become available once sufficient evidence has been gathered on the use of BIM and that will require some form of statistical analysis and causal attribution (e.g., percent reduction in agency cost or staff time attributable to BIM). It is in the context of this third category of data that the TFRS-02 tool provides a framework within which ex-post measurements can be undertaken.

Finally, what are the practical implications of this paper, and potential next steps? This paper provided a description and a qualitative assessment of the costs and benefits to be expected from the use of BIM for Bridges, while outlining potential barriers to implementation and impediments to the realization of benefits. This assessment may be used by agencies to better understand the implications of BIM adoption and to guide efforts towards removing some of these barriers or impediments. The paper also examined a number of existing tools for use in the estimation of benefits and costs, and summarized their scope, capabilities, and data requirements, in a series of tables. This review may be used to assess "the state of the practice" for ROI measurement, and orient agencies towards using a specific tool or approach. The overall conclusion of the review, however, was that the BCA framework and spreadsheet-based tool developed under TFRS-02 was best suited to immediate applications by transportation agencies interested in assessing the ROI of BIM. The paper, next, described a number of principles for the measurement of ROI, and the need, in particular, for causal attribution and the definition of an adequate counterfactual. The idea is simple (when measuring the ROI of BIM, only consider the benefits and costs attributable to BIM), but the application of the idea can be challenging. The paper outlined a number of methods (or "things to think about") to help address this challenge. In a subsequent section, data collection needs for each of the 20 benefit streams and 15 cost categories estimated in the TFRS-02 tool were identified and categorized based on the associated level of effort. This information should provide agencies with a clearer understanding of the data they need to estimate ex-ante (or measure ex-post) the ROI of using BIM. In a last section, the paper provided answers to five commonly asked questions about the ROI of BIM. Some of these answers – and associated recommendations – may have direct implications on the ROI analyses completed by, or on behalf of owner-agencies (e.g., selection of period of analysis and discount rate; need for sensitivity analysis).

Finally, as outlined in the core of the report, the next steps for data collection towards ROI measurement could be as follows.

1) Prioritize data collection needs based on the expected magnitude of benefits and costs and/or the quantity and quality of the supporting evidence currently available within the TFRS-02 tool.
2) For each benefit and cost category selected in Step 1, define an adequate counterfactual and basis for comparison, including the specific processes and technologies used in the absence of BIM.
3) Using the information in this report, determine data needs based on the specific metrics used within the tool to calculate the benefits and costs selected in Step 1.

4) Assess existing data collection efforts and determine whether some of the data identified in Step 3 are currently available within the agency.
5) Identify outstanding data collection needs and determine how the data will be collected and by whom.
6) Initiate data collection, and proceed with data processing and analysis as the data come in.

1. Introduction

What is BIM?

Building Information Modeling (BIM) is best understood as a collaborative working method centered around the digital representation of an asset. That representation – a 3D model or a combination of models – can be shared across multiple stakeholders and used and re-used throughout the asset lifecycle.[1,2] Importantly, BIM is not simply about developing a model. BIM is not a single tool or technology; BIM is a set of technologies, processes, and policies that allow stakeholders to create and manage the production and use of information to perform a broad range of tasks. As noted by FHWA, BIM *"makes it easier […] to generate asset information and distribute it to anyone who needs it, when they need it."*

BIM can be scaled to fit the degree to which information is shared across teams and the scope of the intended uses for BIM. For example, BIM use can be limited to activities within the design and/or construction phases only, or BIM can be used within and across all phases, including maintenance and operations. There are also different degrees of interoperability between different software products used in the BIM process. BIM can be applied within a single software ecosystem with proprietary file formats for data exchange. Alternately, BIM can embrace open data formats (e.g., Industry Foundation Classes or IFC), enabling participants to use different software products to produce data in a format that is durable and accessible.

BIM involves the use of a digital, object-oriented model to store and extract information about a facility. Typically, BIM is initiated during the planning and design phases, with the goal of supporting the construction process. BIM can extend beyond construction, with an update at the end of construction to reflect as-built conditions. In some cases, the as-built model has been connected to an asset management system and the model used to visualize the facility in preparation for maintenance activities. However, in the transportation domain, where assets are more commonly managed in geographic information systems (GIS), information is exported from the as-built model to update the GIS data layers. The model can then be used during subsequent phases, including maintenance and operations, with occasional updates based on data captured during site visits or inspections.[3]

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[1] (Mitchell, Williges, & Messner, 2022; Messner, et al., 2021)

[2] ISO 19650-1:2018 defines BIM as "*the use of a shared digital representation of a built asset to facilitate design, construction, and operation processes to form a reliable basis for decisions.*"

[3] The concepts of "digital shadow" and "digital twin" are often associated with BIM. A digital model becomes a digital shadow if it is updated in real time, through automated data transfers from the physical asset to its digital representation. A digital shadow becomes a digital twin when automated data transfers occur in both directions and are used to monitor asset performance and optimize operations – through sensors, Internet-of-Things connections, and Artificial Intelligence technology. Digital twins are common in manufacturing and hold great promises for infrastructure.

BIM for Bridges

BIM originated and is now commonly used in the (vertical) building sector of the construction industry. Compared to other types of infrastructure assets, bridges have more in common with vertical construction assets. The two share common materials (e.g., steel, concrete) and elements (e.g., beams, columns, slabs, reinforcement). For this reason, the IFC standard has been extended most comprehensively for bridges compared to other infrastructure asset classes. The potential to use the IFC open data standard for bridges in the near term places the bridge industry on the verge of unlocking the benefits of using BIM in construction and beyond.

However, there are several barriers to implementing BIM, including:

- The cost of software and hardware,
- The high cost of training on the BIM-supportive software tools,
- Lack of depth of skills and knowledge of BIM,
- Lack of expertise using BIM,
- A current shortage of software with adequate features, and
- Lack of support from governments.[4]

In the same vein, a 2018 report on the benefits of BIM prepared by PWC[5] highlights multiple challenges, including:

- Large upfront costs,
- Misaligned incentives – as the benefits of BIM do not always accrue to those who pay for its implementation, in particular when benefits are realized later in the asset lifecycle, and
- A lack of hard evidence and broadly-accepted practical guidance on the measurement of benefits, making it difficult for organizations to demonstrate the value of BIM investments.

There is also an issue with the relative timing of benefits and costs. Thus, in stakeholder interviews across Europe, most respondents agreed that there are only a few or no benefits at the beginning of BIM adoption. This was explained by the high costs of BIM implementation, low productivity and additional efforts required initially (during the learning phase), a need for specialized knowledge and expertise, and interoperability issues.

The barriers to implementing BIM for bridges therefore fall into two categories:

- Low maturity and penetration in the supply chain (e.g., lack of fully featured software, cost of training, lack of skilled personnel, lack of expertise and experience, upfront costs); and

[4] (Mitchell, Williges, & Messner, Lifecycle Building Information Modeling for Infrastructure: A Business Case for Project Delivery and Asset Management, 2022)

[5] (PricewaterhouseCoopers LLP, 2018)

- Institutional barriers (e.g., lack of support from owners, misaligned incentives, delayed realization of benefits).

The delayed realization of benefits is a cause for concern, in particular when decision-makers insist on seeing positive returns before committing to additional investments. For owners, the issue is compounded by the need to maintain legacy systems for the management of pre-BIM-built assets,[6] or for the delivery of smaller projects for which the use of BIM is not warranted. Finally, it is important to note that two factors mitigate the institutional barriers: the availability of the open IFC format and increased BIM maturity throughout the supply chain.

Return on Investment of BIM Adoption

So what is the Return on Investment (ROI) of BIM adoption? The short answer is *"we don't really know."* There is little tangible evidence regarding the returns to owner agencies in the long run, when considering the potential use of BIM and/or BIM-originated data in the post-construction phase, for operations, maintenance, and asset management.

While many argue that the benefits of BIM *during delivery* have been demonstrated, this demonstration relies heavily on individual case studies, expert panels, or user surveys – as opposed to more rigorous benefit-measurement techniques (e.g., comparison of several BIM projects to a "control group" of similar projects without BIM). The demonstration is even weaker for the benefits (and returns) realized specifically by owner agencies, as it often relies on optimistic – but not necessarily unrealistic – assumptions on the extent to which cost savings occurring in the first instance within the supply chain would be passed on to owners in the form of lower fees.

The benefits realized during the post-construction phase, are generally not measured in ROI assessments.[7] And while two of the studies reviewed for this paper provided an approach to quantify the benefits of BIM post-delivery, there is limited evidence to support this quantification. With respect to implementation costs, the direct costs of BIM adoption – including initial and recurring investments in hardware, software, and training – are relatively easy to quantify and are generally considered in ROI case studies. On the other hand, the costs of changing workflows, improving processes, developing open standards, and other aspects of BIM maturity (e.g., enhanced quality controls) are more difficult to quantify and are generally not covered in the literature.

Interoperability is an important consideration because many of the benefit streams require the information from BIM to be used many times over the asset lifecycle. It is possible to have interoperability for a limited period of time, such as during the preconstruction and construction phases of a project, by rigidly using products from a single software vendor ecosystem. Creating interoperability through the use of open standards, however, lowers the external costs to the supply chain, which increases participation and competition. Open data also remains accessible over time as software

[6] Discussions with members of the TPF-5(372) Working Group.
[7] One notable exception is the Denver International Airport case study presented in the TFRS-02 report.

evolves. Interoperability through open standards, therefore, is an important enabler and enhancer of BIM benefits.

Importantly, interoperability is not just a technical issue, but also an organizational concern. In order for the technical solution for interoperability to succeed, the parties must implicitly value interoperability and must have aligned technological capabilities, protocols, processes, and quality management procedures. These softer elements of interoperability are difficult to measure objectively.

Finally, while ROI case studies and survey findings can help owners appreciate the potential returns of BIM adoption, the magnitude of benefits and costs are expected to vary greatly across organizations and projects. Thus, the size and complexity of projects are important factors in the ability of practitioners to experience value from the use of BIM; and so are internal agency capabilities and general familiarity with BIM.

Objectives of this Paper

Despite the many limitations highlighted so far, considerable progress has been achieved in the estimation of returns from BIM adoption, most notably with the benefits-measurement methodology introduced by PWC in 2018, and with the ROI framework and tool developed under the TFRS-02 research project.[8] While the former only provides a methodological framework, albeit very detailed – along with instructions on how to populate it through various data collection and analytical efforts – the latter also includes an extensive database of input values which can be used in the calculation of (some) benefits and costs in the absence of agency-specific data. This database, however, relies exclusively on existing case studies, expert panels, and technical reports, and is therefore only as robust and accurate as the source material.

In addition, most of these new resources – and the TFRS-02 tool in particular – were not specifically designed to measure, retrospectively, the impacts of BIM on agency costs or staff time, but rather to estimate, prospectively, the ROI to be expected from the adoption of BIM given what has been observed elsewhere, in other contexts (e.g., case studies) or what BIM practitioners and subject matter experts believe they might be.[9] As noted earlier, for benefits realized post-construction, there is simply not enough evidence to draw from, in particular in the transportation industry. And because BIM implementation for large institutional owners is only nascent, documented ROI from owners who have implemented BIM is also limited.

The overarching objective of this paper, therefore, is to support transportation agencies in their efforts to determine whether the returns from adopting BIM for bridges justify its costs. This involves: 1)

[8] As explained in the core of the report, the TFRS-02 tool was designed specifically for assessing investments in BIM for infrastructure from the perspective of owner agencies.

[9] A combination of ex-post and ex-ante benefits valuation is also possible, as in the case studies summarized in PWC (2018): *"These benefit estimates include ex-post estimates of benefits already realized from the application of BIM, and ex-ante estimates of benefits that are expected to be realized in future stages of the asset lifecycle because of the use of BIM."*

understanding the nature of the benefits and costs expected from BIM; 2) reviewing the tools currently available to quantify these benefits and costs; and 3) determining what data and evidence should be collected to support this quantification.

Structure of this Paper

This paper is comprised of six main sections and two technical appendices. After this introductory section, Section 2 provides a qualitative assessment of the benefits and costs of using BIM. The section relies heavily on findings reported in the literature. Section 3 includes an overview of existing tools and resources available for the quantification of benefits and costs. Section 4 identifies the specific data needed to estimate the ROI of using BIM for bridges with one of the existing tools. Section 5 addresses a number of methodological issues related to ROI measurement. Section 6 concludes with a summary of findings and a brief agenda for future research. Appendix I provides additional information on the methods used in the TFRS-02 ROI tool and the associated data collection needs. Appendix II summarizes, in tables, the data required to populate all five tools reviewed for this paper.

2. Costs and Benefits of Using BIM for Bridges

This section provides a qualitative assessment of the benefits of using BIM at various stages of an asset lifecycle. Benefits and costs are described from the perspective of the owner agency, and include both direct and indirect effects (i.e., those accruing in the first instance to supply chain partners, but eventually passed on to the agency through changes in fees).

An important source of information for this section, and for other parts of this report, is the study prepared under the Cooperative Research Program (CRP) Project TFRS-02 of the Transportation Research Board, *Lifecycle Building Information Modeling for Infrastructure: A Business Case for Project Delivery and Asset Management.*[10] The primary objective of that study was to evaluate the business case for BIM adoption by highway agencies in the United States, while considering the benefits and costs of using BIM throughout a project lifecycle, including for maintenance and operations. The study was completed in two phases. In Phase 1, the research team conducted a review of the literature, developed an initial business case methodology, and identified organizations that could participate in case studies. In Phase 2, the team completed case studies, refined the methodology, developed a tool to estimate the ROI of BIM adoption, drafted recommendations for BIM implementation to support asset data management, and produced a multi-media package to communicate the benefits of BIM to decision makers. All the products from that study are available on the website of the National Academies of Sciences, Engineering, and Medicine.[11]

BIM Use Cases

The benefits and costs of using BIM arise through the adoption of individual use cases. A BIM use case is best understood as a method of applying BIM during an activity in the asset lifecycle to achieve one or more specific objectives.[12] Examples of use cases include documenting existing conditions, authoring a design, and developing quantity and cost estimates.[13]

The definition of use cases facilitates and enhances the measurement of ROI. Use cases can be tied to specific activities, enabling BIM technologies and processes, and eventually agency benefits and other outcomes. They are essentially the “building blocks” of BIM capabilities and use value. In addition, in the early stages of BIM implementation, it is common for agencies to adopt only a few use cases for which they may need to assess the financial returns before committing to further investment.

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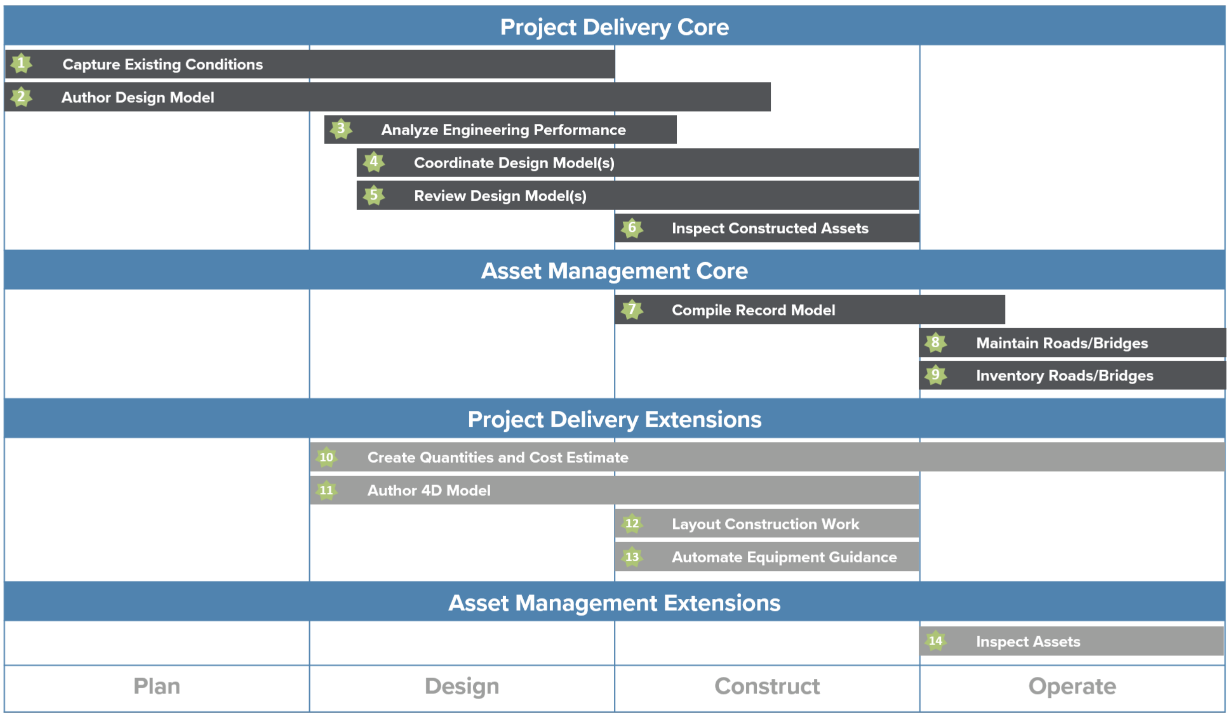
[10] The research was performed by HDR; Pennsylvania State University; Weris, Inc.; and Dr. Fernanda Leite. It is referenced herein as (Mitchell, Williges, & Messner, 2022) and referred to in the text as the TFRS-02 report.
[11] The final version of the study, published as CRP Special Release 4 and dated 2023, is available at https://nap.nationalacademies.org/catalog/26731/lifecycle-bim-for-infrastructure-a-business-case-for-project-delivery-and-asset-management, last accessed 03/19/2024
[12] (Messner et al. 2020)
[13] The upcoming fourth version of the National BIM Standard (developed by the BIM Council of the National Institute of Building Sciences) provides a robust standard for defining a BIM use case.

The TFRS-02 report illustrated the typical BIM use cases for highway and bridge assets in Figure 1 reproduced below. In the figure, the use cases are divided into four categories (project delivery core, asset management core, project delivery extensions, and asset management extensions) and mapped against four lifecycle phases (plan, design, construct, and operate).[14]

Figure 1: Use Cases for BIM over an Asset Lifecycle



Source: Mitchell, Williges, & Messner (2022)

Benefits of Using BIM

The benefits of using BIM encompass a large variety of effects, direct or indirect, tangible or intangible, and accruing to different parties (e.g., owners, designers, contractors, asset users). Adding to this complexity is the often noted disconnect between the time a benefit is enabled (i.e., made possible for future realization) through the use of BIM, and the time it is actually realized, in the form of productivity gains or project cost savings.

Another source of confusion is the distinction between intermediate benefits and end benefits, with the former referring to operational improvements experienced by a BIM practitioner (as a direct result of using BIM), and the latter to beneficial outcomes experienced by an organization, as a result of one or several intermediate benefit(s). Examples of intermediate and end benefits include: 1) easier coordination of design and construction (intermediate) and time savings in design (end); 2) improved

[14] (Mitchell, Williges, & Messner, 2022)

accuracy in materials procurement (intermediate) and environmental benefits from fewer materials used (end); or 3) better understanding of construction operations (intermediate) and improved health and safety in construction (end).

For the purposes of analysis and presentation, the benefits of adopting BIM are typically grouped into broad categories (e.g., time savings, cost savings, environmental benefits) or by asset lifecycle phase.

BIM Benefits by Category

The benefits of BIM can be organized and presented in many different ways. The UK BIM Benefits Measurement Methodology developed by PWC and described in Section 3, for example, identified a total of 117 “impact pathways” grouped into 22 high-level “benefit areas” and eight “measurement categories” (namely, time savings, material savings, cost savings, improved health and safety, reduced risk, improved asset utilization, improved asset quality for end-users, and improved reputation). In contrast, the TFRS-02 report and tool identified 24 benefit streams organized into four main categories – namely, in-house agency benefits (e.g., cost savings from reduced paper use), project cost savings (e.g., avoided change orders), staff time savings (e.g., avoided Requests for Information (RFIs), efficiencies in information retrieval), and benefits to asset users (e.g., time savings from reduced construction road closures) – while the European Commission (EC) Cost-Benefit Analysis (CBA) tool recognized 8 major benefit streams.

For the purpose of this section, the benefits of BIM are organized into seven of the eight categories introduced in the PWC study.[15]

1. **Time Savings**. Time savings accrue directly to agency staff or are realized on projects, through enhanced performance and utilization. As discussed further below, many of the time savings are deferred. Investments in BIM during the design phase, for example, may result in time savings in construction, when the information is actually used. Some design-phase benefits include: 1) efficiency in design development as parametric design propagates changes through the design documents, and 2) faster document review and approval.[16] One of the main enablers of time savings is that BIM makes it easier to manage the vast and complex information needed to support and administer construction, creating efficiency through the reduced reliance on manual information management, particularly the curation of information for exchange.[17] Construction-phase time savings are also observed as schedule compression.[18]

[15] The classification developed for the PWC study is used here as it is both comprehensive and logical. In the PWC study, however, improved reputation and reduced risk (or variance) are presented as two separate measurement categories. We have combined them here into a single “Other Benefits” category, resulting in a total of seven categories, instead of eight in the original study.

[16] (Mitchell, et al., 2021)

[17] (Enshassi, Al Hallaq, & Tayeh, 2019)

[18] (European Commission, Executive Agency for Small and Medium-sized Enterprises, 2021)

2. **Cost Savings.** Agencies benefit from internal cost savings (e.g., reduced physical storage and office space needs, lower inspection costs from the use of unmanned aerial vehicles), as well as project cost savings (e.g., improved schedule management, and optimized material usage).[19] Indirect cost savings also occur as cost avoidance (e.g., by avoiding change orders, errors, incidents, or claims and litigation).[20]

3. **Material Savings**. Material savings arise from more refined designs and construction planning. For example, clash detection algorithms and the ability to coordinate designs with other disciplines using models provided by other disciplines as background references during design to help avoid material losses and/or re-work.[21] But the most frequently noted material savings accruing *directly* to agencies is the reduced use and storage of paper.[22]

4. **Environmental Benefits**. Environmental cost savings arise from improved public engagement (and the enhanced ability to identify resources at risk and suitable mitigation strategies), as well reduced emissions from construction material savings and schedule compression (e.g., fewer tailpipe emissions from construction vehicles and/or due to delay- or detour-inducing lane closures).[23]

5. **Improved Asset Utilization**. Benefits in this category include the increased utilization of Information Technology (IT) assets, data assets, and roadway system assets (e.g., fewer and/or shorter lane closures) as a result of improved construction planning and shorter construction schedules.[24]

6. **Health & Safety Benefits**. Benefits in this category include hazard avoidance and improved risk mitigation through visual construction planning and enhanced staff briefing and training. Secondary benefits include fewer work-zone crashes for the general public, and reduced traffic exposure for workers.[25] Exposure can be reduced as a result of compressed construction schedules, or through construction automation and offsite fabrication enabled by suitable data.

7. **Other Benefits** include reduced variance and improved reputation. Reduced variance arises from improved risk mitigation, clearer communication of the design intent, improved design quality, more consistent data, and more precise quantity take-offs.[26, 27] Improved reputation results from greater cooperation, improved interdisciplinary coordination, faster responses to RFIs and other approvals,

[19] (Mitchell, et al., 2021; Shim & Roh, 2021)
[20] (Samimpay & Saghatforoush, 2020)
[21] (Samimpay & Saghatforoush, 2020; Enshassi, Al Hallaq, & Tayeh, 2019)
[22] (Mitchell, et al., 2021)
[23] (Mitchell, et al., 2021; European Commission, Executive Agency for Small and Medium-sized Enterprises, 2021)
[24] (Samimpay & Saghatforoush, 2020; Mitchell, et al., 2021)
[25] (Mitchell, et al., 2021)
[26] (Samimpay & Saghatforoush, 2020; Mitchell, et al., 2019; European Commission, Executive Agency for Small and Medium-sized Enterprises, 2021)
[27] In (Mitchell, et al., 2019), the reduced variance benefit was quantified using statistical analysis, which demonstrated that projects with 3D models provided to the contractor had the award price trending closer to the engineer's estimate, and the final price trending closer to the award price.

reduced impact on adjacent land uses, and improved customer service (e.g., faster execution of maintenance actions).[28]

There is no readily available information on the distribution of BIM benefits across these seven categories, but most are expected to materialize as either time, material, or cost savings.[29]

On a related note, the top perceived benefits of BIM (intermediate or final) were identified through a large survey of industry participants by Dodge Data & Analytics (2017).[30] In that survey, the benefits were split between two broad categories: 1) internal business benefits, from the perspective of engineering firms and contractors; and 2) project-related benefits.[31] The internal business benefits with the highest ratings in the U.S. (i.e., reported most frequently as being "experienced at a high or very high level" by BIM users) were: Improved ability to show younger staff how projects are constructed; Offering new services; Maintaining repeat business with past clients; Fewer claims or litigation; Recruiting and retention of staff; and Increased profits. More relevant to a state agency perhaps, the top project-related benefits were identified and ranked as follows by survey participants:[32]

- Reduced conflicts, field coordination problems and changes during construction,
- Better multiparty communication and understanding from 3D visualization,
- Reduced errors and omissions in construction documents,
- Reduced construction cost,
- Reduced rework,
- Greater client and/or community engagement, and
- Reduced overall project duration.[33]

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[28] (PricewaterhouseCoopers LLP, 2018)

[29] The PWC study found that over 80% of benefits fell into the categories of time, material, or cost savings. These three categories of benefits are also predominantly represented in the case studies and examples of quantification reviewed for this report.

[30] The Dodge Data & Analytics survey was conducted online between October 2016 and February 2017. It included a series of questions on BIM use in the transportation infrastructure industry, and on the (perceived) benefits and business value of BIM. A total of 368 design and construction professionals responded to the survey, including 33 owners, 153 engineers, and 182 contractors distributed across four countries (the U.S., France, Germany, and the UK). There were 123 respondents in the U.S., including 26 owners, 35 engineers, and 62 contractors.

[31] Described as "project process and outcome benefits" in the Dodge Data & Analytics report.

[32] Respondents were asked to identify their top-three project-related benefits from a list of thirteen. The list shown here (and in the Dodge Data & Analytics report, page 19) only includes the benefits selected by 20 percent or more of the respondents. The ranking reflects the frequency with which the benefits were selected, not their relative magnitude.

[33] The report also identifies how the two final benefits in the list (i.e., reduced construction cost and project duration) would come about, namely through improved staff performance/efficiency/competence; improved planning/programming (leading to construction cost savings); faster coordination/better communication; speed of design/installation; and improved organization/simplified procedures. But it is not entirely clear why these, and no other intermediate benefits in the list, would result in project cost and/or time savings.

BIM Benefits by Lifecycle Phase

Many of the benefits of BIM result from its application in an earlier phase of the asset lifecycle. For example, the application of clash detection during design helps detect interferences and errors, resulting in cost savings in construction. In the same vein, the realization of benefits in asset management is predicated on the collection of detailed as-built information at the end of construction. Below is a brief overview of the benefits to be expected within each phase.

- **Design Phase**. Most benefits expected to occur in design are time savings, including those resulting from improved understanding of the design intent, improved communication and cooperation, faster access to information, or the ability to develop and assess design alternatives more efficiently. In the transition between design and construction (i.e., during pre-construction), additional time savings are expected, in particular through earlier access to information, improved communication between stakeholders, enhanced understanding of the project, and improved collaboration.

- **Construction Phase**. During construction, time savings, material savings, and other cost savings – as well as environmental, health, and safety benefits – have been documented,[34] or postulated. These would typically result from earlier access to information, improved communication between stakeholders, enhanced understanding of the project, improved safety conditions, improved risk management, or improved collaboration. As noted above, many of the benefits realized in construction are enabled by the use of BIM during design.

- **Operation Phase**. Time savings, material savings, and other cost savings, along with health and safety benefits, and improved asset utilization are expected as a result of earlier access to information, improved emergency preparedness, improved asset quality, or improved performance management. Benefits in this phase are typically expected to be the largest, in part because they would be realized repeatedly over a long period of time, over the asset or information lifecycle (whichever is shorter).

For additional information on the benefits of BIM adoption, Appendix II at the end of this paper, includes a complete listing of the benefit streams considered in the five tools reviewed herein.

Costs of BIM Implementation

From the perspective of a client agency, the costs of BIM implementation are either direct or indirect. Direct costs can occur at the programmatic level, where the costs support the use of BIM across an agency's project development program, or at the project level, where the costs only support one project. Indirect costs occur when participants in the Architecture, Engineering, and Construction supply chain pass on their own BIM-related costs to an agency, in the form of higher professional services costs or bid prices.

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[34] A review of the literature on the benefits of BIM in project delivery (design and construction) can be found in Chapter 2, Section 2.3.1.3, of the TFRS-02 report (Mitchell, Williges, & Messner, 2022)

Programmatic Direct Costs

Programmatic direct costs include the costs of establishing the IT business systems required to support project development (i.e., hardware, software, and training),[35] as well as the staff or consultant costs needed to establish and support the use of BIM (e.g., process improvements, development of standards and guidelines, customization of workspaces). Some programmatic costs are one-off, representing an initial, upfront investment, while others are recurring. Some recurring costs are cyclical, with different return periods (e.g., hardware replacements, software license agreements), while others are sporadic (e.g., updates following the release of new software versions).

Project-Level Direct Costs

Project-level direct costs include changes in staff time on BIM vs. non-BIM-based designs (i.e., development and documentation time).[36] For consultant-designed projects, these can be discerned as increases in the average cost of professional services contracts with BIM requirements (i.e., borne indirectly). On a construction project, the use of BIM may change the means and methods of executing construction work and inspection tasks. These new methods may result in additional costs for data preparation, and in time savings when executing the work. Again, agencies may perceive these cost increases indirectly, but the cost of requiring a digital as-built deliverable, for example, can typically be isolated.

Indirect Costs

Indirect costs, as noted above, manifest themselves as higher professional services costs or bid prices. These costs are generally not quantified in the literature. One exception is the Michigan Department of Transportation (DOT) study reviewed in Section 3. Two indirect costs were considered in that study, both in the form of increased professional services costs – one for design, and the other for construction engineering and inspection.

In terms of relative magnitude within the infrastructure industry, the survey data reported in Dodge Data & Analytics (2017) suggest that training, software, and process-improvement costs are currently among the most significant. The full ranking is as follows. It is based on the percent of respondents identifying a cost item among their top-3 BIM-related investments.[37]

- Staff training, 36%
- Software that supports BIM, 29%
- Developing internal collaborative BIM workflows, 25%

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[35] Some of these costs support business functions as a whole and are not specifically related to the use of BIM. Even some BIM-related software costs may not be wholly attributable to BIM adoption, if for instance, the BIM software replaced non-BIM software used to execute the same function (e.g., design authoring and documentation).

[36] In many ROI frameworks, changes in staff time would be reported as a benefit, not a cost. Increases in staff time would be reported as a negative benefit.

[37] Based on a sample of 368 respondents in the US, UK, France, and Germany, including 33 owners, 153 engineers, and 182 contractors.

- Developing collaborative BIM processes with external parties, 21%
- Software customization and interoperability solutions, 20%
- Strategic BIM program deployment, 17%
- New or upgraded hardware, 17%
- Marketing of BIM capability, 17%

For an additional perspective on the costs of BIM implementation, the full set of cost items considered in the tools reviewed in Section 3 can be found in Appendix II.

3. Review of Existing Tools

This section provides an overview of existing resources and tools available for the estimation of benefits and costs, and for the calculation of ROI. Importantly, these tools were not designed with the intent to measure, after the fact, the impacts of BIM on projects costs or staff time, with quasi-experimental data or observations (see Causal Attribution of Benefits and Costs in Section 4). Rather, for all but one tool, the primary objective is to estimate (i.e., calculate approximately) the future expected benefits and costs of BIM adoption, for a project or agency, based on user-specified project and/or agency attributes, and with input values on the expected changes in costs, staff time, etc. brought about by BIM adoption. These assumptions, in turn, were typically derived from a mix of expert judgement, case studies, and technical reports, and – in some tools – can be overridden with user-entered, context-specific values.

Five tools were reviewed for the purpose of this paper:[38]

1) **UK BIM Benefits Measurement Methodology** – a comprehensive framework and methodology for measuring the benefits of delivering projects with BIM Level 2,[39] based on the impact pathway approach, and with a focus on project-level benefits to asset owners in the public sector.
2) **Cooperative Research Programs, Project TFRS-02, Lifecycle BIM for Infrastructure** – a research report and a spreadsheet-based ROI tool to evaluate the business case of transitioning to BIM practices in project delivery and asset management, from the perspective of transportation agencies, with a focus on program-level benefits and costs to the public sector.
3) **European Commission, Methodology for Cost-Benefit Analysis for the Use of BIM in Public Tenders** – a methodology handbook and a spreadsheet-based tool for measuring the benefits and costs of using BIM in public construction projects, from the perspective of EU public clients.
4) **FHWA, ROI for Paperless Project Delivery** – a research report and a spreadsheet-based tool for assessing the economic feasibility of various e-Construction improvement opportunities, from the perspective of state transportation agencies.
5) **Michigan DOT, 3D Highway Design Model Cost-Benefit Analysis** – a research report (including a statistical analysis of historical project-level cost data) and a spreadsheet-based template to assess the ROI of investing in 3D engineering models, from the perspective of the Michigan DOT, but with potential applications in other states.

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[38] These five tools were developed respectively by: 1) PricewaterhouseCoopers; 2) HDR, Pennsylvania State University, Weris Inc., and Fernanda Leite; 3) RINA and B1P Group; 4) WSP|Parsons Brinckerhoff; and 5) WSP Michigan Inc.

[39] The definition of BIM Level 2 used in the PWC study is based on Publicly Available Specification (PAS) 1192-2:2013: “a process of managing information throughout the lifecycle of a built asset, with key features including the definition of information requirements by the client; the use of a collaborative Common Data Environment; and the use of 3D modelling in design, capturing both geometric and non-graphical data.” This Publicly Available Specification has been retired and replaced with ISO 19650.

Summary information on these tools can be found in Table 1 starting on the next page, including an overview of the tool's purpose and scope, approach, duration – in years – of the period of analysis (over which benefits and costs are estimated), and ROI metric, as well as other information considered relevant for this paper.

Additional information – including the full lists of benefits and costs, along with the associated data requirements – can be found in Appendix II at the end of this paper.

Table 1. Summary of Findings from the Review of Existing Tools

Resource	Work Products	Description
1) UK BIM Benefits Measurement Methodology, 2018	Detailed guidelines (PDF documents), no tool	▪ **Overview:** Project-level assessment of the benefits of "BIM Level 2",[40] across eight stages of an asset lifecycle. Also applicable at program or organizational level. ▪ **Approach:** Impact pathway approach, with 117 individual pathways, grouped within 22 high-level benefit areas and 8 measurement categories. Costs not considered at all; beneficiaries not identified. ▪ **Horizon:** Not specified, but framework considers full asset lifecycle, from "Strategy" to "Operation and end of life."[41] ▪ **ROI Metric:** Not specified (measurement of benefits only) ▪ **Other:** Large set of equations, with only a few suggested values (e.g., UK governmental guidance for monetization and discounting[42])
2) Lifecycle BIM for Infrastructure, TFRS-02 Tool, 2022	Research report, benefit-cost analysis (BCA) framework and spreadsheet-based tool	▪ **Overview:** Program-level assessment, based on BCA methodology ▪ **Approach:** Investment Case compared to Base Case, where both can be defined in relation to one of four BIM capability stages. Costs and benefits associated with 14 BIM use cases. 24 benefit categories (6 in-house agency benefits, 5 project cost savings, 9 staff time savings, and 4 user benefits); 15 cost categories (4 initial, 11 ongoing). ▪ **Horizon:** User-specified, up to 50 years (10 years, suggested) ▪ **ROI Metric:** Benefit-Cost Ratio, calculated as Total Benefits over Total Costs, with discounting (4% real, suggested)

[40] The definition of BIM Level 2 used in the study is based on Publicly Available Specification (PAS) 1192-2:2013: "a process of managing information throughout the lifecycle of a built asset, with key features including the definition of information requirements by the client; the use of a collaborative Common Data Environment; and the use of 3D modelling in design, capturing both geometric and non-graphical data." This PAS has been retired and replaced with ISO 19650.

[41] In case studies, project-specific periods of analysis were used: 13.5 years for the refurbishment of an office building (based on lease duration); and 25 years for the upgrade of a flood barrier and pumping site (based on the average design life of various mechanical and electrical components).

[42] The Green Book (a guidance document issued by the UK Treasury department) recommends the use of a social discount rate of 3.5% for 30-year appraisals, and a reduced rate for the very long term: 3.0% (for benefits and costs occurring) in years 31-75 and 2.5% in years 76-125.

Resource	Work Products	Description
		▪ **Other:** Look-up tables providing suggested values for benefits and costs based on research from case studies, expert panels, and technical reports, with ability to override with agency-specific data
3) Cost-Benefit Analysis Model for the Use of BIM in Public Tenders, 2021	Methodology handbook and spreadsheet-based tool, including 6 case studies (building & infrastructure)	▪ **Overview:** Ex-ante project-level assessment, relying heavily on preliminary established values ▪ **Approach:** 8 benefit categories (including cost reductions, time savings and emission cost savings); 9 cost categories (including lower productivity and additional efforts required, and BIM-related investment costs allocated to specific project) ▪ **Horizon:** Up to 35 years, with allocation of costs and benefits to one of three project phases: planning and design (up to 5 years), construction (10 years), and operation and maintenance (20 years) ▪ **ROI Metric:** Benefit-Cost Ratio, calculated as Total Benefits over Total Costs, with discounting (4% nominal, 2% inflation) ▪ **Other:** Database of pre-established values for benefits and costs based on survey results (122 completed questionnaires, by associations, state & local authorities, research institutes, state-owned companies, and universities), included within tool
4) Addressing the Challenge and the Return on Investment for Paperless Project Delivery, 2017	Technical report, spreadsheet-based tool, and one case study	▪ **Overview:** Program-level assessment of ROI to state agencies of implementing e-Construction solutions (e.g., electronic bidding and contract award; digital plans and estimates; digital review of documents; mobile devices; etc.) ▪ **Approach:** 31 benefit categories across 8 applications; up to 14 cost categories (including pre-implementation planning, hardware and software, systems integration, and agency staff time) ▪ **Horizon:** 7 years ▪ **ROI Metric:** Net Benefit Margin, calculated as (Total Benefits – Total Costs) / Total Costs, without discounting ▪ **Other:** Estimates based on size of construction programs (2015) and various assumptions and benchmark data
5) 3D Highway Design Model Cost Benefit Analysis, 2019	Research report and spreadsheet-based template for ROI calculations	▪ **Overview:** Program-level assessment of ROI from investing in 3D engineered models ▪ **Approach:** Quantification of one benefit stream (reduction of change orders due to quantity deviations and errors and omissions) and two cost categories (additional cost to produce 3D models, staff needed for technical support) ▪ **Horizon:** 5 years ▪ **ROI Metric:** Net Benefit Margin, calculated as (Total Benefits – Total Costs) / Total Costs ▪ **Other:** Additional benefits and costs identified in report, including savings from lower bids (due to low bidder using Automated Machine Guidance (AMG))

Other benefits measurement resources were recently reviewed by the Centre for Digital Built Britain (CDBB) in the UK. The review included industry workshops, interviews with subject matter experts, an online survey of nearly 200 industry participants, and the evaluation and testing of three online tools:

1) **Scottish Futures Trust, BIM ROI Tool** – an online tool and dashboard for quantifying the ROI of implementing BIM Level 2 at the project level. The site also lets users complete a qualitative assessment of BIM benefits (https://bimroi.scottishfuturestrust.org.uk).

2) **NATSPEC and the Sustainable Built Environment National Research Centre, BIM Value**: an online, interactive guidance document to help identify and understand the benefits of BIM, for use by a broad range of industry practitioners (i.e., owners, design firms, contractors, etc.). The site provides detailed definitions of potential BIM benefits, along with quantitative examples and supporting references (https://bimvaluetool.natspec.org/).

3) **University of Cambridge, BIM Benefits:** an online benefits-measurement tool based on the UK BIM Benefits Measurement Methodology (not available at the time of this paper).[43]

In their review, CDBB expressed skepticism in the accuracy of the benefits produced by existing tools.[44] Reasons for this skepticism included the lack of benchmarking data, the reliance of estimates on the knowledge of users entering the data, the likelihood of double-counting, or the exploration of anecdotal rather than tangible benefits. The centre also noted that existing tools were most often used to assess individual organizations and top-tier suppliers (e.g., large contractors or consulting firms), instead of looking at digital transformation and capabilities within the supply chain as a whole (see Section 5).

Overall, we believe that the BCA framework and spreadsheet-based tool developed under TFRS-02 is best suited to immediate applications by, or on behalf of, U.S. transportation agencies interested in assessing the ROI of BIM for bridges. It is also well suited to guide future data collection efforts.

We have reached this conclusion based on the following considerations.

- Unlike any of the other tools reviewed, the TFRS-02 tool was designed specifically for assessing investments in BIM for infrastructure from the perspective of owner agencies in the United States.
- The tool includes a database of pre-established values which can be used to derive sketch-level estimates of program-level ROI, with only limited agency-specific data.
- The database was developed through an extensive review of the literature, including technical reports and case studies, and through discussions with subject matter experts.
- The framework is based on BCA principles and defines ROI as the ratio of total discounted benefits to total discounted costs, which is considered best practice for decision-support in the public sector.

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[43] The Centre for Digital Built Britain, at the University of Cambridge, completed its five-year mission and closed its doors at the end of September 2022, https://www.cdbb.cam.ac.uk/, last accessed 03/14/2024.
[44] CDBB also found that benefits measurement tools are not commonly used: only 16% of the survey respondents indicated that they use a tool to measure benefits, 35% that they measure benefits without a tool, and 49% that they don't measure benefits at all. 77% of respondents agreed that there was a need for better tools.

- The tool, a Microsoft Excel workbook, is well structured and relatively easy to use and update. Instructions for how to use it and to explain the contents of the workbook can be found in a user guide available online.[45]

A trial run of the TFRS-02 tool was recently completed by the Washington State Department of Transportation (WSDOT) to help assess the (economic) feasibility of BIM implementation. During that study, the agency worked with the tool's developers to specify input values and to customize the tool to WSDOT's implementation program. All the final assumptions and results were reviewed by a group of in-house experts.

The following lessons learned can be derived from the WSDOT trial run:

- The existing tool provides a useful platform for quantifying the benefits and costs of BIM adoption at a specific agency. As an illustration, in their customization efforts, the WSDOT team removed a number of non-applicable benefits and shifted some (training) costs from external to internal.
- The tool can be tailored to a broad range of implementation plans. In the trial run, an initial pilot program was assessed, over a relatively short period of time (10 years).
- Additional instructions, in the form of a more detailed user guide and/or support from the tool's developers, might be useful in cases where an agency's program does not align perfectly with the tool's existing capabilities.
- Conducting additional case studies would likely help identify desirable improvements for the tool. Thus, two improvements were identified in the course of the WSDOT trial run: 1) the addition of a cost category (i.e., a one-time cost for BIM implementation plans), and 2) the addition of a ramp-up period for BIM use cases and contracts.

To our knowledge, at the time of this report, no other DOTs have tested or used the TFRS-02 tool.

[45] (Mitchell, Williges, & Messner, 2022), Appendix B – ROI Workbook and User Guide, https://nap.nationalacademies.org/download/26731, last accessed 03/19/2024

4. Data Collection Needs

The primary purpose of this section is to identify the specific input data needed to populate the TFRS-02 tool and to estimate the ROI of using BIM for bridges and other infrastructure assets. It describes the specific measures needed to quantify a base case (or counterfactual, without investment in BIM) and one or multiple investment scenarios.

As noted in the previous section (**Table 1**), the TFRS-02 tool includes suggested input values for the estimation of benefits and costs. The tool also provides the option for agencies to override these values if they have access to agency-specific data or strong(er) evidence on the magnitude of benefits and costs. In addition, some of the input values are not specified within the tool and *must* be provided by the agency.

This section focuses on the data collection needs of the existing tool, taking its scope and capabilities as given. Expanding the scope of the tool and/or refining the underlying estimation methods is beyond the scope of this paper.

Conceptual Framework for the Estimation of ROI

The TFRS-02 tool – and many of the existing tools reviewed herein – use benefit-cost analysis (BCA) principles to define and measure benefits and costs, and to estimate ROI.

BCA is a conceptual framework that quantifies in monetary terms as many of the benefits and costs of an initiative as possible. Benefits are typically defined broadly. They include both hard, cash-releasing benefits (e.g., project cost savings, reduced expenditures on paper) and soft, non-cash-releasing impacts (e.g., travel time savings, improved air quality), the combination of which is often referred to as changes in welfare. BCA also adopts the view that a net increase in welfare – as measured by the summation of benefits and costs across all stakeholders – is a good thing, even if some are left worse-off. Thus, an initiative would be rated positively if the benefits to some are large enough to compensate the losses of others.[46] Finally, BCA is generally forward-looking and tries to anticipate the future welfare impacts of initiatives over their lifecycle. Future welfare changes are weighted against today's investment costs through discounting, which is meant to reflect Society's preference for the present.[47]

Benefits in a formal BCA generally have two components: 1) a quantity component, expressed in any unit of measurement (e.g., staff time in hours, office space required for storage in sqft); and 2) a value or dollar-equivalent component, expressed in dollars per unit of measurement (e.g., average hourly

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[46] This is referred to as the Kaldor-Hicks compensation principle in the Economics literature.

[47] Discounting is a method used to convert future benefits and costs into their present-day value, for analysis and comparison. The conversion typically requires the use of a discount rate, the annual percentage change in the present value of a dollar. Discounting relates to the idea that, even with zero inflation, the value attached to a dollar received one year from now is less than the value attached to a dollar received today. This in turn, reflects a general preference for the present, for instant rather than delayed gratification. The Federal Government provides guidelines for the application of discounting in benefit-cost analyses and regulatory impact assessments (Office of Management and Budget, Circular A-4, https://www.whitehouse.gov/wp-content/uploads/2023/11/CircularA-4.pdf (last accessed 01/16/2024)).

wage in $ per hour, rental cost in $ per sqft). Benefits are estimated by looking at changes in either component (quantity and/or value), between a base case or counterfactual (e.g., conditions without BIM) and an investment case (e.g., conditions with BIM). So in many cases, the estimation of benefits involves: 1) calculating the change in the quantity component between the base case and the investment case; 2) applying a monetization factor or value component to the change in quantity; and 3) extrapolating the result to multiple years. This is illustrated, conceptually, in Figure 2 on the right.

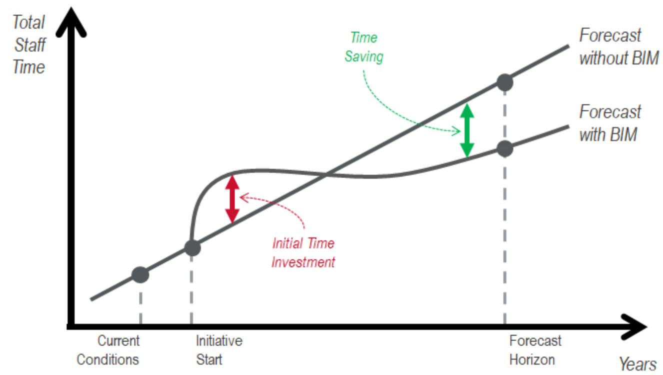

Figure 2: Extrapolation of Staff Time with and without BIM and Calculation of Staff Time Savings over Time (for illustration only)

In a prospective BCA, the base case is typically derived by extrapolating current, observable conditions to multiple years (forecast without BIM) and making assumptions about what future conditions would look like in the investment case (forecast with BIM). These assumptions can be informed by expert judgement or by the transfer of empirical evidence from other projects, sites, or agencies (where the investment already occurred and for which a causal relationship has been established – see below). In a retrospective BCA, where ROI is measured after the fact, conditions without the investment are no longer observable, and assumptions must be made to derive what these conditions would have been.

In the calculation of ROI, benefits can be defined narrowly to only include financial transactions to/from an agency (i.e., hard benefits, or actual dollars and cents saved by the agency) or more broadly to include impacts that do not directly create a flow of money (i.e., soft benefits, including avoided pain and suffering from reduced safety risks, or staff time freed up to work on other tasks) and/or that potentially affect a larger group (e.g., agency suppliers, the general public).[48] When the narrow definition of benefits is used, ROI is essentially a financial ROI. When the broader definition is used – as is standard in BCA – ROI is typically described as economic, or social.[49]

In the context of BIM for infrastructure, an additional question arises with respect to the distribution of benefits and costs, and the extent to which an owner agency may capture some of the benefits accruing in the first instance to the supply chain or may have to pay – through higher fees – for some of the BIM implementation costs born initially by supply-chain participants (see Section 2).

The magnitude of the benefits and costs realized indirectly by an agency will likely depend on two factors: market dynamics and commercial arrangements.[50] If the infrastructure construction market

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[48] The same logic applies to the treatment of costs.
[49] There are other important distinctions between a financial analysis and a benefit-cost analysis, but most are just consequences of the differences in perspective and scope.
[50] PWC (2018)

where an agency operates is sufficiently competitive, and suppliers compete on price, any cost savings realized through the adoption of BIM (in design, fabrication, construction, etc.) will eventually be passed on to client agencies, through lower fees. At the same time, agencies may be able to realize some of these benefits directly, when procuring work through collaborative contracting methods – such as gain-share or cost-plus models.[51]

Finally, in most BCAs, the preferred ROI metric is the benefit-cost ratio. It is calculated as total benefits over total costs, where both benefits and costs are estimated over a project's useful life and expressed in present-discounted value. This is the metric produced in two of the tools reviewed in Section 3.

Causal Attribution of Benefits and Costs

A key methodological issue in estimating the ROI of BIM adoption is the ability to disentangle the impacts of BIM from those of other activities and to establish a *causal relationship* between investing in BIM and the observed changes in staff time, agency costs, or other outcomes.

Citing McDavid & Hawthorn (2006), Territoires Innovants en Economie Sociale et Solidaire,[52] a research center specializing in economic evaluations, highlights three conditions for establishing a causal relationship from empirical observations:

- The initiative must precede the observed outcome,
- The presence or absence of the initiative must be correlated with the presence or absence of the observed outcome, and
- There cannot be any other plausible rival explanatory factors that could account for the correlation between the initiative and the outcome.

The center also notes that the use of a counterfactual makes it possible to establish a causal relationship by respecting these three conditions. A core challenge of causal attribution and benefits measurement, therefore, is the ability to define an adequate counterfactual and basis for comparisons.[53] Three categories of methods are generally set forth to address this challenge:[54]

- **Experimental** – including Randomized Controlled Trials, the preferred method used in clinical research, where a large number of individuals are randomly assigned into an experimental group (receiving treatment) or a control group (no treatment). The randomized selection of

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[51] PWC (2018)
[52] TIESS, Territoires Innovants en Economie Sociale et Solidaire, https://tiess.ca/en/proving-impact-causality-attribution-and-contribution/ (last accessed 03/27/2023)
[53] This challenge is well understood in the literature on BIM. It is expressed in these terms in PWC (2018): *"Even in retrospective assessments, we cannot observe what would have happened if BIM was not in use, for a specific project. Hence, establishing the appropriate counterfactual against which to assess the impact of BIM will always require either input from people who have direct experience of working with BIM and understand its impact against the most likely alternative method that would have otherwise been used on that project or some sort of statistically based analysis of historic projects which provides the basis for estimating this."*
[54] This presentation borrows from UK Department for Transport, TAG unit E-1 on Evaluation, March 2023

individuals ensures that explanatory factors other than the treatment itself are accounted for in the comparison of outcomes between the two groups.

- **Quasi-experimental** – various study designs and techniques, where the treatment group is compared to a group of otherwise similar individuals, in an effort to isolate the impacts of the treatment from that of other factors. Those include:
  - Before-and-after comparisons – same group observed before and after the treatment,
  - Matched comparisons – individuals in the treatment group compared one-on-one to individuals with similar characteristics in the control group,
  - Difference in differences or controlled before-and-after comparisons – outcomes for the treatment group compared over time with outcomes for the control group, and
- **Judgement-based** – use of stakeholder interviews or surveys to assess the direction and magnitude of impacts.

In the context of BIM adoption, the "gold standard" of causal attribution, Randomized Controlled Trials, is not possible. Quasi-experimental designs – including matched comparisons and difference-in-differences techniques – can be used instead, as illustrated in the Michigan DOT study reviewed for this paper.

The recommendations outlined in the UK BIM Benefits Measurement Methodology prepared by PWC[55] and introduced in Section 3 are very much aligned with these general considerations (i.e., need to assess benefits against an adequate counterfactual) and proposed methods. Thus, for the purpose of measuring the benefits of BIM ex-post, after the adoption of BIM, in the context of project-level assessments, PWC outlined the following options:[56]

- Empirical observation – compare the outcomes of two otherwise similar projects, or groups of projects, where one uses BIM, and the other does not.
- Expert judgement – draw on expert opinion to assess the direction and magnitude of impacts on key determinants of benefits and costs.
- Combination of empirical observation and expert judgement – supplement the results derived through observation with inputs from subject matter experts, to determine whether the observed differences are attributable to BIM, for example.

Identifying an exact study design for quantifying the benefits of BIM and/or updating some of the input values used in existing tools, however, is beyond the scope of this paper.

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[55] PWC, Introductory Note to the Benefits Measurement Method, Section 5.3 Assessment against an appropriate counterfactual, 2018

[56] A fourth option was outlined in the paper, whereby the comparison of BIM and Non-BIM projects relies on a large database of projects and the use of statistical techniques (e.g., multiple regression analysis) to estimate the impacts of BIM on project outcomes while controlling for other factors – to the extent that these factors are represented in the database. This fourth option is a form of empirical observation.

Data Needed to Populate the TFRS-02 Tool

As noted in Section 3, the TFRS-02 tool was designed to quantify the expected benefits and costs of BIM adoption on the basis of user-specified inputs about an agency program, along with assumptions on the expected changes in staff time, agency costs, etc. brought about by the adoption. These assumptions were derived from a variety of sources – including case studies, technical reports, and expert judgement – and can be updated or overridden by the user, for the purpose of estimating ROI at a specific agency.

In other words, the TFRS-02 tool produces ex-ante, prospective ROI analyses of investments in BIM and estimates potential returns from future investments based on a "benefit-transfer" approach, whereby the benefits quantified in other contexts (or intuited by subject matter experts) are applied to a specific agency or program. The tool was *not* designed to facilitate ex-post, retrospective evaluations of ROI through the measurement of realized returns (based on observed changes in staff time, agency costs, or other outcomes relative to a counterfactual), but it does provide a framework within which such measurement can be undertaken. This effort would involve the following steps:

- Step 1 – Prioritize data collection needs based on the expected magnitude of benefits and costs (i.e., which benefit streams are most likely to be material and "move the needle" in terms of ROI) and/or the quantity and quality of the supporting evidence currently available in the tool.
- Step 2 – For each benefit and cost category selected in Step 1, define an adequate counterfactual and basis for comparison, including the specific processes and technologies used in the absence of BIM.
- Step 3 – Determine data needs based on the specific metrics used within the tool to calculate the benefits and costs selected in Step 1 (e.g., percent reduction in spending on change orders, percent reduction in time spent completing quantities, etc.).
- Step 4 – Assess existing data collection efforts and determine whether some of the data identified in Step 3 are currently available within the agency.
- Step 5 – Identify outstanding data collection needs and determine how the data will be collected and by whom. Importantly, data must be assembled for the investment case (with BIM) and the counterfactual (without BIM).
- Step 6 – Initiate data collection, and proceed with data processing and analysis as the data comes in.

Describing the exact processes for collecting, organizing, and processing the data is beyond the scope of this paper. In the sections that follow, we provide general descriptions of the data needed to use the existing tool, taking its scope and capabilities as given.

Additional information can be found in the tool user guide (Appendix B of the final TFRS-02 Report) and in Appendix I (Detailed Data Collection Needs) at the end of this paper, where each data requirement is categorized into one of three (anticipated) levels of effort.[57]

The TFRS-02 tool offers two broad options for estimating the ROI of BIM adoption: 1) **Default Analysis**, requiring only a few user inputs and based solely on "rule-of-thumb data" available within the tool; and 2) **Detailed Analysis**, allowing users to perform a detailed ROI assessment, tailored to an agency's context, but requiring a lot more user inputs and agency-specific data.[58]

Minimum Set of User Inputs

The following information is needed to populate the TFRS-02 tool under the Default Analysis option:

- **Definition of Base Case and Investment Case**
  - Maturity level that best describes agency practices in the Base Case (without (further) BIM adoption) and Investment Case (with),
  - BIM use cases in the Base Case and Investment Case, and
  - Year in which the agency will expand its use of BIM.
- **Agency Program**
  - Average construction contract value for the agency's typical project,
  - Average duration of construction project, from start of construction,
  - Average cost of professional services design contract for a typical project,
  - Number of projects requiring BIM (projects per year), and
  - Number of BIM projects completed through professional service contracts.
- **Incremental Software Costs in Investment Case**
  - Incremental spending on software due to (further) adoption of BIM, and
  - Number of in-house (agency) 3D modeling users.

The user must also specify – through a series of yes/no questions – whether additional costs are expected in the investment case, relative to the base case (e.g., will the agency have to upgrade or purchase new hardware?).

Staff and Salary Data

Three broad categories of inputs can be provided by users under the Detailed Analysis option:

- **Salaries and Benefits**: average annual salary, inclusive of benefits, by role – for up to 15 distinct roles; average annual growth rate in salaries.

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[57] Level 1, for data that should be readily available from agency records and/or accounting systems; Level 2, for BIM-related data that will only become available once an agency adopts BIM practices and that may require modifications to existing data-tracking systems and processes; and Level 3, for data or transformed data that will only become available once sufficient evidence has been gathered on the use of BIM and that will require some form of statistical analysis and causal attribution.

[58] Under the "Detailed Analysis" option, the tool offers full flexibility as to what can be tailored to an agency context vs. estimated with default values -- within the limits of the database of default values, of course.

- **Staff Involved in BIM-Related Trainings**: number of staff attending initial BIM training, external refresher training, and internal refresher training, by role.
- **New Hires due to BIM Program**: number of staff hired to support the new or expanded BIM program, by role.

Benefit Data

Benefits within three broad categories can be quantified with the TFRS-02 tool:

- **In-House Agency Benefits**: cost savings that would unambiguously be realized by owner agencies adopting BIM,
- **Project Cost Savings**: reductions in project-related costs which may – depending on market dynamics and contractual agreements – be captured by owners, and
- **Staff Time Savings**: BIM-induced efficiency gains leading to actual reductions in staff time (relative to a counterfactual without BIM) or to increased staff availability for other value-adding tasks.

The data required to estimate these benefits (under the Detailed Analysis option) are too numerous to list here. They are identified in Appendix I, at the end of this report.

Cost Data

The TFRS-02 tool quantifies all agency costs directly related to BIM adoption, including initial investment costs (e.g., software licensing, hardware upgrades, infrastructure modifications) and longer-term outlays (e.g., new staffing, development of standards). Changes in other agency costs caused by the investment are treated as benefits, either positive (cost saving) or negative (cost increase).

Accordingly, within the tool, the costs of BIM adoption are grouped within two broad categories: 1) Initial, one-time costs; 2) and ongoing costs. Detailed requirements for cost data can be found in Appendix I.

5. Methodological Issues

This section addresses a number of methodological issues that arise when trying to quantify the ROI of BIM adoption. It is organized into a series of Questions & Answers, where each issue is expressed as a question (e.g., what is an adequate period of analysis?) and a brief answer is provided with recommendations on how to address it. The challenges of measuring the ROI of BIM are well documented. They include the difficulties of disentangling the effects of BIM from those of other activities; the time lag between the implementation of BIM and the realization of benefits; or the challenges of scaling project-based costs and benefits across an agency's program because of differences in BIM maturity within the supply chain.

The following sub-set of issues are discussed herein:

1) How should differences in BIM maturity levels be considered in an ROI analysis?
2) What is an adequate period of analysis given the delayed realization of some BIM benefits?
3) How should the costs of investing in BIM today be weighed against benefits realized 10 or 20 years from now?
4) How should the benefits and costs of using BIM be distributed across projects, for potential project-level ROI assessments?
5) How do the benefits and costs of using BIM for bridges differ to those for buildings or highway infrastructure in general?

There is no one way of addressing these issues and the recommendations below are based on professional judgment and somewhat subjective, but informed by desktop research, the economics literature, and discussions with subject matter experts.

BIM Maturity and ROI

How should differences in BIM maturity levels be considered in an ROI analysis of BIM for bridges?

In interviews across Europe, most stakeholders agreed that there are only a few or no benefits at the beginning of BIM implementation. Reasons for this include low productivity and additional efforts required initially, the high costs of BIM adoption, a need for specific knowledge and expertise to apply BIM, and interoperability issues. A rigorous ROI analysis, therefore, needs to consider maturity levels, especially if the return period is short. Five areas of maturity are critical for the realization of BIM benefits.

- **Interoperability** – the ability of two or more systems or organizations to exchange information and to work together towards a common goal. Interoperability is critical to the realization of returns because many of the BIM benefit streams require the information from BIM to be shared between multiple stakeholders and used many times over the asset lifecycle.

- **Familiarity with BIM** – the extent of BIM implementation and use within an organization or industry, a combination of BIM capability and experience or mastery.[59] Familiarity with BIM and the extent to which an organization or industry moves from one level to the next as a result of (further) investment in BIM, determine both the nature and the magnitude of the benefits to be expected from the investment.
- **Quality Control Protocols** – including clearly established BIM requirements and guidelines, standardized measures of BIM quality, and automated quality control procedures. The productivity gains that occur as a result of BIM adoption depend critically on the consistency and accuracy of the data. Furthermore, many of the benefits depend on the increased ability to scrutinize the design, but the procedures for doing so have not yet been formalized as part of the quality process.
- **Process Improvements** – the extent to which existing policies, processes, and workflows are actually improved when BIM is introduced, to enable the full realization of BIM benefits, in particular in relation to information sharing and management, knowledge transfer, and collaboration.
- **Adoption through the Supply Chain** – the extent to which organizations along the supply chain, small or large, have access to the technology and skills required to implement BIM practices and can leverage for their own use and benefit, the information created and shared by others.

The issue of maturity is only addressed partially in the tools reviewed herein. The UK Benefits Measurement Methodology was designed specifically to help quantify the benefits of BIM Level 2[60] but also recognizes that each organization within the supply chain is likely to have reached a different level. The extent to which BIM maturity affects the magnitude of benefits is not examined in the study, but the use of BIM enablers (i.e., individual elements of BIM that enable the realization of benefits), closely tied to competency areas within the BIM Maturity Assessment Tool set forth by buildingSMART International, allows users to add/remove benefit streams based on maturity.[61] The TFRS-02 tool goes a step further. In addition to tying the realization of benefits and costs to specific BIM use cases, users (of the tool) can specify the capability stage, from 0 to 3, that best describes agency practices with and without (further) BIM adoption. Within the tool, the benefit estimates are then adjusted with pre-

[59] Several BIM maturity scales are available in the literature, along with multiple maturity assessment tools. Thus, in a comprehensive review of BIM maturity assessment tools available globally, the Center for Digital Built Britain identified fifteen tools, eleven of which were deemed applicable to infrastructure.
[60] The UK BIM levels are not directly comparable to the capability levels described in this section.
[61] The approach is summarized in the terms in the PWC study (edited for clarity): *"The general hypothesis is that the higher the BIM maturity score (of either a government construction client or supply chain partner), the higher the level of benefit that will be realized from use of BIM. We have not tested this hypothesis in our work to date. In developing our benefits framework we have defined individual elements of BIM, called 'BIM enablers' that enable benefits to be realized. These 'BIM enablers' are similar in content and scope to the BIM Maturity Assessment Tool's competency areas, although they do not specifically match. Our framework is based on the principle that a 'BIM enabler' must be present in order for a benefit corresponding to that BIM enabler to be realized."*

defined scaling factors, based on that assumed investment-induced change in capability.[62] Along the same line, the EC CBA Tool adjusts benefit and cost estimates based on user-specified BIM maturity levels with and without the investment (from 0 to 3), and the degree of BIM experience of the client agency (i.e., some or no experience). These adjustments are based on survey results.

None of the tools reviewed, however, provides guidance on how to measure, from project or agency data, the impacts of BIM maturity on benefits realization. In the short run, adjustment factors similar to those used in the TFRS-02 or EC CBA tools should be applied. In the long(er) run, the impacts of maturity will likely be “revealed” in the data collected to measure benefits and costs.

Period of Analysis

What is an adequate period of analysis given the delayed realization of some BIM benefits?

While the adoption of BIM generates significant upfront costs, directly or indirectly, some of the benefits enabled by this adoption will only materialize in the long run – in particular those associated with uses of BIM after construction (e.g., improved asset performance and operation). And while the expected service life of the information systems and digital technologies at the center of BIM practices can be as short as 5 to 10 years, the design life of most infrastructure assets they help build spans multiple decades. So what is an adequate period of analysis for the estimation of ROI, prospectively? How far in the future should we look into to help justify the costs of BIM adoption?

The tools reviewed for this paper use a variety of appraisal periods, ranging from 5 years (Michigan DOT study) to 50 years (TFRS-02 tool, user-specified, up to 50 years, 10 years suggested). In ROI case studies, the period of analysis is typically project-specific and is either determined by 1) the expected service life of the infrastructure asset delivered with BIM, or of the Asset Information Model developed as part of the project, *whichever is shorter*;[63] or 2) the expected service life of the BIM-related systems and equipment used in design or delivery (e.g., BIM workstations).

In general, in prospective ROI assessments, benefits and costs should be estimated over the useful life of the investment – that is, the expected period over which the outputs of the investment will be used, before a major re-investment or replacement is needed. Therefore,

- For a **project-level assessment**, we recommend setting the period of analysis at the *minimum* of 1) the expected service life of the asset, or components of the asset, delivered with BIM, and 2) the useful life of the associated information model.

[62] From Stage 0 to Stage 1: 25% of possible benefits realized; from Stage 1 to Stage 2: an additional 50% realized; and from Stage 2 to Stage 3: an additional 25%. This assumes, implicitly, that all input values specified within the tool, or by the user, correspond to Stage 3 of BIM capability (i.e., full adoption of network-based integration with, for example, 3D models from all disciplines integrated with each other in real time).

[63] With open data standards, the information model lifecycle could be as long as the asset lifecycle, or it could be shorter. For example, when the asset is modified or new data is collected reflecting the current asset conditions, rendering the information derived from BIM obsolete.

- When the analysis focuses on the adoption of a **specific BIM-related technology** (e.g., BIM workstations, mobile devices), we recommend aligning the appraisal period with the useful life of that specific technology (e.g., 5 years).[64]
- For a **program- or agency-level assessment**, we recommend a period of 10 to 20 years, depending on the nature of the BIM-related investment and the portfolio of assets and information models produced through the investment. We also recommend that analysts evaluate the impacts of using a longer appraisal period, as illustrated in the next section.

In all three cases, it is important to consider: 1) the useful life of the shortest-lived asset or BIM-related component; 2) any additional expenses needed to sustain the realization of benefits over the period of analysis; and 3) where applicable, the residual value, at the end of the period of analysis, of any parts of the initial investment.

Finally, as explained below, in the calculation of the benefit-cost ratio, the use of (exponential) discounting considerably reduces the weight of benefits and costs occurring in the distant future, after 30 years. As a result, expanding the period of analysis beyond that horizon may not materially affect the outcomes of an ROI assessment, even when large benefits are expected in the outer years. This, importantly, is not only the result of a mathematical construct, but also a reflection of Society's preference for the present.

Present Valuation

How should the costs of investing in BIM today be weighed against benefits realized 10 or 20 years from now?

In BCA, as noted in Section 4, benefits and costs occurring in the future are discounted (i.e., expressed in present-day value) to reflect Society's general preference for the present[65] and to level the playing field when comparing initiatives whose costs and benefits occur through time at different rates and in different amounts. Discounting is most commonly applied to an annualized time series of benefits or costs, expressed in constant dollars, through the following expression:

$$PV = FV / (1+d)^{t} \qquad \text{Equation 1}$$

Where:

- *FV* is the value, in year t, of a benefit or cost to be realized t years in the future,
- *D* is the (real) discount rate, and
- *PV* is the present value (or present-discounted value) of the benefit or cost.

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[64] If adoption of the technology requires investing in other, supporting assets with a longer useful life (e.g., network infrastructure upgrades), more than one life cycle might be considered (e.g., 5 years x 2), with proper accounting of replacement costs.

[65] Several rationales have been put forward for discounting; this represents the most commonly accepted one.

In this approach, the rate at which future values are adjusted – the discount rate – is held constant throughout the period of analysis, and the discount factor $1/(1+d)^{t}$ is falling exponentially over time. This is called exponential discounting. This implies, in turn, that the relative valuation of benefits and costs arising at two points in the future only depends on the time between these two points and not on the gap between the current period and the two future points.[66] Exponential discounting has important implications. Firstly, benefits and costs occurring in the distant future (after 30 years) may be reduced *considerably*. At the discount rate of 3.1% recommended by the Office of Management and Budget (OMB),[67] $10 million in benefits arising 30 years from now would be worth about $4.0 million today, in present discounted terms. Secondly, because benefits tend to arise later than costs, an increase in the discount rate, holding everything else constant, will typically reduce the benefit-cost ratio estimated for an initiative.[68]

Overall, the benefit and cost estimates used in the evaluation of BIM adoption *must* be discounted, using a discount rate suitable for ROI analyses in the public sector. There are many rationales for setting a discount rate but in the end, it is essentially a policy decision. Therefore, we recommend that transportation agencies follow the discounting guidelines available within their state, and absent of that, adopt the OMB guidance.

As noted above, the latest version of that guidance (dated November 2023) recommends that the benefits and costs of government investments be discounted at an annual rate of 3.1%.[69] This rate is based on an estimate of the Social Rate of Time Preference (SRTP) of 2.0%[70] and an adjustment for systematic risk of 1.1%.[71] OMB also provides a schedule of SRTPs to apply in the very long run, for benefits and costs occurring beyond 2080.[72]

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[66] Alternatives have been proposed in the literature, including discounting at a declining rate or hyperbolic discounting. There are different forms of hyperbolic discounting. But all implicitly assume that the ability to make distinctions between available options diminishes for more distant events, and that as a result people tend to use discount rates that decline over time.
[67] OMB Circular A-94, Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs, Revised, November 9, 2023.
[68] The Economic Internal Rate of Return (EIRR), the discount rate at which the present discounted value of costs is just equal to the present discounted value of benefits, does not depend – by definition – on the discount rate selected for analysis.
[69] This rate should be used to discount all streams of benefits except those associated with reductions in CO2 emissions, which should be discounted at the risk-free rate of 2.0%.
[70] This rate is based on the 30-year (1993-2022) average return on long-term government debt which is generally considered a fair approximation of the SRTP.
[71] This is based on a relatively complex rationale and set of assumptions, but the general idea is that because most people are risk averse, they tend to assign less value to future benefits when these benefits are positively correlated with general economic conditions (i.e., when they receive low benefits when their income is low, or high benefits when their income is high).
[72] A strict application of the latest OMB guidance would also require that agencies account for the potential displacement of capital (through "shadow-pricing") and use project-specific risk adjustments.

Finally, we recommend that analysts perform sensitivity tests and produce ROI estimates under alternative specifications of the discount rate and period of analysis, when warranted. This is illustrated in the table below, for a fictitious BIM investment generating $100 in costs in Year 1 and $10 in net benefits in Year 3 and every year thereafter. The three discount rate alternatives in Table 2 are the OMB's SRTP (2.0%), SRTP plus risk (3.1%), and the Social Opportunity Cost (SOC) of capital (7.0%).

Table 2. Illustrative Example of Sensitivity Analysis Results

	Real Discount Rate		
Period of Analysis	2.0% (SRTP)	3.1% (SRTP + Risk)	7.0% (SOC)
10 years	0.72	0.68	0.56
20 years	1.47	1.32	0.94
30 years	2.09	1.79	1.13

Notes: The rate of 7% is from an earlier version of the OMB Guidance, now superseded. It is an estimate of the Social Opportunity Cost (SOC) of capital, derived from the average return on investment in the private sector during the 70s and 80s.

Project vs. Program-Level ROI

How should the benefits and costs of using BIM be distributed across projects, for project-level ROI assessments?

Out of the five tools reviewed for this paper, three were designed for program-level assessments (TFRS-02 ROI tool, FHWA e-Construction BCA tool, and Michigan DOT study), while the other two considered benefits (and costs) at the project level. There are pros and cons to both approaches.

To justify or support decisions about the acquisition of BIM-enabling systems, the development of standards, or the training of staff, an organizational or program-level assessment is needed. And given the magnitude of these upfront programmatic investments,[73] it is likely that positive returns would only emerge over time, once BIM practices have been applied to a sufficiently large number of projects.[74]

In addition, the broad adoption of BIM within an organization would likely produce efficiency gains and other benefits not otherwise captured in project-level assessments (e.g., reduced space requirements,

[73] As noted earlier in this paper and highlighted in Appendix I (Data Collection Needs), all costs must be quantified in the investment case (BIM adoption) and in a base case or counterfactual of no (new) BIM adoption. In some contexts, for some categories of costs, it is possible that the difference between the two (i.e., the incremental costs of BIM adoption) are rather limited. This could be the case, for example, when agencies can only buy "BIM-compatible" versions of the software products they have been using, at no additional fee; or when new staff are being trained on the use of BIM-enabling vs. traditional drafting software.
[74] TFRS-02 Report, page 66.

smaller design teams). This implies that the benefits generated at the program level would likely exceed the straight summation of benefits estimated for individual projects within a program. [75]

At the same time, it is relatively well established that the benefits of BIM vary across projects, with larger (net) benefits typically expected from more complex projects, involving larger teams, multiple phases of development, and/or complex geometric structures, and thereby presenting the most risk.[76] As a result, the estimation of BIM benefits requires that the intricacies of each BIM-assisted project be examined and that the assumptions used in that estimation be scaled accordingly. This, in turn, suggests that benefit assessments conducted at the project level are more workable and accurate.

One way of reconciling the two approaches, with a view to support decisions about the adoption of BIM practices within an agency or program, would be to: 1) estimate total adoption costs, at the program-level, including all direct and indirect costs; 2) estimate the benefits of all major BIM-assisted projects, ongoing or planned, for which sufficient project-specific information is available to warrant a project-level assessment; and 3) categorize all other projects by type and/or level of complexity, and develop benefit estimates within each category, with input values specifically scaled to that category. The benefits derived from Steps 2) and 3) would then be added together and compared to the costs derived from Step 1). If needed, within each category, the total benefits of BIM could be distributed across individual projects based on relative project value or expected person-hours on BIM-related tasks.

The ROI tool developed under TFRS-02 uses a simplified version of this approach, whereby a single category of projects is considered: an agency's "typical project." The approach is described in these terms within the TFRS-02 report (page 66):

> *"The typical project was intended to capture 85 percent of the type of work the agency does. Identifying the typical project was important for determining how much these projects were expected to benefit from BIM. (…) Once the characteristics of a typical project were set, they were then scaled by the average number of projects each year that would include the use of BIM. While this method did not capture the variety of types that an agency may implement (such as the occasional mega project), it was intended to approximate the average ROI for the agency."*

ROI of BIM for Bridges

How do the benefits and costs of using BIM for bridges differ from those for buildings or highway infrastructure in general?

[75] PWC (2018)

[76] TFRS-02 defines complex projects in relation to risk, in these terms: *"Complex Projects are characterized by the amount of construction activities that introduce the most risk. (…) While complex projects may be described by their major scopes of work, such as new pavement or bridge construction or roadway widening, it is probably more useful to define these projects by the level of perceived risk (…)."*

As noted in the introduction, compared to other types of construction assets, bridges have more in common with assets in the (vertical) building sector – where BIM originated. As such, the benefits of using BIM for bridges should be better aligned with those realized in that sector.

Most bridge projects are also relatively large and complex, providing more opportunities for the realization of BIM benefits than other types of transportation assets. The design and construction of bridges require careful consideration of a variety of factors (e.g., ground conditions, water depth and flow rates, expected loads and pressures, etc.) and coordination across a broad range of disciplines (e.g., transportation planning, structural and civil engineering, geotechnical engineering, materials engineering, etc.). Their geometry is also typically more complex, and often non-linear, to weave through existing structures in the case of an overpass or accommodate a body of water, for example. As a result, many of the benefits of BIM documented in this report will likely be larger for bridges than highways, in particular those associated with design development and reviews, quantity take-offs and cost estimation, clash detection, or information-sharing and collaboration. At the same time, the time and efforts needed to develop a 3D model for a complex bridge project will likely be larger than for other (horizontal) assets,[77] and so will the required software licensing costs or staff training.

As with other types of assets, the benefits of using BIM for bridges will extend beyond design and construction. And because the expected service life of a bridge spans over multiple decades, the use of open data standards – and the development, during the design phase, of an information model that is not linked to a particular software platform which may become outdated or inaccessible over time – is particularly valuable. Post-construction, the use of open standards will also facilitate the involvement of additional third parties and the transfer, use and re-use of information.

[77] Although the use of standardized components in bridge design helps contain these efforts, in particular relative to highway design that tends to be more bespoke.

6. Conclusion

This paper provided a description and a qualitative assessment of the costs and benefits to be expected from the use of BIM for Bridges, while outlining potential barriers to implementation and impediments to the realization of benefits. This assessment may be used by agencies to better understand the implications of BIM adoption and to guide efforts towards removing some of these barriers or impediments. The paper also examined a number of existing tools for use in the estimation of benefits and costs, and summarized their scope, capabilities, and data requirements, in a series of tables. This review may be used to assess “the state of the practice” for ROI measurement, and orient agencies towards using a specific tool or approach. The overall conclusion of the review, however, was that the BCA framework and spreadsheet-based tool developed under TFRS-02 was best suited to immediate applications by transportation agencies interested in assessing the ROI of BIM. The paper, next, described a number of principles for the measurement of ROI, and the need, in particular, for causal attribution and the definition of an adequate counterfactual. The idea is simple (when measuring the ROI of BIM, only consider the benefits and costs attributable to BIM), but the application of the idea can be challenging. The paper outlined a number of methods (or “things to think about”) to help address this challenge. In a subsequent section, data collection needs for each of the 20 benefit streams and 15 cost categories estimated in the TFRS-02 tool were identified and categorized based on the associated level of effort. This information should provide agencies with a clearer understanding of the data they need to estimate ex-ante (or measure ex-post) the ROI of using BIM. In a last section, the paper provided answers to five commonly asked questions about the ROI of BIM. Some of these answers – and associated recommendations – may have direct implications on the ROI analyses completed by, or on behalf of owner-agencies (e.g., selection of period of analysis and discount rate; need for sensitivity analysis).

Finally, as outlined in the core of the report, the **next steps for data collection** towards ROI measurement could be as follows.

1) Prioritize data collection needs based on the expected magnitude of benefits and costs and/or the quantity and quality of the supporting evidence currently available within the TFRS-02 tool.
2) For each benefit and cost category selected in Step 1, define an adequate counterfactual and basis for comparison, including the specific processes and technologies used in the absence of BIM.
3) Using the information in this report, determine data needs based on the specific metrics used within the tool to calculate the benefits and costs selected in Step 1.
4) Assess existing data collection efforts and determine whether some of the data identified in Step 3 are currently available within the agency.
5) Identify outstanding data collection needs and determine how the data will be collected and by whom.
6) Initiate data collection, and proceed with data processing and analysis as the data come in.

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Appendix I – Detailed Data Collection Needs

The descriptions, methods, and data requirements provided in the tables below are derived from the TFRS-02 model documentation, with a few adjustments. Within the "Data Collection Needs" section of each table, we identify an expected level of effort, based on the type of data used in the calculations, as follows:

- **Level 1** – Data that should be readily available from agency records and/or accounting systems (e.g., staff counts and salaries, average design contract value)
- **Level 2** – BIM-related data that will only become available once an agency adopts BIM practices (e.g., spending on BIM-enabling systems, initial training hours, etc.) and that may require modifications to existing data-tracking systems and processes (e.g., keeping track of BIM-related training-hours, documenting the reasons behind change orders, etc.)
- **Level 3** – Data or transformed data that will only become available once sufficient evidence has been gathered on the use of BIM and that will require some form of statistical analysis and causal attribution (e.g., percent reduction in agency cost or staff time attributable to BIM).

Detailed Data Requirements for the Estimation of Benefits

In-House Agency Benefits

BA1. Cost Savings from Reduced Paper, Printing, and Distribution

Description	Reduced spending on the production and distribution of plan sheets plus printing and shipping of bid tabs that results from moving to a digital approach
Quantification	*Annual cost savings = Average annual spending on paper, printing, and distribution in Base Case ($ per year) x Percent reduction in agency costs associated with paper, printing, and distribution due to BIM (%)*
Data Required	▪ Average annual spending on paper, printing, and distribution, $ per year ▪ Percent reduction in spending due to BIM, %
Data & Assumptions Available in Tool	▪ $1,200,000 spent on average per year (expert panel) ▪ 5% to 60% reduction (expert panel; NCHRP report)
Data Collection Needs	▪ Level 1 – Average annual spending on paper, etc. from agency accounting systems ▪ Level 3 – Percent reduction in spending – requires project-level cost allocation and comparison of spending BIM vs. no-BIM from sample of otherwise similar projects
Comments	Agencies that have already implemented e-construction or only issue electronically signed and sealed PDFs of the plans will not experience this benefit.

BA2. Cost Savings from Reduced Physical Storage Needs and Office Space

Description	Reduction in the use of office space and leased building space for storage of paper plans and other physical files due to digital conversion
Quantification	*Annual cost savings = Price of office rental space ($ per sqft per year) x Reduction in office space required for storage due to BIM digital files (sqft)*
Data Required	▪ Price of office rental space, $ per sqft ▪ Reduction in office space required for storage due to BIM digital files, sqft

Data & Assumptions Available in Tool	▪ $16 per sqft (U.S. average, PriceItHere.com) ▪ 20,000 sqft less due to BIM (case studies)
Data Collection Needs	▪ Level 1 – Price of office rental space from agency accounting systems or derived with local real estate data ▪ Level 3 – Reduction in square footage – estimate from case studies could be scaled/adjusted with agency data on current use of office space for storage of paper plans and physical flies, and/or through monitoring of digital conversion for BIM-assisted projects
Comments	Agencies that have already implemented e-construction or only issue electronically signed and sealed PDFs of the plans will not experience this benefit.

BA3. Avoided Vehicle Crashes due to Safety Simulations with BIM

Description	Reduction in agency costs (e.g., cleanup and property repair/replacement costs) from avoided vehicle crashes due to improved safety simulations during project design
Quantification	*Annual cost savings = Average spending on maintenance workorders for post-crash cleanup/repair without BIM ($ per year) x Percent reduction in maintenance workorders for post-crash cleanup/repair due to BIM-enabled safety simulations (%)*
Data Required	▪ Average spending on workorders for post-crash cleanup/repair, $ per year ▪ Percent reduction in workorders for post-crash cleanup/repair, %
Data & Assumptions Available in Tool	▪ $12,000,000 per year (MNDOT, Statewide Highway Systems Operation Plan, 2012) ▪ 13.6% to 20.4% reduction (FHWA, Crash Modification Factor, not BIM-specific)
Data Collection Needs	▪ Level 1 – Average spending from agency accounting systems and/or through additional tracking of expenses on post-crash cleanup/repair ▪ Level 3 – Percent reduction in workorders – requires assessing the effectiveness of BIM-enabled safety simulations, potentially with agency crash data and comparison of crash incidences at sites with vs. w/o simulations
Comments	N/A

BA4. Improved Worker Safety during Construction Inspections

Description	Reduction in the number of safety incidents during construction inspections resulting from the increased use of automation by contractors
Quantification	*Annual cost savings = Average number of work injuries occurring on agency construction sites without BIM (#) x Percent reduction in work injuries during construction due to BIM (%) x Average injury cost ($ per work injury)*
Data Required	▪ Average number of worker injuries on agency construction sites per year ▪ Percent reduction in worker accidents during construction period
Data & Assumptions Available in Tool	▪ No data / agency-specific ▪ 5% to 25% reduction (expert panel; Dodge Data & Analytics (2015))
Data Collection Needs	▪ Level 1 – Number of injuries should be readily available from agency records ▪ Level 3 – Percent reduction in injuries – requires tracking the extent of automation vs. in-person construction inspections on BIM-assisted projects (e.g., avoided in-

	person inspections) to which an agency-specific incident rate (e.g., number of worker injury incidents per inspection) could be applied
Comments	Workers may be less exposed to heavy equipment when contractors use AMG and may spend less time onsite performing inspections by using 3D model viewer apps on mobile devices. This benefit stream is not quantified in the Default Analysis.

BA5. Improved Worker Safety during Maintenance Inspections

Description	Reduction in the number of safety incidents during maintenance inspections, resulting from the use of automation when capturing existing conditions
Quantification	*Annual cost savings = Average number of on-site inspections required (inspections per year) x Average number of work injuries from live traffic per inspection without BIM (injuries per inspection) x Percent reduction in exposure to live traffic during maintenance inspections due to automation (%) x Average injury cost ($ per work injury)*
Data Required	▪ Average number of on-site worker inspections required per year ▪ Average number of worker injury incidents (from live traffic) per inspection ▪ Percent reduction in exposure to live traffic during maintenance inspections, % ▪ Average injury cost, $ per work injury
Data & Assumptions Available in Tool	▪ 1,158 (expert panel; ODOT SPR-787) ▪ 0.0019 (expert panel; FHWA Work Zone Facts and Statistics) ▪ 20% to 40% reduction (expert panel; ODOT SPR-787) ▪ $199,994 per injury (USDOT BCA Guidance, 2021, for injuries of unknown severity)
Data Collection Needs	▪ Level 1 – Number of on-site inspections from agency records and/or project data ▪ Level 1 – Injury rates derived from agency records ▪ Level 3 – Percent reduction – requires tracking the extent of automation vs. in-person maintenance inspections on BIM-assisted projects ▪ Level 1 – Average injury cost – agency may be able to adjust tool's suggested value with information on injury severity in safety records and/or insurance claims
Comments	Workers may be less exposed to live traffic through the use of remote sensors to capture information that can be compared to a 3D as-built model of the asset.

BA6. Cost Savings on Maintenance Inspections due to the Use of Drones

Description	Reduction in the cost of inspections due to the use of drones (e.g., avoided traffic control costs)
Quantification	*Annual cost savings = Average number of in-person maintenance inspections per year (inspections per year) x Average cost per in-person maintenance inspection ($ per inspection) x Percent reduction in average inspection cost (%)*
Data Required	▪ Average number of (in-person) inspections per year ▪ Average cost per (in-person) maintenance inspection, $ per inspection ▪ Percent reduction in average cost per inspection, %
Data & Assumptions Available in Tool	▪ 1,158 (expert panel; ODOT SPR-787) ▪ $3,693 (expert panel; MNDOT (2018)) ▪ 10% to 45% (expert panel; MNDOT (2018))

Data Collection Needs	▪ Level 1 – Number of on-site inspections from agency records and/or project data ▪ Level 1 – Average cost per inspection from agency accounting systems and/or project data ▪ Level 3 – Percent reduction in cost – requires comparing overall inspection costs on drone-assisted vs. in-person inspections, from representative sample of projects and inspection events
Comments	The costs associated with purchasing and maintaining the drones are captured separately, under investment/adoption costs.

Project Cost Savings

BP1. Cost Savings from Avoided Change Orders

Description	Cost savings from avoided change orders due to improved collaboration between disciplines to identify conflicts and constructability issues
Quantification	*Annual cost savings = Total spending on change orders ($ per year) x Percent reduction in spending on change orders due to conflict avoidance from BIM (%)*
Data Required	▪ Total spending on change orders, $ per year ▪ Percent reduction in spending on change orders due to BIM, %
Data & Assumptions Available in Tool	▪ 5% to 25% reduction (expert panel; Azhar (2011); FHWA-HRT-17-027), applied to total project cost (no data on change orders)
Data Collection Needs	▪ Level 1 – Total spending on change orders from agency accounting system and/or project data ▪ Level 3 – Percent reduction in spending on change orders – requires project-level estimates of spending on change orders; information on reasons for change orders; and comparison of spending BIM vs. no-BIM from sample of otherwise similar projects (will be challenging)
Comments	N/A

BP2. Cost Savings from Improved Schedule Management

Description	Cost savings from completing a project early or on time, due to the use of BIM for managing the schedule
Quantification	*Annual cost savings = Average project duration without BIM (days) x Percent improvement or optimization in project schedule due to BIM (%) x Average value of a day saved on project schedule ($ per day)* Where *Average value of a day saved on project schedule ($ per day) = Total project cost ($) x General conditions costs as percent of total project cost (%) / Project duration (days)*
Data Required	▪ Average project duration for typical project w/o BIM, days ▪ Total project cost, $ ▪ General conditions costs as percent of total project cost, % ▪ Percent improvement or optimization in project schedule due to BIM, %
Data & Assumptions Available in Tool	▪ User input / agency-specific ▪ User input / agency-specific ▪ 6% to 12% of total project cost (Ruff (2018))

	▪ 6% to 20% improvement (expert panel; case studies)
Data Collection Needs	▪ Level 1 – Project duration from agency records / project data ▪ Level 1 – Project cost from agency records / project data ▪ Level 1 – General conditions costs from agency records / project data ▪ Level 3 – Percent improvement in project schedule from comparison of durations BIM vs. no-BIM from sample of otherwise similar projects (will be challenging)
Comments	For instance, through the use of 4D model simulations, a project team can identify activities that may interfere with each other and adjust the plan accordingly.

BP3. Lower Construction Bid Prices due to Improved Communication of Design Intent

Description	Reduction in the costs of construction contracts due to reduced risk contingencies from the use of BIM
Quantification	*Annual cost savings = Average project cost without BIM ($) x Percent reduction in project cost from lower risk contingencies (%) x Average number of projects requiring BIM (projects per year)*
Data Required	▪ Average project cost w/o BIM ("typical project"), $ ▪ Percent reduction in project cost from lower risk contingencies, %
Data & Assumptions Available in Tool	▪ User input / agency-specific ▪ 2% to 23% reduction (case studies)
Data Collection Needs	▪ Level 1 – Project cost from agency records / project data ▪ Level 3 – Reduction in risk contingencies from comparison BIM vs. no-BIM from sample of otherwise similar projects and contracts (will be challenging)
Comments	Specifically, contractors bidding on construction contracts may reduce bid amounts by removing the risk contingency given the access to 3D models that better communicate the design intent.

BP4. Cost Savings from Creating Visualizations with BIM

Description	Cost savings of creating a visualization video with the use of modern 3D modeling software, compared to completing a project visualization without 3D design models of the project
Quantification	*Annual cost savings = Average cost of creating visualization products without BIM ($ per project) x Percent reduction in cost to create visualization product due to BIM (%) x Average number of projects requiring BIM (projects per year)*
Data Required	▪ Average cost of creating visualization products without BIM, $ per project ▪ Percent reduction in cost to create visualization product due to BIM, %
Data & Assumptions Available in Tool	▪ No data / agency-specific ▪ No data / agency-specific
Data Collection Needs	▪ Level 1 – Cost of visualization w/o BIM from agency records / project data and/or discussions with internal SMEs ▪ Level 2/3 – Cost of visualization with BIM from sample of BIM projects; and/or formal comparison BIM vs. no-BIM from sample of otherwise similar efforts

Comments	This might include visualizations for public information, safety simulations, or other. This benefit stream is not quantified in the Default Analysis.

BP5. Cost Savings from Optimization of Construction Material Use or Alternative Design Options

Description	Cost savings from optimization of construction material use or alternate design options due to having a detailed 3D model of the project.
Quantification	*Annual cost savings = Average cost of construction materials or alternate design option ($ per project) x Percent reduction in spending on construction materials or alternate design options due to BIM design (%)* Where the average cost of construction materials or alternate design options is calculated as *Average project cost ($) x Percent of project cost spent on materials or alternate design options (%)*
Data Required	▪ Average spending on materials or design options, % of project cost ▪ Percent reduction in spending on construction materials or design options, %
Data & Assumptions Available in Tool	▪ No data / agency-specific ▪ 2% to 5% reduction (case studies)
Data Collection Needs	▪ Level 1 – Average spending on materials or design options from agency records / project data ▪ Level 3 – Reduction in spending risk from comparison BIM vs. no-BIM from sample of otherwise similar projects (will be challenging)
Comments	This refers to the optimization of material use rather than to the reduction of material overruns. Design can optimize construction materials or alternate design options through BIM visualization and design tools. This benefit stream is not quantified in the Default Analysis.

Staff Time Savings

BS1. Time Savings from Re-using Previous BIM Content for Future Similar Work

Description	Time saved to develop a project design by re-using previous BIM content (3D component libraries in CAD)
Quantification	*Annual cost savings = Average time to build models from scratch without templates (hours per project) x Percent reduction in time spent to complete models due to use of templates (%) x Average hourly wage of design staff ($ per hour) x Average number of projects requiring BIM (projects per year)*
Data Required	▪ Average time to build models from scratch, without templates, hours per project ▪ Percent reduction in time spent to complete models due to use of templates, % ▪ Average hourly wage of design staff, $ per hour
Data & Assumptions Available in Tool	▪ 200 hours per project (case studies) ▪ 50% reduction (case studies) ▪ $42 per hour (BLS, U.S. national average wages, transportation engineers)
Data Collection Needs	▪ Level 1/2 – Average time per project from agency records / project data and/or discussions with internal SMEs ▪ Level 2/3 – Reduction in time with templates from sample of BIM projects; and/or formal comparison BIM vs. no-BIM from sample of otherwise similar efforts;

	actual time measurements would be difficult – may require new/expanded time-keeping procedures ▪ Level 1 – Salary data from agency accounting system
Comments	This benefit grows over time as a content library of 3D templates is developed, unless an agency develops a workspace or object library that matches their standards, in which case all subsequent projects have the same efficiencies.

BS2. Time Savings from Avoiding Tracking Down Information for Scoping Project

Description	Time saved tracking down information due to having access to an enterprise database that has been populated from BIM products, such as digital as built or asset inventory record models
Quantification	*Annual cost savings = Hours saved on project scoping (hours per project) x Average hourly wage of staff used for project scoping ($ per hour) x Average number of projects requiring BIM (projects per year)*
Data Required	▪ Hours saved on project scoping (all staff), hours per project ▪ Average hourly wage of staff used for project scoping, $ per hour
Data & Assumptions Available in Tool	▪ 1 to 70 hours per project (case studies) ▪ $46 per hour (BLS, U.S. national average wages, transportation planners and project managers (simple average))
Data Collection Needs	▪ Level 1/2 – Time spent tracking down information for non-BIM projects, potentially from discussions/interviews with agency staff; actual time measurements would be difficult – may require new/expanded time-keeping procedures ▪ Level 1 – Salary data from agency accounting system
Comments	This benefit depends on the accessibility of the data, for example, if it is in an open format (such as IFC) or an old proprietary format that may not be readable with contemporary software.

BS3. Time Savings from Improved Design Efficiency

Description	Time saved creating a design due to improved work efficiency, including parametric design, and avoided design rework
Quantification	*Annual cost savings = Average time spent on project design without BIM (hours per project) x Percent reduction in time spent on design (%) x Average hourly wage of design staff ($ per hour) x Average number of projects requiring BIM (projects per year)*
Data Required	▪ Typical hours spent on project design without BIM, hours per project ▪ Percent reduction in time spent on design, % ▪ Average hourly wage of design staff, $ per hour
Data & Assumptions Available in Tool	▪ 670 hours (case studies) / agency-specific ▪ 5% to 15% reduction (case studies) ▪ $42 per hour (BLS, U.S. national average wages, transportation engineers)
Data Collection Needs	▪ Level 1 – Time spent on project design w/o BIM from project data, budgeting documents, and/or discussions with agency staff

	▪ Level 3 – Percent change from sample of BIM projects; and/or formal comparison BIM vs. no-BIM from sample of otherwise similar projects; could focus on extent of design rework; actual time measurements would be difficult – may require new/expanded time-keeping procedures ▪ Level 1 – Salary data from agency accounting system
Comments	N/A

BS4. Time Savings in Document Review and Approval due to Faster Turnaround Time by Using Cloud-Based Software

Description	Time saved reviewing and approving documents due to faster turnaround time by using cloud-based software
Quantification	*Annual cost savings = Average time spent reviewing/approving documents without BIM (hours per project) x Percent reduction in time spent on document review/approval (%) x Average hourly wage of reviewers ($ per hour) x Average number of projects requiring BIM (projects per year)*
Data Required	▪ Typical time spent reviewing/approving documents w/o BIM, hours per project ▪ Percent reduction in time spent on document review or approval, % ▪ Average hourly wage of reviewers, $ per hour
Data & Assumptions Available in Tool	▪ No data / agency-specific ▪ 10% to 50% reduction (expert panel, case studies) ▪ $53 per hour (BLS, U.S. national average wages, transportation planners and project managers (simple average))
Data Collection Needs	▪ Level 1 – Time spent reviewing/approving documents w/o BIM from project data, budgeting documents, and/or discussions with agency staff ▪ Level 3 – Percent change from sample of BIM projects; and/or formal comparison BIM vs. no-BIM from sample of otherwise similar projects; actual time measurements would be difficult – may require new/expanded time-keeping procedures ▪ Level 1 – Salary data from agency accounting system
Comments	This benefit will not be realized for agencies already using real-time review workflows with cloud-based software to review PDF plan sheets (e.g., Bluebeam). This benefit stream is not quantified in the Default Analysis.

BS5. Time Savings from Avoided Requests For information (RFI) due to Improved Clarity of Design

Description	Avoided time spent responding to requests for information (RFI) due to improved clarity of design from BIM models
Quantification	*Annual cost savings = Average number of RFIs per project (RFIs per project) x Percent reduction in RFIs (%) x Average staff time spent on responding to RFIs (hours per RFI) x Average hourly wage of those who respond to RFIs ($ per hour) x Average number of projects requiring BIM (projects per year)*
Data Required	▪ Average number of RFIs per project ▪ Average staff time spent on responding to RFIs, hours per RFI ▪ Percent reduction in RFIs, % ▪ Average hourly wage of staff responding to RFIs, $ per hour

Data & Assumptions Available in Tool	▪ No data / agency-specific ▪ No data / agency-specific ▪ 10% to 32% (expert panel; Applied Software (2009)) ▪ $42 per hour (BLS, U.S. national average wages, transportation engineers)
Data Collection Needs	▪ Level 1 – Number of RFIs from agency records / project data ▪ Level 1 – Time spent responding to RFIs from discussions with agency staff ▪ Level 3 – Percent reduction in RFIs from comparison BIM vs. no-BIM from sample of otherwise similar projects ▪ Level 1 – Salary data from agency accounting system
Comments	This benefit stream is not quantified in the Default Analysis

BS6. Time Savings from Improved Schedule Management and Workforce Utilization

Description	Time saved due to improved schedule management, enabling teams to reallocate tasks from one activity to another (i.e., improved workforce utilization)
Quantification	*Annual cost savings = Average project duration without BIM (days) x Percent reduction in project schedule due to BIM (%) x Number of staff affected by improved schedule (staff per project) x Average hourly wage of staff involved in construction ($ per hour) x Average number of projects requiring BIM (projects per year)*
Data Required	▪ Average project duration for typical project w/o BIM, days ▪ Percent improvement or optimization in project schedule due to BIM, % ▪ Number of employees affected by improved schedule, employees per project ▪ Average hourly wage of staff involved in project construction, $ per hour
Data & Assumptions Available in Tool	▪ User input / agency-specific ▪ 6% to 20% improvement (expert panel; case studies) ▪ 5 employees (place-holder value) / agency-specific ▪ $40 per hour (BLS, U.S. national average wages, construction inspectors)
Data Collection Needs	▪ Level 1 – Project duration from agency records / project data ▪ Level 3 – Percent improvement in project schedule from comparison of durations BIM vs. no-BIM from sample of otherwise similar projects (will be challenging) ▪ Level 1/2 – Staff per project from agency records / project data ▪ Level 1 – Salary data from agency accounting system
Comments	N/A

BS7. Time Savings During Construction Inspections due to Use of 3D Digital Design Data

Description	Time saved during construction inspections, from utilizing 3D digital design data and GPS equipment or mobile model viewers instead of traditional methods (such as plan sets, cross-sections, or level and tape methods).
Quantification	*Annual cost savings = Average time spent on construction inspections without BIM (hours per project) x Percent reduction in time spent on inspections due to BIM (%) x Average hourly wage of construction inspection staff ($ per hour) x Average number of projects requiring BIM (projects per year)*
Data Required	▪ Average time spent on construction inspections without BIM, hours per project ▪ Percent reduction in time spent on inspections due to BIM, %

	▪ Average hourly wage of construction inspection staff, $ per hour
Data & Assumptions Available in Tool	▪ No data / agency-specific ▪ 30% reduction (expert panel) ▪ $40 per hour (BLS, U.S. national average wages, construction inspectors)
Data Collection Needs	▪ Level 1 – Time spent on inspections w/o BIM from agency records / project data and/or discussions with agency staff ▪ Level 3 – Percent reduction from comparison of inspections BIM vs. no-BIM from sample of otherwise similar projects; actual time measurements would be difficult – may require new/expanded time-keeping procedures ▪ Level 1 – Salary data from agency accounting system
Comments	This benefit stream is not quantified in the Default Analysis

BS8. Time Savings on Completing Design Quantities

Description	Time saved when estimating design quantities due to BIM-enabled automation.
Quantification	*Annual cost savings = Average time spent calculating design quantities by hand, without BIM (hours per project) x Percent reduction in time spent completing quantities due to automation (%) x Average hourly wage of design staff ($ per hour) x Average number of projects requiring BIM (projects per year)*
Data Required	▪ Average time spent calculating design quantities by hand, hours per project ▪ Percent reduction in time spent completing quantities due to automation, % ▪ Average hourly wage of design staff, $ per hour
Data & Assumptions Available in Tool	▪ 80 hours (case studies) ▪ 25% to 70% (expert panel, case studies) ▪ $43 per hour (BLS, U.S. national average wages, transportation engineers and cost estimators (simple average))
Data Collection Needs	▪ Level 1 – Time spent estimating quantities w/o BIM from agency records / project data and/or discussions with agency staff ▪ Level 2/3 – Percent reduction from sample of BIM projects; and/or formal comparison BIM vs. no-BIM from sample of otherwise similar projects; actual time measurements would be difficult – may require new/expanded time-keeping procedures ▪ Level 1 – Salary data from agency accounting system
Comments	This refers to the BIM software functionality to automate reports for all pay item quantities instead of using manual methods with spreadsheet calculations.

BS9. Avoided Time Spent Tracking Down Information Needed for Routine Maintenance or Repair Work

Description	Avoided time spent tracking down information needed for routine maintenance or repair work due to having all information saved in a centralized location.
Quantification	*Annual cost savings = Average time spent tracking down information for maintenance work (hours per year) x Percent reduction in time spent tracking down information, due to BIM (%) x Average hourly wage of those responsible for tracking down information ($ per hour)*
Data Required	▪ Average time spent on data collection for maintenance (all staff), hours per year

	▪ Percent reduction in time spent tracking down data for maintenance, % ▪ Average hourly wage of maintenance data collection staff, $ per hour
Data & Assumptions Available in Tool	▪ 7,093 hours per year, all staff (FHWA-HIF-15-023 UDOT Case Study) ▪ 84% (FHWA-HIF-15-023 UDOT Case Study) ▪ $22 per hour (BLS, U.S. national average wages, construction maintenance)
Data Collection Needs	▪ Level 1 – Average time spent tracking down information w/o BIM potentially from discussions/interviews with agency staff and extrapolation based on number of maintenance/repair events; actual time measurements would be difficult – may require new/expanded time-keeping procedures ▪ Level 2/3 – Percent reduction from sample of BIM projects; and/or formal comparison BIM vs. no-BIM from sample of otherwise similar projects
Comments	N/A

Detailed Data Requirements for the Estimation of Costs

One-Time Costs

CI1. Initial System Configuration

Description	Initial cost of BIM, asset management software, or system configuration and customization (i.e., professional services to set up system solution)
Quantification	*Total investment cost = Average cost of professional service contractor visit to setup, program, configure, and/or customize system solution ($)*
Data Required	▪ Average cost of professional service contractor to setup, program, configure, and/or customize system solution
Data & Assumptions Available in Tool	▪ $400,000 to $750,000 (expert panel; research; estimates by BIM personnel)
Data Collection Needs	▪ Level 2 – actual agency spending on system configuration
Comments	This cost may be present in the counterfactual as vendors withdraw support for legacy versions of their software and an agency has to adopt contemporary versions regardless of whether they use the BIM-compatible features.

CI2. Initial Hardware Investments or Upgrades

Description	Initial BIM hardware investments or upgrades (e.g., computer workstations, tablets, GPS rovers, drones, robotic stations)
Quantification	*Total investment cost = cost per computer ($ per computer) x number of computers + cost per tablet ($ per tablet) x number of tablets + cost of stations and/or GPS rover systems ($) + cost of drones / UAS ($) + cost of automatic digital levels and tripod system + cost of Lidar systems ($) + other hardware component costs ($)*
Data Required	▪ Computers: unit cost, $ per computer; quantity ▪ Tablets: unit cost, $ per tablet; quantity ▪ Stations & GPS Rover Systems (equipment and accessories): total cost ▪ Drones/UAS: total cost ▪ Automatic Digital Levels & Tripod System: total cost ▪ Lidar Systems: total cost

	▪ Other Component: total cost
Data & Assumptions Available in Tool	▪ Computers: $1,000 to $2,000 (case studies); user input / agency-specific ▪ Tablets: $650 to $1,050 (cost research); user input / agency-specific ▪ Stations & GPS Rover Systems: $15,000 to $40,000 (agency data; research) ▪ Drones/UAS: $3,000 to $39,079 (ODOT (2018); agency data) ▪ Automatic Digital Levels & Tripod System: $300 to $8,000 (agency data; research) ▪ Lidar Systems: $20,000 to $61,000 (agency data, case studies) ▪ Other Component: $0 (none specified)
Data Collection Needs	▪ Level 2 – amount spent on hardware; will need to determine how much would have been spent without (new) BIM adoption
Comments	N/A

CI3. Initial Staff Training

Description	Cost of initial comprehensive staff training
Quantification	*Total investment cost = Hourly fee for external training sessions ($ per hour) x Number of session-hours, all sessions (hours)*
Data Required	▪ Fee for external training sessions, $ per hour ▪ Number of session-hours, by type of session: roadway modeling, drainage/utility modeling, bridge modeling, survey modeling, construction inspection
Data & Assumptions Available in Tool	▪ $250 per hour (cost research) ▪ Roadway modeling: 32 hours ▪ Drainage/utility modeling: 32 hours ▪ Bridge modeling: 16 hours ▪ Survey modeling: 24 hours ▪ Construction inspection: 27 hours All session-hours informed by case studies and BIM practitioners
Data Collection Needs	▪ Level 2 – amount spent on training; number of training-hours by type
Comments	N/A

CI4. Opportunity Cost of Staff Time for Initial Training

Description	Opportunity cost of staff time for initial comprehensive training
Quantification	*Total investment cost = Number of session-hours, all sessions (hours) x Number of staff required to attend initial comprehensive training (employees) x Average hourly wages of staff attending training ($ per hour)*
Data Required	▪ Number of session-hours, all sessions, hours ▪ Number of staff required to attend initial comprehensive training, employees ▪ Average hourly wages of staff attending training, $ per hour
Data & Assumptions Available in Tool	▪ 131 hours (sum of all session-hours from CI3) ▪ 3 to 30 staff (case studies) / agency-specific ▪ $49 per hour (BLS, U.S. national average wages, all roles (simple average))

Data Collection Needs	▪ Level 2 – number of training-hours; number of staff attending by role and/or with exact salary information
Comments	N/A

Ongoing Costs

CO1. Incremental Costs of BIM-Related Software Subscription

Description	Incremental costs of BIM-related software subscription
Quantification	*Annual investment cost = Annual software cost per user ($ per user per year) x Number of in-house software users*
Data Required	▪ Annual software cost per user, $ per user per year ▪ Number of in-house software users
Data & Assumptions Available in Tool	▪ $5,000 per user per year (online research) / agency-specific ▪ 10 software users (suggested value) / agency-specific
Data Collection Needs	▪ Level 2 – amount spent on software subscription; will need to determine how much would have been spent without (new) BIM adoption
Comments	N/A

CO2. Incremental Spending on IT Resources or Infrastructure

Description	Incremental spending on IT resources or infrastructure from BIM (e.g., cloud storage capacity/data storage, ProjectWise capacity, internet speed/capacity)
Quantification	*Annual investment cost = Incremental cost to upgrade current versions or purchase new supporting software / data storage services ($ per year)*
Data Required	▪ Cost to upgrade current versions or purchase new supporting software / data storage services (e.g., cloud storage capacity, ProjectWise capacity, internet speed), $ per year
Data & Assumptions Available in Tool	▪ No data / agency-specific
Data Collection Needs	▪ Level 2 – amount spent on additional IT resources and infrastructure; will need to determine how much is attributable to (new) BIM adoption
Comments	This cost stream is not considered in the Default Analysis

CO3. Semi-regular Hardware Replacement Costs

Description	Semi-regular hardware replacement costs (e.g., GPS rovers, drones, robotic stations)
Quantification	*For each hardware component, annual investment cost = Frequency of replacement (1 / component useful life, in years) x Initial purchase cost ($ per component) x Replacement cost as percent of initial cost (%)*
Data Required	▪ Useful life, in years for Computers, Tablets, Stations & GPS Rover Systems (equipment and accessories), Drones/UAS, Automatic Digital Levels & Tripod System, Lidar Systems, and Other Component ▪ Replacement cost as percent of initial cost, %

Data & Assumptions Available in Tool	▪ Computers: 3 years (assumption based on case studies) ▪ Tablets: 3 years (assumption based on case studies) ▪ Stations & GPS Rover Systems: 8 years (estimate) ▪ Drones/UAS: 3 years (estimate) ▪ Automatic Digital Levels & Tripod System: 6 years (estimate) ▪ Lidar Systems: 5 years (estimate) ▪ Other Component: not specified ▪ Replacement cost as percent of initial cost: 90% for all components (assumption)
Data Collection Needs	▪ Level 2 – frequency and amount spent on hardware replacement; will need to determine how much would have been spent without (new) BIM adoption
Comments	N/A

CO4. Cost of External Refresher Staff Trainings

Description	Cost of external refresher staff trainings
Quantification	*Annual investment cost = Frequency of external refresher training sessions (1 / average interval, in years, between sessions) x Duration of external refresher training sessions (hours) x Fee for external refresher training sessions ($ per hour)*
Data Required	▪ Frequency of external refresher training sessions, years ▪ Duration of sessions, hours per session ▪ Fee for external ongoing training sessions, $ per hour
Data & Assumptions Available in Tool	▪ Refresher every 3 years (suggested value) / agency-specific ▪ 8 hours per session (suggested value) / agency-specific ▪ $250 per hour (cost research)
Data Collection Needs	▪ Level 2 – amount spent on external refresher training; number of external refresher training-hours
Comments	N/A

CO5. Opportunity Cost of Staff Time for External Refresher Trainings

Description	Opportunity cost of staff time for external refresher trainings
Quantification	*Annual investment cost = Frequency of external refresher training sessions (1 / average interval, in years, between sessions) x Duration of external refresher training sessions (hours per session) x Number of staff attending external refresher trainings (employees) x Average hourly wages of staff attending external refresher trainings ($ per hour)*
Data Required	▪ Frequency of external refresher training sessions, years ▪ Duration of sessions, hours per session ▪ Number of staff attending external refresher trainings, employees ▪ Average hourly wages of staff attending external refresher trainings, $ per hour
Data & Assumptions Available in Tool	▪ Refresher every 3 years (suggested value) / agency-specific ▪ 8 hours per session (suggested value) / agency-specific ▪ 3 staff (suggested value) / agency-specific ▪ $78 per hour (BLS, U.S. national average wages, project managers and BIM managers (simple average))

Data Collection Needs	▪ Level 2 – number of external refresher training-hours; number of staff attending by role and/or with exact salary information
Comments	N/A

CO6. Opportunity Cost of Staff Time for Internal Refresher Trainings

Description	Opportunity cost of staff time for internal refresher trainings
Quantification	*Annual investment cost = Frequency of internal refresher training sessions (1 / average interval, in years, between sessions) x Duration of internal refresher training sessions (hours per session) x Number of staff attending internal refresher trainings (employees) x Average hourly wages of staff attending internal refresher trainings ($ per hour)*
Data Required	▪ Frequency of internal refresher training sessions, years ▪ Duration of internal refresher training sessions, hours per session ▪ Number of staff required to attend internal refresher trainings, employees ▪ Average hourly wages of staff attending internal refresher trainings, $ per hour
Data & Assumptions Available in Tool	▪ Refresher every 3 years (suggested value) / agency-specific ▪ 8 hours per session (suggested value) / agency-specific ▪ 3 to 30 staff (case studies) / agency-specific ▪ $49 per hour (BLS, U.S. national average wages, project managers and BIM managers (simple average))
Data Collection Needs	▪ Level 2 – number of internal refresher training-hours; number of staff attending by role and/or with exact salary information
Comments	N/A

CO7. Opportunity Cost of Creating New Training Materials

Description	Opportunity cost of creating new training materials
Quantification	*Annual investment cost = Number of internal session-hours (hours per year) x Hours required to create new training materials (hours per 8-hour session) x Average hourly wages of staff creating training material ($ per hour) / 8.0*
Data Required	▪ Number of internal session-hours, hours per year ▪ Hours required to create new training materials, hours per 8-hour session ▪ Average hourly wages of staff creating training material, $ per hour
Data & Assumptions Available in Tool	▪ Calculated from CO6 / agency-specific ▪ 40 hours per 8-hour training session (case studies) ▪ $92 per hour (BLS, U.S. national average wages, BIM managers)
Data Collection Needs	▪ Level 2 – Time spent developing training material, from discussions/interviews with agency staff; actual time measurements would be difficult – may require new/expanded time-keeping procedures; number of staff involved by role and/or with exact salary information
Comments	N/A

CO8. Increase in the Cost of Professional Services Contracts due to BIM Design Requirements

Description	Average cost increase of professional services contracts due to requiring BIM for design
Quantification	*Annual investment cost = Average annual number of design contracts (contracts per year) x Average design contract value without BIM ($ per contract) x Percent increase in average price of design contracts due to use of BIM to create designs (% of design contract value)*
Data Required	▪ Average annual number of design contracts, contracts per year ▪ Average design contract value w/o BIM, $ per contract ▪ Percent increase in average price of design contracts due to BIM, % ▪ Duration of cost increase (i.e., expected time for BIM requirements to become non-burdensome), years
Data & Assumptions Available in Tool	▪ User input / agency-specific ▪ User input / agency-specific ▪ 10% increase in design contract value (expert panel; MNDOT SPR-1680) ▪ 3 years (suggested value) / agency-specific
Data Collection Needs	▪ Level 1 – Number of design contracts from agency records / project data ▪ Level 1 – Design contract value from agency records / project data ▪ Level 2/3 – Percent increase in contract value from sample of BIM projects; and/or formal comparison BIM vs. no-BIM from sample of otherwise similar projects ▪ Level 3 – Duration of cost increase to be observed over time (will be difficult to establish, while controlling for other contributing factors)
Comments	The increase in contract prices is expected to be temporary. The duration of this increase can be specified within the tool (default value of 3 years).

CO9. Cost of Additional Staff Needed for BIM Program

Description	Cost of hiring additional staff needed for BIM program
Quantification	*Annual investment cost = Number of staff required by role (employees) x Average annual staff salary by role ($ per employee per year)*
Data Required	▪ Number of staff required by role, employees ▪ Average annual staff salary by role, $ per employee per year
Data & Assumptions Available in Tool	▪ 3 new staff, including 1 project manager, 1 transportation engineer, and 1 IT/CADD staff (assumptions based on case studies) ▪ $131,500 for project manager; $93,600 for transportation engineer; and $75,600 for IT/CADD staff (BLS, U.S. national average annual salaries)
Data Collection Needs	▪ Level 2 – number of new hires by role, with exact salary information
Comments	N/A

CO10. Cost of Acquiring Digital As-builts once Project is Completed

Description	Cost of acquiring digital as-builts once a project is completed
Quantification	*Annual investment cost = Average number of projects requiring BIM (projects per year) x Average cost to procure digital as-built ($ per project)*
Data Required	▪ Number of projects requiring BIM, projects per year ▪ Average cost to procure digital as-built, $ per project requiring BIM

	▪ Years until manual process becomes automated, and thus cost is no longer incurred
Data & Assumptions Available in Tool	▪ User input / agency-specific ▪ $181,601 per project (FHWA, MNDOT & Iowa DOT) ▪ 5 years (suggested value) / agency-specific
Data Collection Needs	▪ Level 2/3 – Cost of digital as-built from sample of BIM projects/contracts ▪ Level 3 – Duration of cost increase to be observed over time
Comments	This cost would only be incurred in the short run until the process, now manual, becomes automated. The time when this would occur is agency-specific (default value of 5 years specified in the tool).

CO11. Cost to Maintain Database of Digital As-Builts

Description	Cost to maintain database of digital as-builts
Quantification	*Annual investment cost = Staff time to maintain digital as-built database (hours per year) x Average hourly wages of staff maintaining database ($ per hour)*
Data Required	▪ Staff time to maintain digital as-built database (all staff), hours per year ▪ Average hourly wages of staff maintaining database, $ per hour
Data & Assumptions Available in Tool	▪ No data / agency-specific ▪ $42 per hour (BLS, U.S. national average wages, transportation engineers)
Data Collection Needs	▪ Level 3 – Time spent maintaining database of as-builts from discussions/interviews with agency staff; actual time measurements would be difficult – may require new/expanded time-keeping procedures; number of staff involved by role and/or with exact salary information
Comments	This cost stream is not considered in the Default Analysis

Appendix II – Additional Information on Tools Reviewed

Data Requirements for UK BIM Benefits Measurement Framework

Measurement Category	#	High-Level Benefit Areas	Associated Pathways	Data Requirements
Time Savings	**1**	Time savings in Strategy & Definition Stages	3	▪ Reduction in direct labor costs: ○ Time savings from BIM for each person who saves time, days ○ Average daily wage, including overheads, $ per day ▪ Reduction in time-dependent recurring preliminary costs (e.g., labor, general site administration, services, and security) ○ Project schedules for two similar projects with and without BIM, days; understanding of schedule reduction that can be attributed to BIM ○ Average daily 'prelim' costs, $ per day
	2	Time savings in Design	15	
	3	Time savings in Build & Commission	12	
	4	Time savings from answering RFIs	2	▪ RFI logs; understanding of any changes in RFIs (both in terms of quantity issued, and time taken to respond) attributable to BIM ▪ Average daily wage, including overheads, $ per day
	5	Time savings in Handover	4	▪ Project schedules for two similar projects with and without BIM, days; understanding of schedule reduction that can be attributed to BIM ▪ Average daily project costs during Handover, $ per day
	6	Time savings in incident response	1	▪ Incident logs, understanding of any changes in incidents (i.e., time taken to respond) that can be attributed to BIM ▪ Average daily wage including overheads, $ per day
Material Savings	**7**	Materials savings in Build & Commission	5	▪ Project cost plan detailing material usage in physical units; design-stage or final bills of quantities ▪ Understanding of any change in materials attributable to BIM, % or in physical units (e.g., tons) ▪ Cost of materials, $ per unit
	8	Environmental benefit from fewer materials used	20	▪ Project cost plan detailing material usage, including quantities and types of materials used ▪ Values of carbon dioxide equivalent per material, and estimate of the social cost of carbon (from applicable guidance documents)
Cost Savings	**9**	Cost savings from better clash detection	6	▪ Clash logs or other records containing number of identified clashes for BIM project and for suitable counterfactual

Measurement Category	#	High-Level Benefit Areas	Associated Pathways	Data Requirements
				▪ Assumptions re. average cost of clashes, including time and materials, with and without BIM
	10	Cost savings from fewer changes	5	▪ Change logs or other records containing number of approved change requests for BIM project and for suitable counterfactual ▪ Assumptions re. average cost of changes, including time and materials
	11	Cost savings in operations – facilities management	4	▪ Maintenance costs (e.g., staffing, CAFM systems, utility bills) for project delivered with BIM and for suitable counterfactual ▪ Estimate for the reduction in greenhouse gas emissions attributable to BIM (e.g., change in energy use, and emissions per GWh)
	12	Cost savings in asset maintenance	4	▪ Time required for maintenance planning and execution using Asset Information Models (AIM) vs. conventional documentation ▪ Total annual cost of holding inventory for an asset using AIM for maintenance vs. total cost without ▪ Total cost of training staff in maintenance using BIM models vs. traditional site-based methods (e.g., in-person site visits)
	13	Cost savings in refurbishment	4	▪ Cost estimates, time, and materials, for refurbishment projects (e.g., change in asset use) undertaken with and without BIM
	14	Cost savings in asset disposal	3	▪ Total cost of demolition planned with and without BIM (including labor and material costs, and value of salvaged materials) ▪ Change in time required to sell an asset resulting from the use of AIM; and average daily wage including overheads, $ per day
	15	Cost savings in litigation	4	▪ Reduction in number of claims attributable to BIM (BIM project vs. counterfactual); and average cost of claims, $ per claim ▪ Historic cost / time estimates / quotes for claims-investigation work from external consultants, with and without BIM
Health & Safety	**16**	Improved H&S in construction	3	▪ Number of fatal and non-fatal accidents per project; number of incidents of work-related ill-health per project ▪ Details about those accidents / incidents to determine whether BIM could have affected them ▪ Cost to society per accident / incident
	17	Improved H&S in maintenance / demolition	3	

Measurement Category	#	High-Level Benefit Areas	Associated Pathways	Data Requirements
Reduced Risk	**18**	Reduced project risk contingency in delivery phase	5	▪ Project contingency detail for relevant stage (capital/operating) for two similar projects, with and without BIM ▪ Understanding of any factors affecting project contingency due to events that BIM could not influence ▪ Social rate of time preference (~opportunity cost of contingency held), % per annum
	19	Increased certainty in operating expenditure estimates	1	
Utilization	**20**	Improved asset utilization	5	▪ Change in asset's downtime or improvement in asset's productivity due to BIM (with context-specific productivity metric) ▪ Value foregone when the asset is unavailable and/or avoided asset replacement costs
Quality	**21**	Improved asset quality	3	▪ No specific data requirement: asset-specific (e.g., reduction in staff turnover from improved working environment; reduced roadway accidents)
Other	**22**	Improved reputation	5	▪ No specific data requirement: generally not quantified / monetized – could be assessed through surveys

Data Requirements for TFRS-02 ROI Tool

Benefits

Benefit Categories	#	Benefit Streams	Data Requirements	Sources Used in Tool
In-House Agency Benefits	**1**	Cost savings from reduced paper, printing, and distribution	▪ Percent reduction in agency costs associated with paper, printing, and distribution ▪ Average annual spending on paper, printing, and distribution, $ per year	▪ Expert panel, and NCHRP Report 866 ▪ Expert panel
	2	Cost savings from reduced physical storage needs and office space	▪ Reduction in office space required for storage due to BIM digital files, sqft ▪ Price of office rental space, $ per sqft	▪ Case Studies ▪ U.S. average per sqft, PriceItHere.com
	3	Avoided vehicle crashes due to safety simulation with BIM	▪ Percent reduction in workorders for post-crash cleanup/repair ▪ Average spending on workorders for post-crash cleanup/repair, $ per year	▪ CMFs for treatments to reduce poor sight distance; Not specific to BIM (FHWA-SA-11-08) ▪ MNDOT, Statewide Highway Systems Operation Plan (2012)
	4	Improved worker safety during construction inspections	▪ Percent reduction in worker accidents during construction period ▪ Average number of worker injuries occurring on agency construction sites per year	▪ Expert panel, and Dodge Data & Analytics (2015) ▪ Agency-specific
	5	Improved worker safety during maintenance inspections	▪ Percent reduction in exposure to live traffic during maintenance inspections ▪ Average number of worker injury incidents per inspection ▪ Average number of on-site worker inspections required per year	▪ Expert panel, and ODOT SPR-787 ▪ Expert panel, and FHWA Work Zone Facts and Statistics ▪ Expert panel, and ODOT SPR-787
	6	Cost savings on inspections due to the use of drones	▪ Percent reduction in average cost per inspection ▪ Average cost per (in-person) maintenance inspection, $ per inspection ▪ Average number of (in-person) inspections per year	▪ Expert panel data and MNDOT (2018) ▪ Expert panel data and MNDOT (2018) ▪ Expert panel data and ODOT SPR-787

Benefit Categories	#	Benefit Streams	Data Requirements	Sources Used in Tool
Project Cost Savings	**7**	Cost savings from avoided change orders	▪ Reduction in spending on change orders due to conflict avoidance, % of project cost	▪ Expert panel, Azhar (2011), and FHWA-HRT-17-027
	8	Cost savings from improved schedule management	▪ Percent improvement or optimization in project schedule ▪ Average duration of project schedule for typical project w/o BIM, days ▪ General conditions costs, % of total project cost ▪ Average value of a day saved on project schedule, $ per day	▪ Expert panel, Case studies, and Bentley YII Case Studies ▪ Agency-specific ▪ Ruff (2018), 6 to 12% ▪ Agency-specific
	9	Lower construction bid prices due to improved communication of design intent	▪ Percent reduction in average project cost	▪ Bentley YII Case Studies, and Case Studies
	10	Cost savings from creating visualizations with BIM	▪ Percent reduction in cost to create visualization product ▪ Average cost of creating visualization products w/o BIM, $ per project	▪ Agency-specific ▪ Agency-specific
	11	Cost savings from optimization of construction material or design options	▪ Percent reduction in spending on construction materials or alternate design options ▪ Average spending on materials or design options, % of project costs or $ value	▪ Bentley YII Case Studies ▪ Agency-specific
Staff Time Savings	**12**	Time savings from re-using previous BIM content for future similar work	▪ Percent reduction in time spent to complete models due to use of templates ▪ Average time to build models from scratch, without templates, hours per project ▪ Average hourly wage of design staff, $ per hour	▪ Case studies ▪ Case studies ▪ Staff & salary data (BLS)
	13	Time savings from avoiding tracking down information for scoping project	▪ Hours saved on project scoping (all staff), hours per project ▪ Average hourly wage of staff used for project scoping, $ per hour	▪ Case studies ▪ Staff & salary data (BLS)

Benefit Categories	#	Benefit Streams	Data Requirements	Sources Used in Tool
	14	Time savings from improved design efficiency	▪ Percent reduction in time spent on design ▪ Typical hours spent on project design without BIM, hours per project ▪ Average hourly wage of design staff, $ per hour	▪ Bentley YII Case Studies, and Case Studies ▪ Value from Bentley YII Case Studies / Agency-Specific ▪ Staff & salary data (BLS)
	15	Time savings in document review and approval due to faster turnaround time	▪ Percent reduction in time spent on document review/approval ▪ Typical time spent reviewing/approving documents without BIM, hours per project ▪ Average hourly wage of reviewers, $ per hour	▪ Case studies, expert panel, and Bentley YII Case Studies ▪ Agency-specific ▪ Staff & salary data (BLS)
	16	Time savings from avoided RFIs due to improved clarity of design	▪ Percent reduction in RFIs ▪ Typical number of RFIs per project ▪ Average staff time spent on responding to RFIs, hours per RFI ▪ Average hourly wage of RFI responders, $ per hour	▪ Expert panel, and Applied Software (2009) ▪ Agency-specific ▪ Agency-specific ▪ Staff & salary data (BLS)
	17	Staff time saved from improved schedule management / improved workforce utilization	▪ Percent improvement or optimization in project schedule due to BIM ▪ Average duration of project schedule for "typical project" (without BIM), days ▪ Number of employees affected by improved schedule, employees per project ▪ Average hourly wage of staff involved in project construction, $ per hour	▪ Expert panel, Case studies, and Bentley YII Case Studies ▪ Agency-specific ▪ Agency-specific ▪ Staff & salary data (BLS)
	18	Time savings during construction inspections due to use of 3D digital design data	▪ Percent reduction in time spent on inspections due to BIM ▪ Average time spent on construction inspections without BIM, hours per project ▪ Average hourly wage of construction inspection staff, $ per hour	▪ Expert panel ▪ Agency-specific ▪ Staff & salary data (BLS)
	19	Time savings on completing design quantities	▪ Percent reduction in time spent completing quantities due to automation	▪ Expert panel, Case studies, and Bentley YII Case Studies ▪ Case studies

Benefit Categories	#	Benefit Streams	Data Requirements	Sources Used in Tool
			▪ Typical time spent calculating design quantities by hand, hours per project ▪ Average hourly wage of design staff, $ per hour	▪ Staff & salary data (BLS)
	20	Avoided time spent tracking down information for routine maintenance or repair work	▪ Average time spent on data collection for maintenance (all staff), hours per year ▪ Percent reduction in time spent tracking down data for maintenance due to BIM ▪ Average hourly wage of maintenance data collection staff, $ per hour	▪ FHWA-HIF-15-023 UDOT Case Study ▪ FHWA-HIF-15-023 UDOT Case Study ▪ Staff & salary data (BLS)

Costs

Cost Categories	#	Cost Streams	Data Requirements	Sources used in Tool
Initial / One-Time Costs	**1**	Initial cost of BIM and AM system configuration and customization	▪ Average cost of professional service contractor to setup, program, configure, and/or customize system solution	▪ Expert panel, cost research, and estimates by BIM personnel
	2	Initial BIM hardware investments or upgrades	▪ Cost of equipment required: number of units and average cost per unit, for computers, tablets, GPS rovers, drones, automatic digital levels & tripods, Lidar systems, etc.	▪ Agency data received, case studies, and cost research ▪ Quantities will be agency-specific
	3	Cost of initial comprehensive staff training	▪ Fee for external training sessions, $ per hour ▪ Number of session hours, by session-type (e.g., roadway modeling, drainage/utility modeling bridge modeling, survey modeling, construction inspection)	▪ Cost research ▪ Assumptions informed by case studies and BIM practitioners
	4	Opportunity cost of staff time for initial comprehensive training	▪ Number of staff required to attend initial comprehensive training, employees ▪ Average hourly wages of staff attending training, $ per hour	▪ Case studies ▪ Staff & salary data (BLS)

Cost Categories	#	Cost Streams	Data Requirements	Sources used in Tool
Ongoing Costs	**5**	Incremental costs of BIM-related software subscription	▪ Annual software cost, $ per year	▪ Cost research, to be adjusted with agency-specific inputs
	6	Incremental spending on IT resources or infrastructure from BIM	▪ Cost to upgrade current versions or purchase new supporting software / data storage services (e.g., cloud storage capacity, ProjectWise capacity, internet speed), $ per year	▪ Agency-specific
	7	Semi-regular hardware replacement costs	▪ Average replacement cycle for all BIM-supporting hardware (e.g., computers, tablets, GPS rovers, drones, automatic digital levels & tripods, Lidar systems), years	▪ Assumptions informed by Case studies / Agency-specific
	8	Cost of external refresher staff trainings	▪ Fee for external ongoing training sessions, $ per hour ▪ Duration of session, hours per session ▪ Frequency of external refresher training session, years	▪ Cost research ▪ Agency-specific ▪ Agency-specific
	9	Opportunity cost of staff time for external refresher trainings	▪ Number of staff attending external refresher trainings, employees ▪ Average hourly wages of staff attending external refresher trainings, $ per hour	▪ Agency-specific ▪ Staff & salary data (BLS)
	10	Opportunity cost of staff time for internal refresher trainings	▪ Duration of internal refresher training sessions, hours per session ▪ Frequency of internal refresher training session, years ▪ Number of staff required to attend refresher trainings, employees ▪ Average hourly wages of staff attending training, $ per hour	▪ Agency-specific ▪ Agency-specific ▪ Assumptions informed by Case studies ▪ Staff & salary data (BLS)
	11	Opportunity cost of creating new training materials	▪ Hours required to create new training materials, ahead of refresher trainings, hours ▪ Average hourly wages of staff creating training material, $ per hour	▪ Assumptions informed by Case studies ▪ Staff & salary data (BLS)

Cost Categories	#	Cost Streams	Data Requirements	Sources used in Tool
	12	Increase in cost of professional services due to requiring BIM for design	▪ Change in average price of professional services contract, % of design contract value ▪ Duration of cost increase (time for BIM requirements to become non-burdensome), years	▪ Expert panel and MNDOT SPR-1680 ▪ Agency-specific
	13	Cost of hiring additional staff needed for BIM program	▪ Number of staff required by type, new employees ▪ Salary of staff by type, $ per employee per year	▪ Assumption informed by Case studies ▪ Staff & salary data (BLS)
	14	Cost of acquiring digital as-built once project is completed	▪ Cost to procure digital as built, $ per project ▪ Years until manual process becomes automated (and thus cost is no longer incurred)	▪ FHWA, MNDOT & Iowa DOT ▪ Agency-specific
	15	Cost of maintaining database of digital as-builts	▪ Staff time to maintain digital as-built database (all staff), hours per year ▪ Average hourly wages of staff maintaining database, $ per hour	▪ Agency-specific ▪ Staff & salary data (BLS)

Data Requirements for EC BCA Tool

Benefits

#	Benefit Streams	Data Requirements	Sources & Notes in Tool
1	Cost reduction due to early clashes and error detection, and subsequent reduction in changes necessary in construction phase	▪ Average cost reduction due to BIM, % ▪ Adjustment in case project is for existing vs. new asset, reducing potential BIM benefits (-20%)	▪ Extracted from survey, 0s included, condition set (<= 10%) ▪ Assumption
2	Cost reduction associated with more precise quantity take-offs	▪ Average cost reduction due to BIM, %	▪ Extracted from survey, 0s included, condition set (<= 10%)

#	Benefit Streams	Data Requirements	Sources & Notes in Tool
3	Cost reduction related to lower costs for claims/litigations	▪ Average reduction in litigations-related costs due to BIM, % ▪ Average cost of litigations, expressed as share of total project cost (planning, design, and construction), %	▪ Extracted from survey, 0s included, no condition set ▪ Extracted from survey, 0s excluded, condition set (<= 20%)
4	Time savings in design and construction phases, and associated reduction in project duration	▪ Average time reduction due to BIM, % ▪ Adjustment in case project is for existing asset (-30%)	▪ Extracted from survey, 0s included, condition set (<= 10%) ▪ Assumption
5	Public entity personnel labor cost reduction due to faster document analysis for facility management and maintenance (FMM)	▪ Average reduction in time necessary to plan FMM by public entity employees due to BIM, % ▪ Average number of days to plan FMM for single asset, days ▪ Average number of days worked per year by an individual	▪ Extracted from survey, 0s included, average condition set (<80%) ▪ Extracted from survey, 0s excluded, condition set (<100 days), focus on BIM maturity level 0 ▪ Calculated, EU-27 average (2019)
6	Cost reduction associated with more efficient annual maintenance	▪ Annual maintenance expense on project asset ▪ Average cost reduction in annual maintenance due to BIM, %	▪ Project-specific (user-specified) ▪ Extracted from survey, 0s included, condition set (<70%)
7	Cost reduction due to better Health & Safety	▪ Average societal cost of work-related injuries and diseases, $ ▪ Average number of accidents avoided per tender/project	▪ European Agency for Safety and Health at Work ▪ Extracted from survey, 0s included, condition set (<40)
8	Reduction in CO2 emissions due to reduced material waste	▪ Average CO2 emitted per square meter, tonnes ▪ Average reduction in CO2 emissions due to BIM, % ▪ Adjustment in case project is for existing asset (-50%) ▪ Price of CO2 emissions, $ per tonne	▪ Source not specified ▪ Extracted from survey, 0s included, condition set (<40%) ▪ Assumption ▪ EU Emissions Trading System (ETS)

Costs

#	Cost Streams	Data Requirements	Sources & Notes in Tool
1	Public entity personnel labor cost increase during pre-tendering phase	▪ Overall procurement cost, % of total project cost ▪ Percent of total procurement cost in pre-tendering phase, % ▪ Pre-tendering phase cost increase due to BIM, by maturity level, % ▪ Adjustment in case project is for existing asset (-20%)	▪ Extracted from survey, 0s excluded, condition set (<40%), varies with total project cost (between 5% and 10%) ▪ Extracted from survey, 0s excluded, no condition set ▪ Extracted from survey, 0s included, condition set (<80%) ▪ Assumption
2	Public entity personnel labor cost increase during tendering phase	▪ Percent of total procurement cost in tendering phase, % ▪ Tendering phase cost increase due to BIM, by maturity level, % ▪ Adjustment in case project is for existing asset (-20%)	▪ Extracted from survey, 0s excluded, no condition set ▪ Extracted from survey, 0s included, condition set (<80%) ▪ Assumption
3	Public entity personnel labor cost increase during post-award phase	▪ Percent of total procurement cost in post-award phase, % ▪ Post-award phase cost increases due to BIM, by maturity level, %	▪ Extracted from survey, 0s excluded, no condition set ▪ Extracted from survey, 0s included, condition set (<80%)
4	Increased cost for consulting services to the public procurement process	▪ Percent of total procurement cost outsourced to consultants, % ▪ Consulting cost increase due to BIM, by maturity level, %	▪ Extracted from survey, 0s excluded, no condition set ▪ Extracted from survey, 0s included, condition set (<80%)
5	Costs of BIM modelling activity (outsourced)	▪ Level of details/development required in tender, LOD 200-350-500 ▪ Hours of model development by LOD, overall and for individual systems (by level of complexity), hours per sqm ▪ Average national hourly cost for BIM specialist, $ per hour	▪ Project-specific (user-specified) ▪ Data source not specified, presumably from survey ▪ User-specified (no value in tool)
6	Public entity hardware upgrade investment, allocated to specific project	▪ Average investment in hardware upgrade, $ per organization	▪ Extracted from survey, 0s excluded, condition set (minimum investment = €100; maximum = €1,100,000)

#	Cost Streams	Data Requirements	Sources & Notes in Tool
		▪ Average number of employees trained on BIM ▪ Number of employees working on BIM for project	▪ Extracted from survey, 0s excluded, condition set (<900 individuals) ▪ Project-specific (user-specified)
7	Public entity annual software license fee, allocated to specific project	▪ Annual license for CDE Software (e.g., BIM Collab, Trimble Connect) ▪ Annual license for Review / Model Check (e.g., Navisworks) ▪ Annual license for Modelling Software (e.g., REVIT, Autodesk AEC)	▪ 1 license for 10 users, based on advertised prices ▪ 1 license for projects < €50M; 2 for projects > €50M ▪ 1 license during construction and FM / Operations
8	Personnel training costs, allocated to specific project	▪ Average cost to train an employee, depending on BIM maturity level ▪ Number of hours required to train an employee, hours	▪ Extracted from survey, 0s excluded, condition set (minimum investment > €100; maximum < €20,000) ▪ Assumption (150 hours)
9	BIM coordination costs (calculated as function of model development costs and asset complexity level)	▪ Total model development costs, $ ▪ Actual, overall asset complexity level ▪ Maximum asset complexity level	▪ Calculated – cost item #5 ▪ Calculated from user-specified inputs (score of 1 to 3 for individual systems) ▪ Parameter, set to 3

Data Requirements for FHWA Paperless Delivery ROI Tool

Benefits

Improvement Opportunity	#	Benefit Streams	Data Requirements
Electronic Bidding and Contract Award	**1**	▪ Savings resulting from non-responsive low bids due to math or clerical errors	▪ Annual construction program, $ ▪ Annual cost savings from non-responsive low bids due to math or clerical errors, %
	2	▪ Savings resulting from improved workforce utilization	▪ Number of hours saved by staff in bid data entry, evaluation, reporting and verification/validation, hours per bid ▪ Hourly rate for staff, fully loaded, $ per hour ▪ Number of project bids per year
Digital Plans, Specifications and Estimates (Pre-construction)	**3**	▪ Time savings during PS&E review/comments	▪ Number of hours saved per design contract for PS&E review/comments ▪ Hourly rate for staff, fully loaded, $ per hour ▪ Number of project bids per year
	4	▪ Cost saving for quantity take-off and other analysis activities	▪ Number of hours saved for quantity take-off and other analysis activities ▪ Number of design contracts per year
	5	▪ Eliminated use of paper, printing, mailing, faxing, scanning and reduced paper storage requirements	▪ Number of eliminated plan sheets printed per project/contract ▪ Total cost (paper, toner, processing, storage) per page for plan sheets, $ ▪ Number of eliminated pages printed per project/contract, specifications ▪ Total cost (paper, toner, processing, storage) per page, $
Digital Review	**6**	▪ Eliminated use of paper, printing, mailing, faxing, scanning and reduced paper storage requirements	▪ Number of projects per year ▪ Average number of eliminated pages printed per contract ▪ Total cost per page, $
	7	▪ Increase in the overall efficiency and effectiveness of the delivery of the agency's construction program by streamlining and	▪ Average project duration, weeks ▪ Time savings per week on project through more efficient reviews, hours

Improvement Opportunity	#	Benefit Streams	Data Requirements
		standardizing key processes (e.g., faster review and approvals)	▪ Hourly rate for staff, fully loaded, $ per hour
Project Construction Management System	**8**	▪ Increase in the overall efficiency and effectiveness of the delivery of the agency's construction program by streamlining and standardizing key processes (e.g., faster review and approvals) and integration of material testing and laboratory functions.	▪ Number of projects per year ▪ Average project duration, weeks ▪ Average number of agency staff members working on project ▪ Average number of hours saved each week per person per project, through improved efficiency and effectiveness, hours ▪ Hourly rate for staff, fully loaded, $ per hour
	9	▪ Reduction in claims	▪ Total value of claims processed annually, $ ▪ Percent reduction/avoidance in annual claims due to more comprehensive project documentation, %
	10	▪ Reduction in change orders	▪ Total value of change orders processed annually, $ ▪ Percent reduction in change orders, %
	11	▪ Reduced use of paper, printing, mailing, faxing, scanning	▪ Number of eliminated pages printed per project ▪ Total cost (paper, toner, processing, storage) per page, $
Project Collaboration through Document Management System	**12**	▪ Eliminated use of paper, printing, mailing, faxing, scanning, and reduced paper storage requirements	▪ Number of projects per year ▪ Number of eliminated pages printed per project ▪ Total cost (paper, toner, processing, storage) per page, $
	13	▪ Increase in the overall efficiency and effectiveness of the delivery of the agency's construction program by streamlining and standardizing key processes (e.g., faster review and approvals)	▪ Average project duration, weeks ▪ Average number of agency staff members working on project ▪ Average number of hours saved each week by project staff, hours ▪ Hourly rate for staff, fully loaded, $ per hour
Digital As-Builts	**14**	▪ Reduced time to verify as-builts	▪ Number of projects per year ▪ Reduction in number of hours to verify as-builts as submitted by contractor, hours per project ▪ Hourly rate for staff, fully loaded, $ per hour

Improvement Opportunity	#	Benefit Streams	Data Requirements
	15	▪ Faster access to data in the future and ability to use the information for asset management and other activities	▪ Number of completed projects accessed per year ▪ Reduction in number of hours to retrieve project data, hours per project
Mobile Devices	16	▪ Time to create daily inspection report	▪ Number of inspectors ▪ Number of workdays per week ▪ Duration of construction season, weeks ▪ Hourly rate for staff, fully loaded, $ per hour ▪ Estimated time savings from entering data on mobile device vs. recording on paper and then entering on a computer, hours per inspector per week
	17	▪ Time to travel offsite to office to submit documentation	▪ Estimated time savings from traveling offsite to the office to submit documentation per daily inspection report, hours per inspector per week
	18	▪ Time to search for content	▪ Estimated time savings from searching for content per daily inspection report, hours per inspector per week
	19	▪ Additional benefit to digital review process through use of mobile devices	▪ Annual construction program, $ ▪ Annual cost savings from ability to access files in field, %
	20	▪ Additional benefit to project collaboration through use of mobile devices	▪ Annual cost savings from ability to access files on site and upload information such as pictures, %
	21	▪ Additional benefit to project construction management through use of mobile devices	▪ Annual cost savings from electronic review of payroll information, entry of daily work reports and other similar activities, %
Seamless Integration	22	▪ Use of a common database for the complete project delivery process to reduce data entry, ensure more complete and accurate project data, increase efficiency of information retrieval, and provide data for analysis, reporting, and management reporting.	▪ Annual construction program, $ ▪ Annual cost savings from seamless integration, %
	23	▪ Use of a pre-construction management system to prepare bid materials. Contract language in bid materials would specify the requirements of geospatial data so that there	▪ Annual construction program, $ ▪ Annual cost savings from seamless integration, %

Improvement Opportunity	#	Benefit Streams	Data Requirements
		is a common data environment for design, construction, and construction management.	
	24	▪ Integrating the pre-construction management system with the electronic bidding tool to seamlessly upload bid materials to the agency's electronic bidding tool.	▪ Annual construction program, $ ▪ Annual cost savings from seamless integration, %
	25	▪ Use of electronic bidding and digital signatures by contractors to submit bids, and subsequently by the agency to review bid data (including verifying bid bonds) and conducting bid analysis.	▪ Annual construction program, $ ▪ Annual cost savings from seamless integration, %
	26	▪ Integration of construction data into the agency project management system to allow for agency wide views of all projects information including budgets, expenditures, commitments, status, schedule, and other key project metrics.	▪ Annual construction program, $ ▪ Annual cost savings from seamless integration, %
	27	▪ Integration with federal systems for FHWA project authorizations and modifications	▪ Annual construction program, $ ▪ Annual cost savings from seamless integration, %
	28	▪ Linking bid submittal information (e.g., contract unit prices, pay items, etc.) into the construction management system for project initiation.	▪ Annual construction program, $ ▪ Annual cost savings from seamless integration, %
	29	▪ Managing contract administration, contract records, daily work reports, contractor payments, materials management, and laboratory inventory management using the project construction management system. The project construction management system should have workflows built in to ensure seamless document routing.	▪ Annual construction program, $ ▪ Annual cost savings from seamless integration, %

Improvement Opportunity	#	Benefit Streams	Data Requirements
	30	▪ Use of a project collaboration tool to effectively manage all contract documents (including the ones listed above in the construction management system).	▪ Annual construction program, $ ▪ Annual cost savings from seamless integration, %
	31	▪ Use of the construction management system to conduct the final close-out process (including final acceptance), confirm all approvals and signatures are in place, send the project for final payment to financial and accounting systems.	▪ Annual construction program, $ ▪ Annual cost savings from seamless integration, %

Costs

Improvement Opportunity	#	Cost Streams
Electronic Bidding and Contract Award	1	Systems integration services
	2	Systems integration services for upgrade
	3	Managed services support
	4	Hardware and other technical infrastructure
	5	Hardware replacement/updates
	6	Agency staff costs for implementation and ongoing support
Digital Plans, Specifications and Estimates (Pre-construction)	7	Pre-implementation planning consultant
	8	Commercial Off-The-Shelf (COTS) software licenses
	9	COTS software maintenance
	10	Systems integration services
	11	Managed services support
	12	Hardware and other technical infrastructure
	13	Hardware and infrastructure maintenance
	14	Hardware replacement/updates
	15	Systems integration services for upgrade

Improvement Opportunity	#	Cost Streams
	16	Agency staff costs for implementation and ongoing support
Digital Reviews	**17**	Pre-implementation planning consultant
	18	COTS software licenses
	19	COTS software maintenance
	20	On-site training/web-based training
	21	Agency staff costs during project
	22	Agency staff costs for ongoing system support
	23	Conversion of existing paper documents to electronic documents / scanning
Project Construction Management System	**24**	Pre-implementation planning consultant
	25	COTS software licenses
	26	COTS software maintenance
	27	Systems integration services
	28	Managed services support
	29	Hardware and other technical infrastructure
	30	Hardware and infrastructure maintenance
	31	Hardware replacement/updates
	32	Agency staff cost during project
	33	Agency staff cost to support system ongoing
	34	Systems integration services for upgrade
Project Collaboration through Document Management System	**35**	Pre-implementation planning consultant
	36	COTS software licenses
	37	COTS software maintenance
	38	Systems integration services
	39	Managed services support
	40	Hardware and other technical infrastructure
	41	Hardware and infrastructure maintenance
	42	Hardware replacement/updates
	43	Agency staff cost during project

Improvement Opportunity	#	Cost Streams
	44	Agency staff cost to support system ongoing
	45	Systems integration services for upgrade
Digital As-Builts	**46**	Additional contracting cost
Mobile Devices	**47**	Pre-implementation planning consultant: General
	48	Pre-implementation planning consultant: Digital review (Optional)
	49	Pre-implementation planning consultant: Project collaboration (Optional)
	50	Pre-implementation planning consultant: Project construction management (Optional)
	51	COTS software licenses
	52	COTS software maintenance
	53	Systems integration services
	54	Managed services support
	55	Hardware and other technical infrastructure
	56	Hardware and infrastructure maintenance
	57	Hardware replacement/updates
	58	Agency staff cost during project
	59	Agency staff cost to support system ongoing
	60	Systems integration services for upgrade

BIM FOR BRIDGES AND STRUCTURES TPF-5(372)

Data Requirements for the Michigan DOT ROI Tool

Benefits

#	Benefit Streams	Data Requirements	Sources & Notes in Tool
1	Reduction in change orders due to quantity deviations, and errors and omissions	▪ Annual construction program by year, \$ ▪ Average percent of change orders per year, % of overall construction program ▪ Percent of all change orders due to quantity changes ▪ Percent of all change orders due to errors and omissions	▪ Data from MDOT ▪ Historical data from MDOT ▪ FHWA (2018), national study ▪ FHWA (2018), national study
2	Cost savings from the use of AMG	▪ Annual savings from low bids, due to low bidder using AMG construction	▪ User-specified (not provided in tool)

Costs

#	Cost Streams	Data Requirements	Sources & Notes in Tool
1	Cost of producing 3D models	▪ Professional Engineering services cost as percent of construction cost, % ▪ Cost to produce 3D models, as percent of design contract, %	▪ MDOT ▪ Assumption based on survey responses
2	Additional staff to provide technical support of models	▪ Engineering support staff for 3D design, number of FTEs ▪ Hourly Rate for Engineering Support Staff, \$ per hour ▪ Loaded rate factor ▪ Salary increases factor ▪ Professional services for 3D Model implementation (e.g., software configuration, training, etc.)	▪ Assumption (one FTE) ▪ Default value (no source) ▪ Default value (no source) ▪ Assumption (2% annual raise) ▪ User-specified (not provided in tool)

Appendix 18: Technical Solution Summary for the Design-to-Construction Data Exchange Standard for Highway Bridges

BIM FOR BRIDGES AND STRUCTURES

TPF-5(372)

Technical Solution Summary for the Design-to-Construction Data Exchange Standard for Highway Bridges

Date: March, 2024

Version: Final

BIM FOR BRIDGES AND STRUCTURES TPF-5(372)

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TPF-5(372) Technical Solution Summary

What is It?

The TPF-5(372) technical solution is based on the standards and services provided by buildingSMART International (bSI) and the four key deliverables produced by the TPF-5(372) study. Together, all these products and services will enable stakeholders to exchange model-based deliverables using open data standards.

The four TPF-5(372) products are listed below and are further explained within the details of this document and illustrated in an infographic (Appendix A).

1. *Information Delivery Manual (IDM) for the Design to Construction Data Exchange for Highway Bridges, 1St Edition* (1).
2. *AASHTO Bridge Data Dictionary (ABDD).*
3. *Information Delivery Specification (IDS) for the Design to Construction Data Exchange for Highway Bridges, Version 1.0.*
4. *Unit Test Suite.*

The bSI standards and services used as the foundation for the TPF-5(372) Technical Solution products include:

1. The Industry Foundation Classes (IFC) Schema and the Alignment-based Reference View (AbRV), which is a subset of the entire IFC schema.
2. The Information Delivery Specification (IDS) standard.
3. The buildingSMART Data Dictionary (bSDD) Service.
4. The IFC Validation Service.
5. The Software Certification Service.

Specifically, this technical solution was created to enable the use of IFC as a data exchange standard to deliver model-based files that contractors can rely on to prepare bids for design-bid-build (D-B-B) projects involving workhorse bridges; and execute construction activities including the initiation of fabrication of bridge components. The four TPF-5(372) products mark the cornerstones along the way to utilize the IFC standard for exchanging data in the U.S. for workhorse bridges. Workhorse bridges in the U.S. are defined as bridges with spans of less than 300 feet, generally constant girder-type structures assembled from standard structural components and systems – and are parts of the landscape that go unnoticed until it is time for their replacement.

To achieve the goal of enhanced interoperability between design and construction data exchanges, the TPF-5(372) technical solution needed to develop specific products that that would work with the bSI standards and services. bSI is the authority behind IFC and other open data standards. The technical solution described herein provides an overview of the products and methodology to enhance interoperability between the design and construction data exchange of bridge data.

Why is it Needed?

The purpose of this document is to provide stakeholders with a base level of information needed to enhanced interoperability using IFC and related standards and services. In specific, this document provides a detailed explanation of the four key products delivered by the TPF-5(372), which were created to start bridging the gap between the current state of the practice and an AASHTO unified vision to use open data standards to deliver model-based information to facilitate the exchange between design and construction. Because the adoption of open data standards is a complex process, it required creating these technical solutions and an information management strategy focused on digital processes, communication and sharing structured data that is both human and machine interpretable. This strategy is the focus of the TPF-5(372) Technical Solution that helps translate owner data requirements for specific exchanges into computer deliverables for highway bridge projects in the U.S. These computer deliverables are derived from bridge 3D models (geometry, structured data) that may be supplemented with documents, and referenced to various engineering standards.

Who Will Use it?

While the intended audience of the TPF-5(372) Technical Solution is U.S. State Departments of Transportation, other highway agencies delivering highway projects involving “workhorse bridges” (regardless of jurisdiction) will benefit from the products developed as part of this effort. The international community will also benefit from these products given they are based on an international standard.

The intended audience for this document is the individuals within a State DOT or a highway agency responsible for setting up, implementing, and maintaining modeling standards and project requirements related to bridge model-based deliverables.

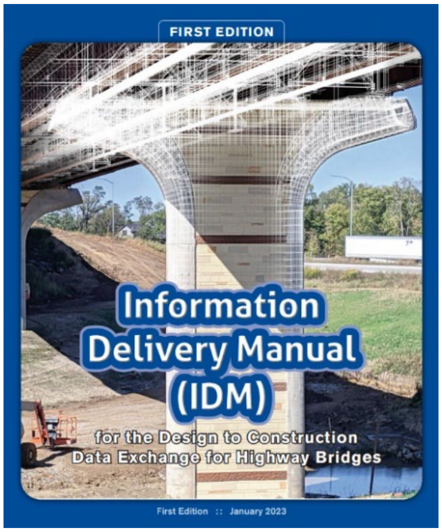
Overview of TPF-5(372) Technical Solution

The technology providers offering bridge modeling software for the Architecture, Engineering and Construction (AEC) industry work globally to provide these technical solutions. Therefore, there is consensus among the international community as well as the bridge industry in the U.S. to leverage the IFC standard and other technical solutions offered by bSI. The IFC4.3 standard is the most current version approved through the ISO process, and the basis for the TPF-5(372) Technical Solution.

While the technical baseline solution is based on the international IFC open data standard and its specific 4.3 version (including the AbRV), the AASHTO approved information requirements for the design-to-construction exchange depends on national and regional needs. These national and regional needs are reflected in the TPF-5(372) four key products. This section provides an overview of these four key products.

IDM for Design to Construction Data Exchange for Highway Bridges, 1st Edition

Overview



The AASHTO IDM is the authoratiative standard, published by AASHTO, defining the exchange requirements for bridge model data exchange requirements in a comprehensive set of tables presented in an engineering manual format.

In general, an IDM provides a methodology for a common understanding of the processes involved during the development of model-based data of the built environment within the asset management lifecycle. The data exchange requirements found in the AASHTO IDM are specific to the exchange of IFC files between design and construction, which could be used as the contractual deliverables for the construction of highway bridges. The use of IFC files will allow contractors to view bridge models in the software of their choice so they can prepare bids, execute construction activities, and initiate fabrication.

The AASHTO IDM was developed following the guidance provided by the ISO 29481 Part 1, which was the part of the ISO standard most applicable to the TPF-5(372) scope of work. Parts 1 and 2 of this ISO standard were available at the time of the development of the AASHTO IDM. Part 3 of this ISO standard was published in September 2022 after the development of the AASHTO IDM had concluded. This section provides an overview of the three parts of the ISO 29481 standard for general awareness.

ISO 29481-1: 2016 Building Information Modeling – Information Delivery Manual Part 1: Methodology and Format (2). This part of the standard specifies the methodology that links the business processes undertaken during the construction of built assets with information requirement specifications, and a way to create data flow diagrams that describe the information processes within the boundary of business process. Specifically, the AASHTO IDM defines the information requirements for the design-to-construction exchange from a bridge domain expert perspective.

ISO 29481-2: 2012 Building Information Modeling – Information Delivery Manual Part 2: Interaction Framework (3). This part of the standard specifies a methodology and format for describing coordination activities throughout the lifecycle of a given asset.

ISO 29481-3: 2022 Building Information Models – Information Delivery Manual – Part 3: Schema (4)**.** The new standard specifies a machine applicable, readable and transferable (SMART) data schema for the efficient development, management and reuse of IDM specifications based on the original Part 1 of the standard. In the past, the development and sharing the contents of an IDM in a digital format, were developed either as a static document file or as a data file specified in a proprietary data format, making the exchange, sharing and using of IDM content inefficient. So, Part 3 of the standard was developed to define a standard data schema that could expedite the development and sharing of future IDM specifications.

Considerations for Future IDM Development and Updates

The IDM provides a list of exchange information requirements (EIR) in a table format that classifies bridge objects in hierarchical categories (or systems) and identifies data properties for each object within the class (see foreword page iv in ISO 29481-1:2016) in a static manual style format that is easy for bridge domain experts to read and interpret. While Part 3 of the ISO standard is useful for long-term maintenance and advancement of BIM adoption, it is important to recognize that the contents of the TPF-5(372) AASHTO adopted IDM and future publications will need to be evaluated, reviewed and balloted by bridge domain experts who may prefer a traditional manual over an extensible markup language (XML) file, which is the recommended format deliverable for future IDM specifications.

Nevertheless, the AASHTO *IDM for the Design to Construction Data Exchange for Highway Bridges, 1st Edition*, will serve as an example that can be improved upon based on the new recommendations provided in Part 3 of the ISO standard.

Another consideration for future development of AASHTO adopted IDM is to evaluate how the ISO 29481 IDM standard and the currently in development **ISO 7817 (Part 1) Building Information Modeling - Level of Information Need - Concepts and Principles** overlap (5). This standard will:

- Focus on guidance related to determining the right level of information at a particular time of the lifecycle for a specific stakeholder (actor). It is intended to cover all lifecycle phases of built assets, and consider the purpose of the information, information delivery milestones, actors and the model objects breakdown structure.
- Define Level of Information Need (LOIN) and its subdivisions based on geometrical and alpha-numerical information, documentation needed for the deliverables, and the relationship between the various LOIN.
- Include a section for defining relationship diagrams on LOIN and guidance on verification and validation. In essence, this methodology partially overlaps with the IDM approach, which is why it is being noted.

These data exchange international standards continue to evolve as more countries apply lessons learned from their BIM deployments. Terminology and methodologies may change over time. It is recommended to consider establishing a governance process for AASHTO members to evaluate and make updates to the adopted BIM national standards. Recommendations for this governance process was provided in a separate document titled Governance Recommendations, Appendix 20 of the TPF-5(372) Final Report.

AASHTO Bridge Data Dictionary

Overview

In general, a data dictionary is a structured repository of terminology, definitions and metadata that helps describe the data being used. In other words, a data dictionary provides additional context and information about each piece of data so that software developers and people who create or use the described data can understand it better. The AASHTO Bridge Data Dictionary (ABDD) was developed to capture consistent bridge domain terminology specific to AASHTO members to better understand the requirements defined in the IDM. The purpose of published content is therefore to explain used terms and to enrich with further information that helps to understand and use these terms in a consistent way. The main focus is on human communication, but also enables software to annotate in an IFC-based data exchange, in particular to classify entities. Specifically, all terms are differentiated into classes (entity groups or systems). The mapping to IFC is first focused on class level, then an evaluation is performed to determine whether the property is something that can be calculated directly from the model object geometry or derived from other model data such as an attribute attached to the item. Another portion of the content is the linkage to metadata that provides further clarification on items such as language origin (e.g., English versus German), ownership, status, license, etc.

The desired outcome for this product was to create an AASHTO approved bridge domain content to make available via the buildingSMART Data Dictionary (bSDD) service. The bSDD service is an online service hosting classes (terms) and properties, allowed values, units, translations, relations between those objects and more. It provides a standardized workflow to provide data quality, information consistency and interoperability. Users of the bSDD can enrich their model deliverables with information requirements based on a variety of international, national, regional and local standards through specific BIM software platforms. The bSDD also allows technology providers and modelers using the service to link user-specific requirements to other domains using semantic relationships that describe the type of link in more detail. By such relationship it is for instance possible to find equivalent representations in the IFC domain, which essentially enables the translation between domains back and forth. However, it should be noted that although the IFC standard is published in bSDD with all important entities and selected attributes and properties, it does not contain all definitions from the schema. The benefit of this technical approach within the overall framework will make it possible for linking AASHTO bridge requirements specified in the IDM to the IFC classification hierarchy and their properties, and other bSI specifications, such as the IDS. In fact, the relationship between the bSDD and the IDS standard is that the bSDD provides a mechanism for a user to access the owner-defined IDS via an application programming interface (API) within the modeling software. This is further explained in the *Information Delivery Specification for the Design to Construction Data Exchange for Highway Bridges* section of this document.

Considerations for Future Updates to the AASHTO Bridge Data Dictionary

The best way for a domain owner to publish content to the bSDD web service is via a JSON file. JSON stands for JavaScript Object Notation, which is an open standard file format commonly used in electronic data interchange. An initial JSON file was delivered as part of the TPF-5(372). This bSDD import file was automatically converted from a spreadsheet in which terms and semantic definitions were collected and organized to meet the requirements specified in the IDM. The latest update of the bSDD structure and API were published in November 2023, which was used as the basis of the final TPF-5(372) US Bridge Data Dictionary deliverable. The latest spreadsheet is still available as a reference and for further editing.

It is recommended to pay close attention to bSI updates regarding bSDD service updates, as well as ISO-related standards as they continue to improve the service. Available content can be accessed via the bSDD API or queried through the bSDD website that is available at: https://search.bsdd.buildingsmart.org/. It also represents a reference for further IDS development, which is particularly interesting for understanding the significance of customer-specific properties and can therefore support software implementation.

ISO standards to consider for future updates of the ABDD include those listed below. These standards are the foundation for building data dictionaries to support BIM processes and open data standards to enhance interoperability.

- **ISO 12006: 2015 Building Construction – Organization of Information About Construction Works Part 2: 2015.** This standard "defines a framework for development of built environment classification systems. It identifies a set of recommended classification table titles for a range of information object classes according to particular views, e.g., by form or function supported by definitions. It shows how the object classes classified in each table are related, as a series of systems and sub-systems, e.g., in a building information model." However, "it does not provide a complete operational classification system, nor does it provide the content of the tables, though it does give examples. It is intended for use by organizations which develop and publish such classification systems and tables…" (6)
- **ISO 23386: 2020 Building Information Modeling and Other Digital Processes Used in Construction.** This standard establishes the "methodology to describe, author and maintain properties in interconnected data dictionaries." Specifically, the methodology provides "…definitions of properties and groups of properties as list of attributes; definitions of all the provided attributes; definitions and roles of applicants; definitions and roles of experts and the commission of experts; definitions of requestor's attributes; definitions of expert's attributes; an established governance model for a data dictionary; a framework for a network of data dictionaries." (7)
- **ISO 23387: 2020 Building Information Modeling – Data Templates for Construction Objects Used in the Life Cycle of Built Assets. Concepts and Principles.** This standard "…sets out the principles

and structure for data templates for construction objects. It is developed to support digital processes using machine-readable formats using a standard data structure to exchange information about any type of construction object…" (8)

Information Delivery Specification (IDS) for the Design to Construction Data Exchange for Highway Bridges, v1.0

Overview

In general, IDS is a new standard being developed by bSI. An important aspect in the development of IDS was that it should be easy to use and simple to implement. An IDS is not bound to a specific version of IFC. It is thus IFC schema version agnostic and will work with the latest IFC4.3 standard as well as previous versions. The functional scope of IDS 1.0 standard was determined based on a use case analysis carried out at the beginning of 2021 and focuses on most frequently required types of model quality control functions (9). It includes the check of properties and quantities, IFC schema attributes, object classification, material names, and selected relationships such as containment, grouping and aggregations. More complex types of checks such as element connections, logical combination of requirements, mathematical functions or required object geometry are outside of the scope for this standard.

The IDS developed by TPF-5(372) is a computer-interpretable document that defines the exchange requirements of the model-based exchange per the AASHTO published IDM, and focuses on alphanumeric data captured as properties and quantities. An IDS is a file that contains information that specialized computer software can use to validate the contents of an IFC file relative to exchange requirements defined in an IDM but does not validate geometry. Specifically, the IDS standard serves two purposes:

1. It provides the requirements, as stated in the IDM, of the subset of the IFC schema for the data export.
2. Checks the export's properties and quantities along with the IFC schema attributes such as object classification and material names as well as selected relationships such as containment, grouping, and aggregations.

Although the TPF-5(372) IDS is dependent on the bSI's development of IFC 4.3, it is a separate product used to verify the exchange information requirements comply with the AASHTO IDM. **All properties that are explicitly required in the project model-based data exchange must be named exactly to match the AASTHO IDM terminology during the export IFC model process. The IDS explicitly checks for the exact terminology required by the AASHTO IDM.**

Considerations for Future Development of AASHTO Defined IDS Files

The IDS standard[1] published by bSI provides a template that can be used to define the expected content to be delivered in an IFC. The TPF-5(372) delivered IDS is therefore the basis for enabling automated techniques on quality assurance for the AASHTO IDM. The TPF-5(372) EIR encoded in the IDS-XML file represents the full set of information as defined in the Design to Construction for Highway Bridges use case, which is delivered at the end of design for State DOTs to prepare a bidding package for construction.

[1] https://github.com/buildingSMART/IDS

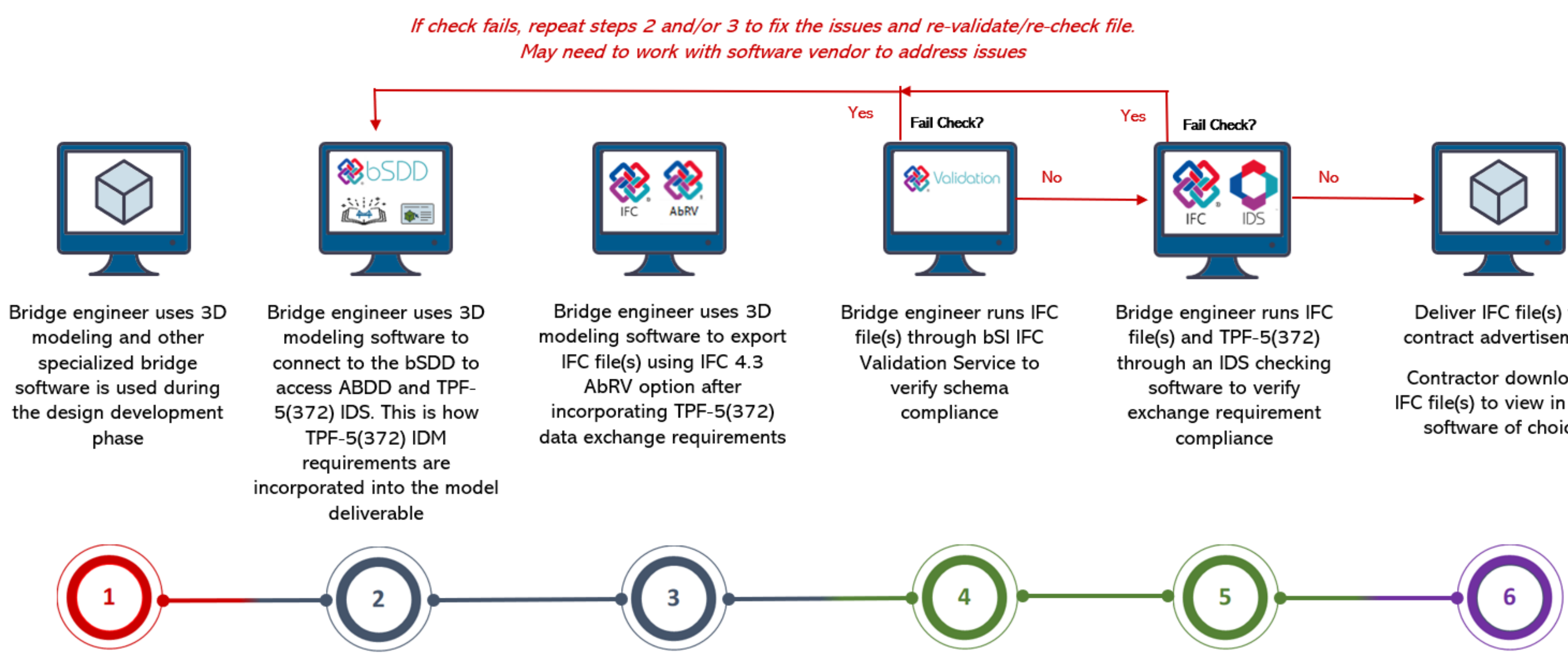
However, it is highly recommended for individual State DOTs to evaluate modification to the delivered TPF-5(372) IDS to use as a validation tool for interim model-based deliverables during the design phase of a project, for example deliverables for 30%/60%/90% completion.

The IDS is both human and machine-readable format, so it could be edited by someone familiar with basic XML and HTML programming knowledge. This may be advantageous for State DOTs that would like to consider additional custom properties beyond what was captured in the AASHTO IDM. For example, a State DOT may want to edit the TPF-5(372) IDS to add properties unique for a design-build project not covered within the scope of the IDM.

TPF-5(372) Relationships and Dependencies to Open Data Standards

All products used for the TPF-5(372) technical solution are essential for the complete solution to support the design-to-construction exchange of highway bridges. This section provides an overview of how the TPF-5(372) are used with the bSI products and services, and additional explanation regarding how their development and updates are executed, and how the TPF-5(372) products depend on future changes by the international community. Figure 1 illustrates the general workflow for creating and validating an IFC file using TPF-5(372) technical solution and bSI products and services.

Figure 1. Typical Design Process Using the Technical Solutions from TPF-5(372)



Understanding Open Data Standards

Grocery Store Analogy

To better understand the bSI open data standards, this section introduces a simple analogy comparing bSI products and services to a grocery store. A more detailed description of the IFC and MVD follows the simplified analogy descriptions.

Industry Foundation Classes (IFC)
Short Description: The foundation for all model-based data that represent the built-environment, including objects, assemblies, relationships, and materials.
Analogy: A grocery store that has all the ingredients to make various kinds of recipes.

Model View Definition
Short Description: A subset of the entire IFC schema, for example the AbRV
Analogy: Aisles in a grocery store that have specific types of items (e.g., baking, frozen, dairy) needed for similar types of recipes.

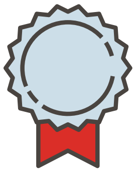
Alignment-based Reference View (AbRV)
Short Description: A specific type of base MVD that provides the IFC subset for linear infrastructure entities.
Analogy: The baking aisle in the grocery store, provides items needed for baking a cake.

Information Delivery Manual (IDM)
Short Description: Manual with the information requirements for one exchange, such as the design-to-construction exchange to support bidding, construction, and initiation of fabrication.
Analogy: Cookbook recipe for baking a chocolate cake.

BuildingSMART Data Dictionary (bSDD) Service
Short Description: Online service that hosts catalog of standard information classifications and their properties, allowed values, units, and translations that can be referenced when identifying the meaning of data in an exchange.
Analogy: An index of ingredients that can be found at the grocery store, where they may be grouped in a variety of ways, such as according to ingredient types (e.g., flours, sweeteners, etc.), recipe types (bread, cake, etc.), or even ethnic origin (German, Italian, etc.)

Information Delivery Specification (IDS)
Short Description: A computer interpretable file (i.e., XML file) that checks if an IFC file complies with the model-based requirements for a specific data exchange or use. An IDS is a more detailed specification of data exchange requirements for the MVD being used, based on a specific use case.
Analogy: A tool that automatically checks chocolate cake ingredients and brand information, measurements, etc. It flags any items not in compliance with the recipe and your shopping list.

bSI IFC File Validation Service
Short Description: A free online self-service used by a user to check a given IFC file against IFC schema, syntax, and other normative rules of the standard.
Analogy: A quality management process that checks the quality of the resulting dish meeting the criteria in terms of correct use of ingredients, measurements, cooking methods, and temperature.



bSI Software Certification Program
Short Description: A paid program administered by bSI to certify software against specific IFC versions and base MVD (e.g., IFC 4.3 AbRV. Software vendors pay to become certified by bSI.
Analogy: A process by which an independent authority, such as the Gluten Free Certification Organization, determines whether a product meets the quality and integrity to label it "gluten free certified".

Industry Foundation Classes (IFC)

The IFC 4.3 standard is the foundation of the TPF-5(372) Technical Solution, and it represents a schema specification for the structure of model-based construction data to facilitate information exchange sharing between modeling software applications. This bSI standard is governed by the ISO 16739 standard, which has gone through multiple updates over the years, with the ISO 16739-1: 2024 expected to be published in early 2024 as the most recent version[2]. The IFC schema specification is the primary technical deliverable of bSI promoting openBIM®, and it is a standardized model that codifies the identity and semantics of the information, as well as characteristics or attributes and relationships of objects. It also codifies abstract concepts, processes and people involved in the exchange of model-based data.

Dependencies: Due to the long development cycle of the standard, which may take up to five years, it is recommended to stay within the boundaries of the existing IFC releases when implementing any national, regional or local standards based on IFC.

[2] ISO has approved IFC 4.3 as the final standard in January 2024, however, at the time of publication of this document, the ISO 16739-1: 2024 has not been published.

Base Model View Definition (MVD)

As previously discussed, the scope of the IFC standard is very broad encompassing many domains (i.e., buildings, roads, bridges, rails, tunnels, ports and waterways). Moreover, it covers the whole lifecycle of a building from design to construction and later asset management.

In contrast, software modeling tools are usually focused on a series of business cases and can therefore only implement a subset of the entire IFC schema. For example, a bridge engineer typically uses a different software to develop bridge 3D models than a roadway engineer does for creating corridor models. Software developers have a variety of modeling applications within their portfolio. As a result, the MVD approach was introduced by buildingSMART to tailor the IFC into manageable subsets for software implementation. These base MVDs are implemented in collaboration with the international software vendor community. This collaboration happens through the bSI Implementers Forum, an organized group that comes together to determine how the technical specifications of the MVDs should be implemented. The outcome of this collaboration is a series of international agreements among software vendors that are directly dependent on the readiness of the IFC version being adopted and are a critical basis for the implementation of specific use cases.

The base MVD applicable to bridges is the AbRV, which is a reference view. What exactly does that mean? A reference view is not intended to store parametric properties of the bridge geometry, such as how the deck geometry and girder alignment might change with a change to the roadway algnment, or how a girder cross-section might change with a change in the length or depth property. Once an IFC file has been imported into an authoring software, it depends on the software design and implementation whether the geometry could be changed. For example, *a software product could allow for an imported concrete element to be used to design the reinforcement within that concrete object. The resulting refinforcement design, as well as the its relationship to the imported concrete element, would be part of the new, proprietary file. If this design were to be exported to IFC, the parametric relationship between the concrete element and the reinforcement would not be preserved in the IFC file.*

Nevertheless, IFC 4.3 AbRV enables users to export model files from one software and import to another application to view the reference model, coordinate between disciplines and extract information digitally. Further, IFC provides the mechanism to reference or archive information, much like a PDF - an instance of the source model-based information that is frozen in time, making it difficult to edit, which is why it is ideal for contractual model-based project delivery and archiving records. (11)

Although the responsibility to develop and publish existing and new MVDs remains with bSI, it is important to note that AASHTO will need to communicate future exchange needs to be covered by these MVDs. The current process is to closely work through the Infrastructure Domain Steering Committee, the buildingSMART USA Chapter, and the Implementer's Forum. This approach will enable bSI technical services team, the software vendors, and the user-based community to work together in developing the provisions for test case instructions and the certification program. The key objective through these engagements is to evaluate the limitation of existing MVDs and determine the need for future extensions and updates. Table 1 provides an overview of the bSI base MVD Specifications and software certification status (13)

Table 1. Overview of the bSI Base MVD Specifications

MVD Name	Description	IFC Version Dependency	Status
Reference View (RV1.2)	Provides technical specifications for supporting export exchanges related to architectural, structural, and building services	IFC 4	Software certification in place along with formal documentation or test instructions.
Alignment-based Reference View (AbRV)	Provides technical specifications to enable the use of an alignment for positioning of infrastructure elements. It is inclusive of new IFC elements from infrastructure domains with their simplified geometric representation as already agreed in the Reference View.	IFC 4.3	Formal documentation and further machine-readable specifications are not yet in place. It is expected that such documentation will be provided after final publication of IFC4.3 as an ISO standard. However, a specific timeline has not been communicated by bSI.
Coordination View (CV2.0)	Provides technical specifications for supporting export exchanges related to architectural, structural and building services specifically for the purpose of multi-disciplinary coordination needed during design.	IFC 2x3	Software certification in place along with formal documentation or test instructions.

Note: A software certification program for IFC 4.3 and AbRV is not established due to lack of funding. The TPF-5(372) Unit Test Suite provides the instructions for bridge specific needs to use the AbRV that could be used to develop test instructions through bSI. The next steps are for buildingSMART chapter members to submit a project proposal and secure funds to initiate an international project to establish a global certification program for IFC 4.3 AbRV.

Using TPF-5(372) Technical Solution and the bSI Products and Services

Each of the TPF-5(372) Technical Solution products have a very specific purpose. This section provides an overview on how a State DOT may use the TPF-5(372) products within the bSI ecosystem to validate IFC files comply with the AASHTO IDM. Figure 2 illustrates a general workflow for producing and validating IFC files using the bSI open data standards.

Creating IFC Files

The process of creating IFC files starts at the very beginning of the 3D model development process when the bridge engineer setups up the preliminary model. Understanding that the final deliverable will need to be provided as an IFC file that complies with the AASHTO IDM at the very beginning of the project, is an important step in creating quality files.

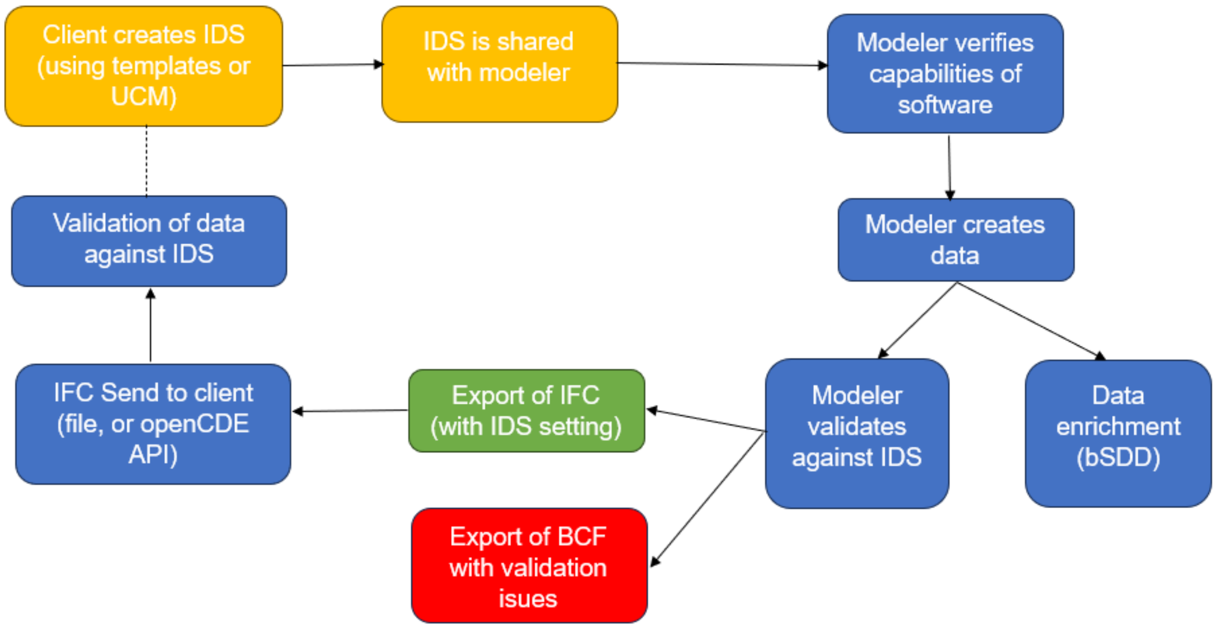
The design team should be familiar with the information requirements defined in the AASHTO IDM and request the TPF-5(372) IDS file before starting the bridge modeling process. In addition, the bridge engineer should verify the capabilities of the modeling software for:

- Creating 3D bridge model geometry and any data that is associated with the model elements (e.g., pay items, special attributes). Each software vendor offers different tools to develop 3D bridge models and create attributes to add non-graphical information or data that is not derived directly from the model.
- Connecting to the bSDD Service through an API within the modeling tool to enable the user to translate AASHTO IDM terminology. This functionality is critical when preparing an IFC deliverable that has specific exchange information requirements. The process within modeling software using Uniform Resource Identifier (URI) to link to link to the bSDD service that enable the users to attach the IDS.
- Exporting IFC files is dependent on the software functionality. Some vendors may have an easy tool out of the box that automatically calls out a dialog box that is user friendly. Others may offer functionality that requires special configuration or may out of the box tools that are not intuitive or user friendly. The bridge engineer is encouraged to work closely with their software providers to get specific training for exporting IFC files. It is important to be clear in communicating to the software vendor the design team needs a workflow to export files using the IFC 4.3 ADD2 version and the AbRV. Since the ISO certified version of IFC (IFC 4.3 ADD2) was only published in January 2024, most software vendors will only have the capability on a trial or beta version of the software. It may take another year or so to see certified support of IFC 4.3 ADD2 and AbRV in software. While it is not imperative to have software that supports IFC 4.3 ADD2 and AbRV to export a quality IFC file, the design team may need the services of someone with specialized skill sets to map the model elements to the correct IFC schema entities. This manual process of creating IFC files is rather time consuming and potentially expensive for the design team, but it is possible.

Validating IFC Files and Verifying Compliance with Information Requirements

Figure 2 from bSI illustrates the verification mechanism using IFC, bSI Validation Service and IDS (10) using the bSI recommended workflow. This verification process does not on checks or validates the completeness of the model or accuracy of the design. Rather, the bSI Validation Service is used to check the compliance of the IFC file as exported from the software against the standard schema. Design quality management must continue to be performed using visual inspection of the model, and check lists to document the design review process.

Figure 2. buildingSMART Validation Mechanism for Verification of Exchange Requirements



BCF: BIM Collaboration Format
bSDD: buildingSMART Data Dictionary
IDS: Information Delivery Specification
IFC: Industry Foundation Classes
UCM: Use Case Management
API: Application Programming Interface

TPF-5(372) Dependencies to bSI Open Data Standards

Each product has a unique place within the openBIM standards ecosystem and are under the jurisdiction of different parties. Table 1 provides an overview of each of product, including a brief description, its dependencies, and roles and responsibilities for developing the product. All TPF-5(372) products are based on ISO standards and the openBIM standards governed by bSI.

Table 2: Overview of TPF-5(372) Products and Dependencies to bSI Open Data Standards.

Product Name and Description	bSI Related Standard	ISO Related Standard	Roles and Responsibilities
IDM for Design to Construction Data Exchange for Highway Bridges, 1st Edition	IFC (v. 4.3)	ISO 29481-1: 2016 ISO 29481-2: 2012 ISO 29481-3: 2022 ISO 7817.2: 202X? *(Under development)*	***AASHTO COBS:*** Content development ***ISO:*** Publication of standard ***bSI:*** Guidance and technical assistance for implementation
AASHTO Bridge Data Dictionary	bSDD		***AASHTO COBS:*** Content development ***bSI:*** Governance, development and maintenance of service, technical guidance for implementation, and certification of software applications
IDS for Design to Construction Data Exchange for Highway Bridges, 1st Edition	IDS (v. 1.0)		***AASHTO COBS:*** Content development ***bSI:*** Governance, development and maintenance of standard, technical guidance for implementation, and certification of software applications
Unit Test Suite	IFC (v.4.3) AbRV Technical documentation and templates	ISO 16739: 2024	***AASHTO COBS:*** Content development ***bSI:*** Development of IFC and base MVD's (i.e., AbRV), publication of technical documentation and templates, certification of software applications

References

1. **American Association of Highway and Transportation Officials.** Information Delivery Manual for Design to Construction Data Exchange for Highway Bridges, 1st Edition. January 2023.

2. **International Standards Organization.** ISO 29481-1: 2016 Building Information Models Information Delivery Manual Part 1: Methodology and Format. Nat 2016.

3. —. ISO 29481-2: 2012 Building Information Models Information Delivery Manual Part 2: Interaction Framework. December 2012.

4. —. ISO 29481-3: 2022 Building Information Models - Information Delivery Manual - Part 3: Data Schema. 2022.

5. —. ISO/DIS 7817.2. *ISO.* [Online] [Cited: December 1, 2023.] https://www.iso.org/standard/82914.html.

6. —. ISO 12006-2: 2015 Building Construction - Organization of Information about Construction Works Part 2: Framework for Classification. May 2015.

7. —. ISO 23386: 2020 Building Information Modeling and Other Digital Processes Used in Construction. March 2020.

8. —. ISO 23387: 2020 Building Information Modeling (BIM) Data Templates for Construction Objects Used in the Lifecycle of Built Assets. July 2020.

9. **buildingSMART International.** buildingSMART/IDS . *buildingSMART Github.* [Online] [Cited: November 27, 2023.] https://github.com/buildingSMART/IDS/tree/master/Use-cases.

10. —. Information Delivery Specification (IDS). *buildingSMART International.* [Online] [Cited: December 3, 2023.] https://www.buildingsmartusa.org/standards/bsi-standards/information-delivery-specification-ids/.

11. —. What is IFC (Industry Foundation Classes). *Building SMART Interantional.* [Online] [Cited: December 2, 2023.] https://www.buildingsmartusa.org/standards/bsi-standards/industry-foundation-classes/.

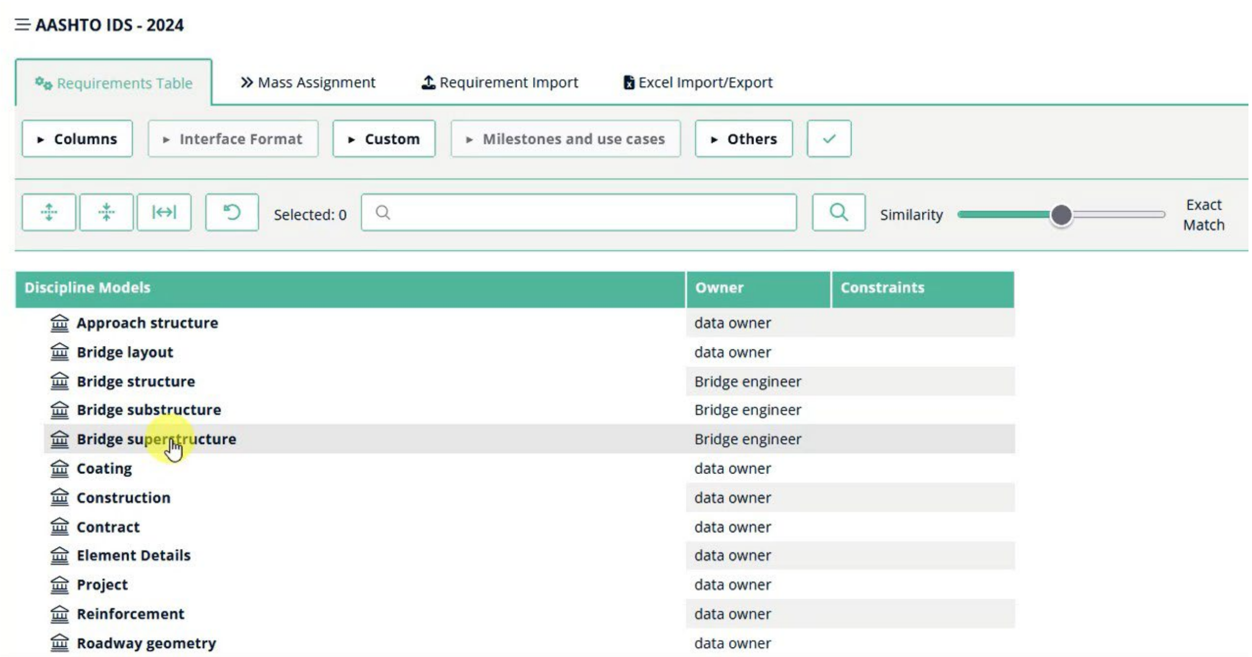
12. —. IFC Formats. *buildingSMART International.* [Online] [Cited: December 2, 2023.] https://technical.buildingsmart.org/standards/ifc/ifc-formats/.

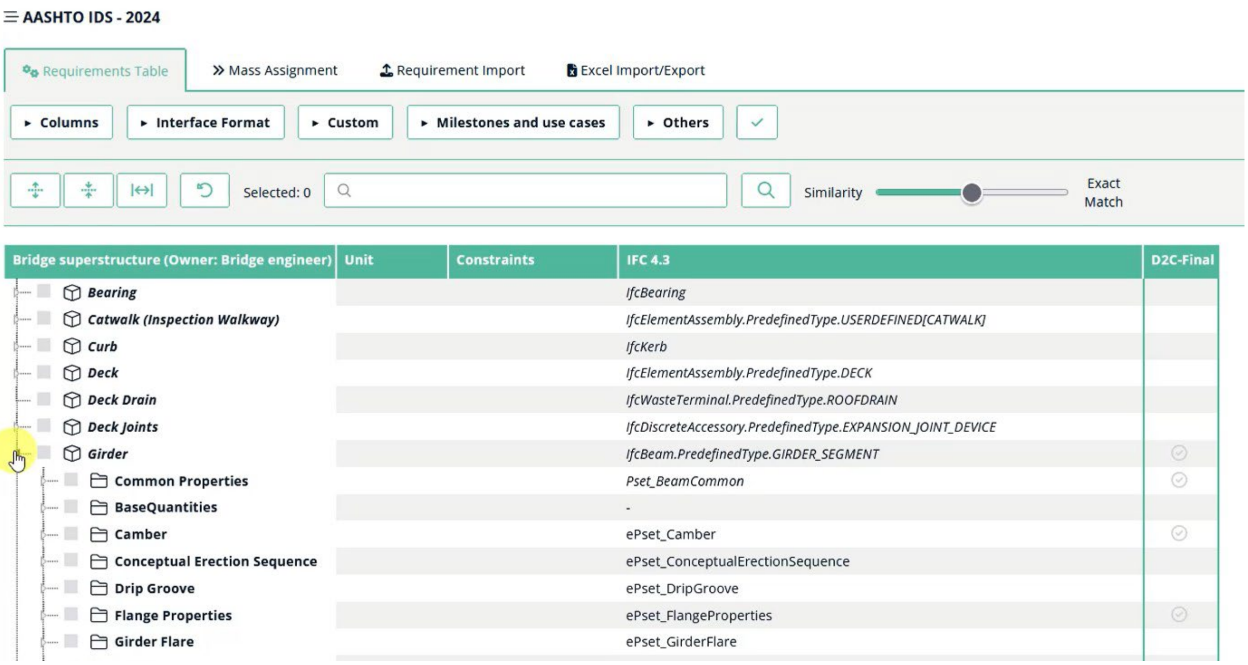
13. —. bSI Software Certification Program. *buildingSMART International.* [Online] [Cited: December 3, 2023.] https://technical.buildingsmart.org/services/certification/.

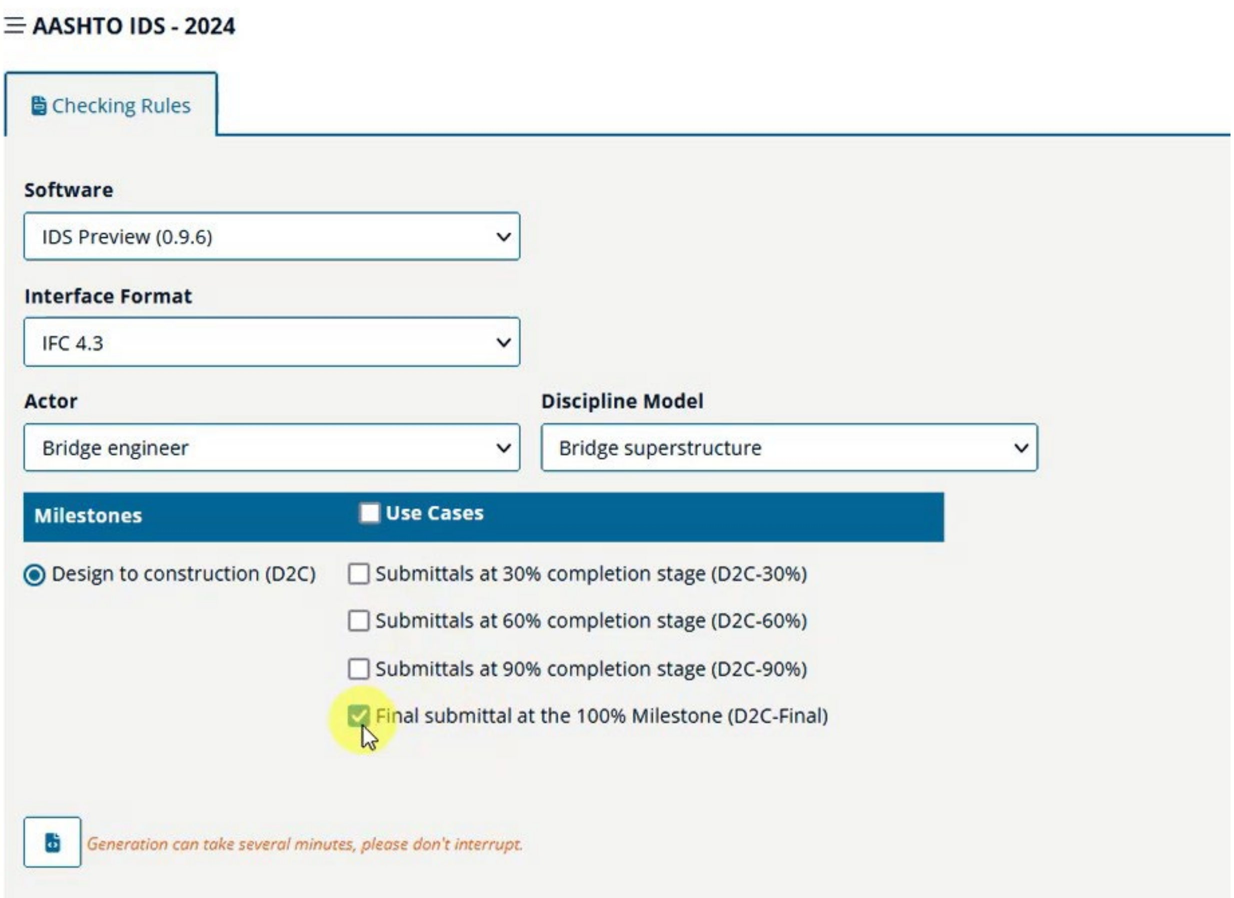
Appendix A. Using TPF-5(372) IDS Requirements

Appendix A provides examples of using an information management software to view the contents of the TPF-5(372) and to validate an IFC file against the requirements defined in the IDS.

Reviewing Contents of TPF-5(372) IDS File

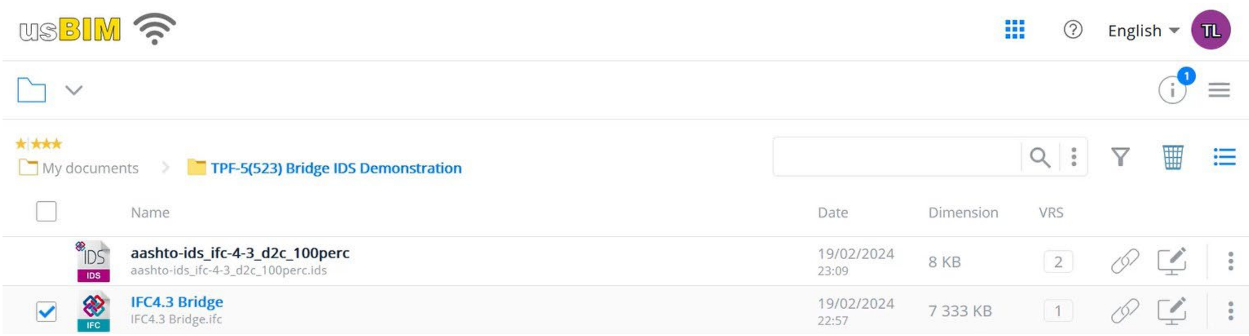



AASHTO IDS - 2024
Requirements Table
Mass Assignment
Requirement Import
Excel Import/Export
Columns
Interface Format
Custom
Milestones and use cases
Others
Selected: 0
Similarity
Exact Match
Bridge superstructure (Owner: Bridge engineer)
Unit
Constraints
IFC 4.3
D2C-Final
Bearing
IfcBearing
Catwalk (Inspection Walkway)
IfcElementAssembly.PredefinedType.USERDEFINED[CATWALK]
Curb
IfcKerb
Deck
IfcElementAssembly.PredefinedType.DECK
Deck Drain
IfcWasteTerminal.PredefinedType.ROOFDRAIN
Deck Joints
IfcDiscreteAccessory.PredefinedType.EXPANSION_JOINT_DEVICE
Girder
IfcBeam.PredefinedType.GIRDER_SEGMENT
Common Properties
Pset_BeamCommon
BaseQuantities
-
Camber
ePset_Camber
Conceptual Erection Sequence
ePset_ConceptualErectionSequence
Drip Groove
ePset_DripGroove
Flange Properties
ePset_FlangeProperties
Girder Flare
ePset_GirderFlare

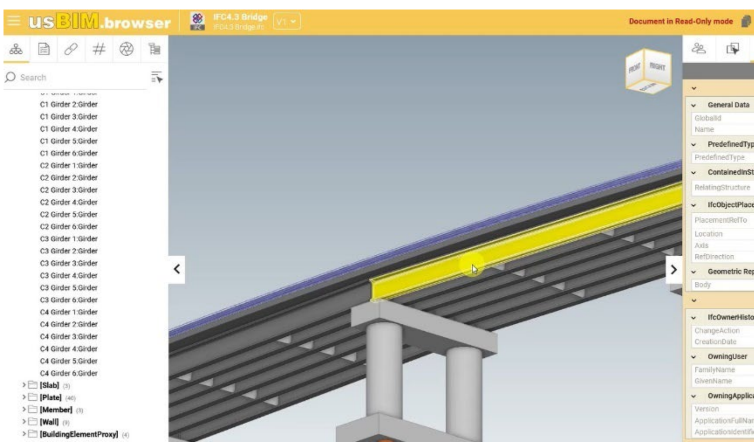

AASHTO IDS - 2024
Checking Rules
Software
IDS Preview (0.9.6)
Interface Format
IFC 4.3
Actor
Bridge engineer
Discipline Model
Bridge superstructure
Milestones
Use Cases
Design to construction (D2C)
Submittals at 30% completion stage (D2C-30%)
Submittals at 60% completion stage (D2C-60%)
Submittals at 90% completion stage (D2C-90%)
Final submittal at the 100% Milestone (D2C-Final)
Generation can take several minutes, please don't interrupt.

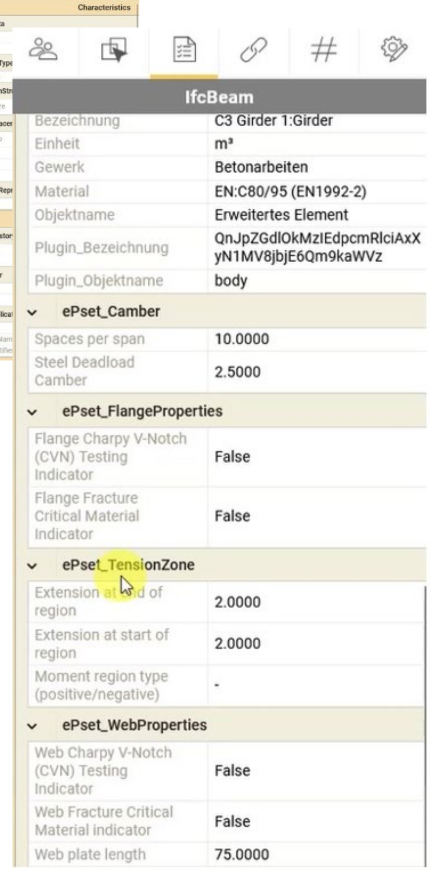
Validating IFC File with IDS Checker

1. Import the IFC and IDS files into the validation software

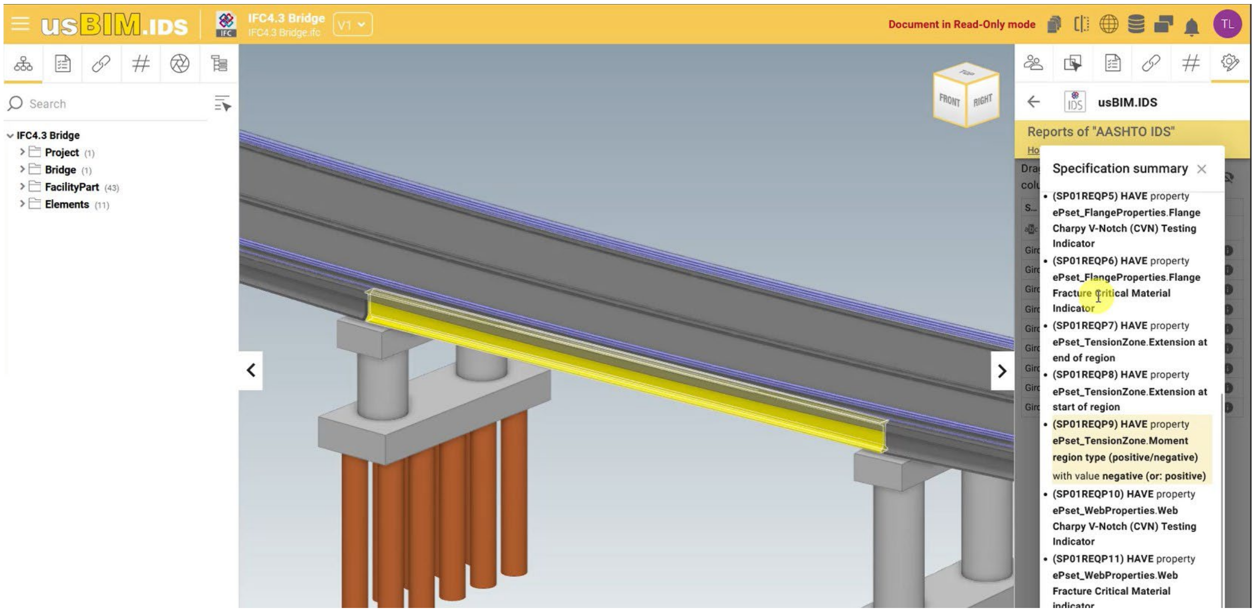


2. Within the software, select the model geometry to review IFC information





3. Run the IDS file


usBIM.IDS
IFC4.3 Bridge
IFC4.3 Bridge.ifc
V1
Document in Read-Only mode
TL
Search
IFC4.3 Bridge
Project (1)
Bridge (1)
FacilityPart (43)
Elements (11)
FRONT
RIGHT
usBIM.IDS
Reports of "AASHTO IDS"
Specification summary
(SP01REQP5) HAVE property ePset_FlangeProperties.Flange Charpy V-Notch (CVN) Testing Indicator
(SP01REQP6) HAVE property ePset_FlangeProperties.Flange Fracture Critical Material Indicator
(SP01REQP7) HAVE property ePset_TensionZone.Extension at end of region
(SP01REQP8) HAVE property ePset_TensionZone.Extension at start of region
(SP01REQP9) HAVE property ePset_TensionZone.Moment region type (positive/negative) with value negative (or: positive)
(SP01REQP10) HAVE property ePset_WebProperties.Web Charpy V-Notch (CVN) Testing Indicator
(SP01REQP11) HAVE property ePset_WebProperties.Web Fracture Critical Material indicator

Appendix B. TPF-5(372) Technical Solution Summary Infographic

TPF-5(372) TECHNICAL SOLUTION SUMMARY FOR THE DESIGN-TO-CONSTRUCTION DATA EXCHANGE STANDARD FOR HIGHWAY BRIDGES

Grocery Store Analogy

Industry Foundation Classes (IFC)
Short Description: The foundation for all model-based data that represent the built-environment, including objects, assemblies, relationships, and materials.
Analogy: A grocery store that has all the ingredients to make various kinds of recipes.

Model View Definition (MVD)
Short Description: A subset of the entire IFC schema, for example the AbRV.
Analogy: Aisles in a grocery store that have specific types of items (e.g., baking, frozen, dairy) needed for similar types of recipes.

Alignment-based Reference View (AbRV)
Short Description: A specific type of base MVD that provides the IFC subset for linear infrastructure entities.
Analogy: The baking aisle in the grocery store, provides items needed for baking a cake.

Information Delivery Manual (IDM)
Short Description: Manual with the information requirements for one exchange, such as the design-to-construction exchange to support bidding, construction, and initiation of fabrication.
Analogy: Cookbook recipe for baking a chocolate cake.

buildingSMART Data Dictionary Service
Short Description: Online service that hosts catalog of standard information classifications and their properties, allowed values, units, and translations that can be referenced when identifying the meaning of data in an exchange.
Analogy: An index of ingredients that can be found at the grocery store, where they may be grouped in a variety of ways, such as according to ingredient types (e.g., flours, sweeteners, etc.), recipe types (bread, cake, etc.), or even ethnic origin (German, Italian, etc.).

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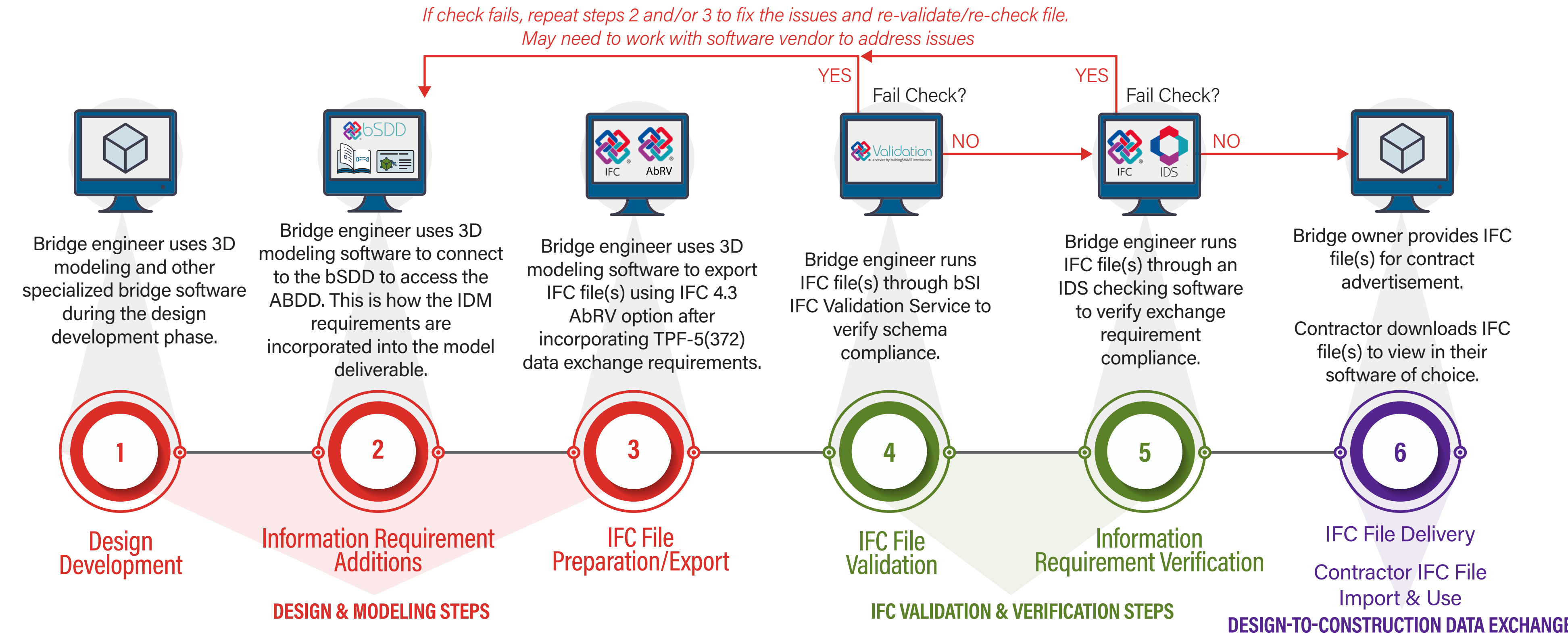
Short Description: A computer interpretable file (i.e., XML file) that checks if an IFC file complies with the model-based requirements for a specific data exchange or use. An IDS is a more detailed specification of data exchange requirements for the MVD being used, based on a specific use case.
Analogy: A tool that automatically checks chocolate cake ingredients and brand information, measurements, etc. It flags any items not in compliance with the recipe and your shopping list.

bSI Validation Service
Short Description: A free online self-service used by a user to check a given IFC file against IFC schema, syntax, and other normative rules of the standard.
Analogy: A quality management process that checks the quality of the resulting dish meeting the criteria in terms of correct use of ingredients, measurements, cooking methods, and temperature.

bSI Software Certification Program
Short Description: A paid program administered by bSI to certify software against specific IFC versions and base MVD (e.g., IFC 4.3 AbRV) Software vendors pay to become certified by bSI.
Analogy: A process by which an independent authority, such as the Gluten Free Certification Organization, determines whether a product meets the quality and integrity to label it "gluten free certified".



TYPICAL DESIGN PROCESS USING THE TECHNICAL SOLUTIONS FROM TPF-5(372)

(for Design-Bid-Build Delivery Method)

AASHTO Governing Body

Who adopts the open data standards?

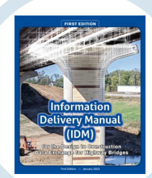
AASHTO adopts open data standards and associated products that are created by AASHTO Technical Committees, or through national efforts such as Transportation Pooled Funds, with State DOT input

Software Vendors

Who provides the mechanisms to enable open data standard workflows?

Software vendors incorporate open data standards into their products, and develop applications to:

- Model bridges, connect to bSDD, export/import IFC files
- Validate IFC files using IDS



Information Delivery Manual (IDM)

for the Design to Construction Data Exchange for Highway Bridges

The authoritative standard, published by AASHTO, defining the exchange information requirements in tables in a manual.

Unit Test Suite

A set of bridge drawings and tables with properties to be used by software vendors as instructions to certify their software can produce AASHTO compliant IFC bridge models.

Information Delivery Specification (IDS)

for the Design-to-Construction Data Exchange for Highway Bridge

A machine-readable specification of information requirements which defines the data needed for the design-to-construction exchange for highway bridges, which can be used to aid in the quality control of delivered IFC files.

AASHTO Bridge Data Dictionary (ABDD)

Knowledge based repository for understanding requirements from the IDM in terms of categories of objects, terms and descriptions, semantic object relationships, property type and unit of measure and metadata.

IFC — Industry Foundation Classes (IFC)

IFC — Alignment-based Reference View (AbRV)

Validation — a service by buildingSMART International — bSI Validation Service

buildingSMART Software Certification — bSI Certification Program

Unit Test Suite

bSDD — a service by buildingSMART International — bSI Software Data Dictionary Service

AASHTO Bridge Data Dictionary

BIM FOR BRIDGES AND STRUCTURES TPF-5(372)

Appendix 19: Industry Foundation Classes (IFC) Implementation Guide for State Departments of Transportation

BIM FOR BRIDGES AND STRUCTURES

TPF-5(372)

Industry Foundation Classes (IFC) Implementation Guide

for State Departments of Transportation

March 2024

Version 2.0 – Final

BIM FOR BRIDGES AND STRUCTURES
COMMITTEE ON BRIDGES AND STRUCTURES

Table of Contents

BIM FOR BRIDGES AND STRUCTURES
COMMITTEE ON BRIDGES AND STRUCTURES

Introduction

Purpose of this Document

The purpose of this guide is to provide recommendations for implementing the technical solutions developed by the TPF-5(372) study. The use of Industry Foundation Classes (IFC)-based data exchange depends on stakeholders becoming more mature with their Building Information Modeling (BIM) practices to reach optimal benefits. This implementation guide provides recommendations for conducting activities that will help State DOTs and other stakeholders formalize their commitment to the adoption of open data exchange.

The recommendations herein are presented at a high level to provide flexibility in implementing open data standards within the constraints of each owner agency. This implementation guide will facilitate a smoother transition to the use of open data standards framework and technical solutions delivered by the TPF-5(372) study, ultimately enhancing collaboration, efficiency, and innovation in the design and construction of highway bridges.

Project Background

The objective of the work under the TPF-5(372) *Building Information Modeling (BIM) for Bridges and Structures Project* is to establish an open data standard for bridge semantic and geometric information that is common to highway bridge owner agencies in the United States (US). The TPF-5(372) study builds upon previous efforts by the US highway owner community to create national data standards and by the buildingSMART International (bSI) community to create international standards for data interoperability. The products of the TPF-5(372) study are specific to the **design to construction** data exchange for common workhorse highway bridges and include:

1. **An Information Delivery Manual (IDM)**, a human-readable list of US bridge and structure entities, property sets, and properties, determined by US bridge and structure domain experts. Entities are grouped into categories or systems. The IDM defines the business process and information requirements for model-based file deliverables exchanged between the owner agency and the bridge construction contractor in the US. In general, an IDM is a document that captures information needed to be exchanged for a particular exchange regardless of format or technology used to perform the exchange. The IDM is now available as an official authoritative source, from the AASHTO Store (Information Delivery Manual (IDM) an AASHTO Guide Specification), for creating the content to be included in the AASHTO Bridge Data Dictionary.
2. **An AASHTO Bridge Data Dictionary,** a structured repository containing specific AASHTO bridge domain content that explains standard terms for US bridge model objects (including synonyms), their class hierarchy, properties, and semantic relationships to IFC entities. The AASHTO Bridge Data Dictionary, when published, will be accessed via the buildingSMART Data Dictionary (bSDD) service. The bSDD offers a software solution to link various data standards. The bSDD is a bSI online service hosting multiple data dictionaries for various owners and industry domains. The content found in the AASHTO Bridge Data Dictionary includes terminology used in the published IDM. The AASHTO Bridge Data Dictionary is presented in a structured and standardized way that makes it possible for software vendors to access the information and connect it or integrate it to their specific tools. The bSDD service is designed to supplement the Industry Foundation Classes

(IFC) by making it easier for software developers to connect their applications to available data dictionaries within a specific user domain standard.

3. **An Information Delivery Specification (IDS) Standard**, a computer-interpretable document that defines the exchange requirements of the model-based exchange per the AASHTO published IDM. An IDS is a file that contains information that specialized computer software can use to validate the contents of an IFC file relative to exchange requirements defined in an IDM and does not validate geometry. Specifically, the IDS standard serves two purposes
    a. It provides the requirements, as stated in the IDM, of the subset of the IFC schema for the data export.
    b. Checks the export's properties and quantities along with the IFC schema attributes such as object classification and material names as well as selected relationships such as containment, grouping, and aggregations.

    The IDS standard is dependent on bSI's development of IFC, which is intended to be used as a validation tool to check IFC data file exports against user specific exchange requirements. This IDS is a companion product to the AASHTO Bridge Data Dictionary, but a separate standard used to independently validate the IFC files was produced to include the exchange requirements stored in the AASHTO Bridge Data Dictionary via the bSDD service.

4. **A Unit Test Suite (UTS)**, a set of test instructions to assist vendors of bridge modeling software to validate their products against the requirements of the TPF-5(372) study products described herein. These test instructions (Unit Test GitHub) were developed in collaboration with the software vendor advisory group over the course of the TPF-5(372) study and an international project team developing bridge test instructions for bSI. The Unit Test Suite will be shared with bSI (bSI GitHub) to be evaluated, updated, and shared with the international community as part of the official bSI Certification and Validation Services. The UTS will be made available to bSI for them to assess how they can be used to help reduce the cost of certification and increase participation by software vendors.

Purpose of Open Data Standards

The US bridge industry began working toward the transformative potential of an open, non-proprietary format in 2004. In 2016, an updated roadmap identified IFC as the desired option for open standard data exchange for US bridges, in alignment with international consensus regarding IFC. The purpose of open data standards implementation include:

1. **Data Ownership**: The ability for the contracting agency to maintain access to its intellectual property without the need for a subscription based proprietary commercial software. Owner agencies are stewards of extremely valuable data sets that are often expensive to create. Open data standards enable agencies to free their data from vendor specific systems, providing durability and longevity of the information.

2. **Interoperability:** An open standard provides transparent and equal access to participating vendors to develop data exchange protocols between different software applications. This interoperability enables bridge designers to choose the most relevant tools for their specific needs without being constrained by compatibility issues.

3. **Efficient Collaboration:** By providing a standardized method for data exchange, an open standard facilitates more efficient collaboration between bridge designers, contractors, and other stakeholders. Standardization decreases the likelihood of errors during an exchange but increases shared understanding, and accuracy of interpretation during the project lifecycle.

4. **Innovation and Futureproofing:** The adoption of an open, international consensus standard opens the door to innovation by allowing the integration of emerging technologies and tools into the bridge design process. As an open standard, IFC ensures that the industry can adapt to future technological advancements without being tied to proprietary formats. There is also an element of synergy and collaboration by a global community working towards developing, implementing, refining, and improving open data standards. This international global community allows for many more people who have a vested interest in using the standard to oversee long term viability, and inclusion of various needs to be considered in its development.

5. **Cost Savings:** Standardized data exchange reduces the need for time-consuming and error-prone manual interventions in data translation. This efficiency not only saves time but also contributes to cost savings by minimizing the likelihood of rework and associated delays. Standardized data exchange using an open standard format also reduces the cost to software vendors to implement support for information exchange within their products.

6. **Archiving:** A dataset provided in an internationally maintained ISO data standard format assures the owner of access to their project deliverables without concern of maintaining constant software platform updates.

The implementation of IFC as a standard data exchange for the US bridge design industry, with a specific focus on aiding the State Departments of Transportation (DOTs), marks a pivotal moment in the evolution of the sector. This move towards an open, non-proprietary data schema is poised to transform how information is shared, setting the stage for increased collaboration, improved efficiency, and innovation. As the US bridge design industry embraces IFC, it provides a stable and durable format for archiving bridge design data and lays the foundation for a more connected and dynamic future, where the robust exchange of data becomes a cornerstone of successful bridge projects.

Implementing Open Data Exchange for Bridges

The products developed by the TPF-5(372) study may be used by States DOTs, other stakeholders in the US, and the international community at large. Specifically, the TPF-5(372) study products may assist in:

1. Identifying project requirements for the bridge 3D model files delivered at the end of design to enable contractors to extract information that is reliable for:
    a. Preparing bid documents for design-bid-build highway projects involving workhorse bridges.
    b. Executing construction activities, including initiating the process of fabricating bridge components.
2. Selecting software offerings from vendors who support IFC file exchanges that are compliant with:
    a. The bSI Alignment-based Reference View (AbRV) subset of the ISO certified version of the IFC 4.3 standard.

   b. The AASHTO Information Delivery Manual (IDM) for the Design to Construction Data Exchange for Highways Bridges, 1st Edition publication.
   c. The Design to Construction Data Exchange for Bridges IDS as a validation tool.
3. Preparing training and presentation materials to educate bridge design staff, contractors, and third-party partners about the value of open data standards and, specifically, the use of the TPF-5(372) study products.
4. Piloting the use of open data standards on select projects to demonstrate the practical application of the TPF-5(372) study products.

Identifying Project Requirements

In order to deliver project data in the IFC format that fully satisfies the exchange requirement defined in the IDM, the designer needs to develop a 3D model of the bridge structure to a level of development (LOD) that fully conveys the design intent. The 3D virtual model provides elements to which the data is applied for the exchange. The following sections relate to, and offer suggestions for, describing the project requirements for the 3D model deliverables both in the proprietary bridge modeling software and in the open standard of IFC.

Application of Model-Based Deliverables by Project Type

The determination of whether to develop a bridge or structure model should be based on the degree of improvement required. A new or replacement bridge is a certain candidate for full model development, but a rehabilitation may not have enough of the structure involved to warrant a model.

The requirements for model-based deliverables do not change in regard to project delivery or bridge type. The model-based deliverables, as stated in the project's BIM Execution Plan, should follow the same development and quality control procedures regardless of who the data is delivered to or what type of bridge design is being used. A BIM Execution Plan is a document prepared by the design team to describe approach, methodology, and technologies being used to incorporate the BIM process.

Developing Model Development Standards

A model development standard communicates the *minimum* requirements for developing bridge models, particularly concerning the LOD. The provision of a detailed model development standard enables the model author to prepare a model capable of completely fulfilling the exchange requirement documented in the IDM. The AASHTO Joint Technical Committee on Electronic Engineering Standards (JTCEES) and BIMForum are actively shaping and refining US-based standards for LOD that serve as a common language and approach to developing modeling requirements. BIM Forum is a membership organization that is responsible for publishing the LOD Specifications used by architects and the building industry when using BIM to deliver building construction projects. BIM Forum is also a supporter of open data standards and BIM implementation and may be an organization to consider for future collaboration and coordination efforts. Other resources are NIBS NBIMs V4 BIM Execution Planning module and the ISO standard ISO/DIS 7817.2 *Level of Information Need (LOIN) Concepts and Principles*. These standards provide guidance for defining the amount of detail needed in the model geometry and attached data (attributes).

A model development standard should communicate the minimum requirements for each type of model element (e.g., bearings, piers, girders) in terms of geometry and data. Models that are developed to meet this minimum standard can export an IFC file that provides the data authorized for the exchange as defined in the IDM.

An agency may have additional requirements for geometric detail and attribution above the minimum standard. In general, the model will be developed by the bridge engineer to convey the design intent of the bridge and its elements. A bridge engineer may, at their discretion, decide that additional detail is needed. As part of the fabrication process, fabricators may develop more detailed models of respective elements based on their design detailing process and performance requirements. The following list is an example of additional model detail that may be developed during design:

- Hole locations and patterns, but *not* fasteners or shear studs,
- Concrete reinforcing, including tensioning elements, but *not* lift loops, carriers, spacers, or ties,
- Splice plates and connection plates,
- Brackets and weld plates, but *not* welds or fasteners,
- Bearings modeled as cubic (rectangular or cylindrical) primitives,
- Electrical conduit and junction boxes, but *not* detailed connections,
- Location and extents of deck drains and piping, but *not* connection and anchoring details, and
- Location and extents of mechanical joints, but *not* connection and anchoring details.

Detailed construction drawings from the bridge engineer may still be provided in addition to a 3D model deliverable as further guidance/reference for desired detailed element conditions, like bearings, but will be used by the fabricator as reference during their design and development process.

Defining Roles and Responsibilities

The responsibilities for bridge modeling and model management need to be clearly defined and assigned to specific roles. Standardizing the workflow establishes a clear structure of accountability and efficiency for developing, reviewing, and delivering models. Clearly defined roles help team members understand their specific contributions to the overall workflow. The new roles that need to be assigned include:

- **Bridge Model Author**, who is responsible for creating and updating the bridge model and exporting and verifying the applicable IFC data.
- **BIM Manager**, who is responsible for federating discipline models, which includes the validation of the exported IFC data as well as the bridge model quality assurance process. This position is also accountable for ensuring that the modeling standards have been implemented correctly. A BIM Manager may also use the IDS for an added check if the person is knowledgeable in the information requirements.

Larger projects, with multiple bridges and structures, may require an intermediate role of Model Manager who would assist the BIM manager with certain responsibilities.

Data Management

A Common Data Environment (CDE) is a combination of technical solutions and process workflows for managing data. Per ISO 19650, an international standard that provides guidance for information management, a CDE is defined as "an agreed source of information for any given project or asset, for collecting, managing, and disseminating each information container through a managed process". A CDE serves as a crucial component in the successful implementation of BIM on projects. It provides a secure and centralized platform for the management, exchange, and coordination of project information. Establishing and maintaining a robust CDE is necessary for ensuring the efficient, accurate, and secure use of models on projects. A well-implemented CDE is a strategic asset that enhances the overall effectiveness of BIM workflows and promotes successful project outcomes.

Key Importance of a CDE:

1. **Collaboration and Communication:**
   - **Centralized Information Hub:** A CDE acts as a centralized repository where project stakeholders can access, contribute, and retrieve the latest information. This fosters seamless collaboration and communication among architects, engineers, contractors, and other parties involved in the project.
   - **Real-time Updates:** By providing real-time updates on project data, the CDE enhances communication, reduces errors, and ensures that stakeholders are working with current and accurate information.
2. **Data Integrity and Consistency:**
   - **Versioning:** A CDE provides access to a number of document versions, which are indexed for quick retrieval.
   - **Data Validation:** The CDE can be configured to enforce data validation rules to ensure that the information entered into the system meets specified criteria, which helps in maintaining the integrity of the data.
3. **Security and Access Control:**
   - **Secure Storage:** CDEs provide a secure environment for storing sensitive project information, protecting it from unauthorized access or potential breaches. This security is crucial given the sensitive nature of design and construction data.
   - **Access Permissions:** Role-based access control within the CDE ensures that only authorized individuals have access to specific information. These permissions help in maintaining confidentiality and controlling data access based on the responsibilities of each team member.
4. **Efficient Project Lifecycle Management:**
   - **Lifecycle Traceability:** CDEs support end-to-end project lifecycle management by maintaining a traceable record of changes and activities. This traceability is vital for auditing purposes, issue resolution, and lessons learned for future projects.
   - **Document Management:** CDEs streamline document management processes by organizing and storing project documentation in a structured manner. This enhances retrieval speed, reducing the time spent searching for critical information.
5. **Compliance and Standards Adherence:**

- **Standards:** A CDE facilitates adherence to standards by providing a common platform where different software tools can exchange information seamlessly. This interoperability is essential for the success of projects that use BIM.
- **Regulatory Compliance:** CDEs can assist in meeting regulatory requirements by providing a documented and controlled environment for data management, supporting compliance with industry standards and regulations.

Quality Management

Quality management is a cornerstone of the success of any project. In the dynamic landscape of technology, where rapid advancements and evolving client expectations are the norm, ensuring the highest standards of quality is challenging without proactive planning. Effective quality management encompasses both quality control (QC) and quality assurance (QA), providing a robust framework that not only detects and corrects defects but also prevents them from occurring. These four key points highlight the integral role that quality management plays in digital delivery projects.

Early Identification of Requirements and Expectations

Quality management in model-based projects begins with a comprehensive understanding of project requirements. By clearly defining the project scope and objectives, potential issues and ambiguities can be identified and managed before model development begins. This proactive approach sets the stage for effective quality assurance throughout the project life cycle.

Structured Quality Control Processes

Quality control (QC) is a critical component of quality management, focusing on the identification and rectification of defects during the project execution. Implementing structured QC processes involves continuous monitoring of project deliverables against predefined quality standards. QC processes for models include comparing the model to the minimum modeling requirements, ensuring that the model meets the relevant code requirements, testing and validating outputs (e.g., validating that the IFC file meets the schema requirements), and regular inspections of the discipline and federated models to identify and address deviations from project requirements. By integrating QC of the model into each phase of the project, teams can quickly address issues, minimizing the impact on the overall timeline and ensuring that the resulting IFC file satisfies the exchange requirement.

Comprehensive Quality Assurance

Quality assurance (QA) is a proactive and preventive approach to quality management. Rather than waiting for defects to surface, QA establishes processes and standards to prevent defects from occurring in the first place. This involves implementing best practices, standards, and guidelines, as well as conducting thorough reviews of project QC documentation. QA ensures that the project is on track to meet its objectives and that each deliverable aligns with predefined quality standards.

Continuous Improvement and Feedback Loops

Quality management is an iterative process that thrives on continuous improvement. A robust quality management framework establishes performance metrics across the program and feedback loops to incorporate lessons learned from each project to refine the quality framework and enhance future project outcomes. By analyzing project performance, identifying areas for improvement, and implementing corrective actions, owners can adapt and evolve the quality management framework as digital delivery strategies and supportive technologies mature, ensuring a more efficient and effective use of models in the project development process.

Data Validation

Validation tools play a pivotal role in ensuring the accuracy, integrity, and compatibility of BIM data exchanged between engineers, contractors, and other project stakeholders. The process of implementing a validation workflow helps identify and rectify potential errors or inconsistencies before exchanging the data, preventing costly rework and delays. The three tools that have been developed to assist with the creation and validation of IFC files include:

1. The bSDD Service houses the AASHTO Bridge Data Dictionary developed by TPF-5(372) within the AASHTO Domain designation. The data dictionary works in conjunction with the IDS to provide a means for the precise matching of terms which is required for correct IFC matching.
2. TPF-5(372) IDS serves two purposes. It provides the requirements, as stated in the IDM, of the subset of the IFC schema for the data export. The IDS also checks the export's properties and quantities along with the IFC schema attributes such as object classification and material names as well as selected relationships such as containment, grouping, and aggregations.
3. The buildingSMART International's Validation Service checks an IFC file for compliance with IFC syntax, schema, and geometric rules. It also checks that the file has an association with a data dictionary domain.

More detailed information about how these three tools relate to each other can be found in the Technical Solution Summary and Infographic.

Working with Software Vendors

There are a considerable number of software solutions available to develop bridge models. Each product addresses the needs and workflows of a community of stakeholders (e.g., designers/engineers, contractors, fabricators, material/product suppliers, operators, asset managers, etc.). Many of the software vendors who have served the bridge market with 2D CAD products have developed corresponding BIM solutions. Other vendors are in the process of making such model-based functionality available in their solutions, or developing new, sometimes complementary, applications or platforms. When it comes to support for open standards for BIM (e.g., IFC, bSDD, IDS, etc.), the number of applications which contain such functionality varies widely and is continually growing. Each vendor approaches support differently based on how their software is used (e.g., model-authoring vs. model/data analysis) in a specific domain (e.g. buildings, infrastructure).

The Role of Software Vendors in openBIM Standards

Software certification has traditionally been optional for software vendors, but the certification does afford increased confidence to the users that the IFC exchanges will be fully supported without data loss or corruption. Software users should view the certification as a validation of an application's capabilities, but also recognize that the “correctness” of an IFC file export also depends on proper usage by the end user. It is recommended for a certification program to combine the use of documentation, implementation guides, and test instructions to determine if a software product can meet the specified requirements.

IFC Software Certification vs. IFC File Validation

The purpose of the Software Certification program is to verify that a software product is technically capable of exchanging IFC formatted information (e.g., export and/or import) based on specific requirements. Certification is against a specific version of the IFC schema and/or bSI technical solution and often within a specific domain (e.g., “Bridge”).

bSI provides an ongoing platform and process to certify software applications for a specific version and subset of the IFC schema and multiple software applications have been certified using this program. Currently, the bSI Certification Program is only available for IFC2X3 Coordination View 2.0 and IFC4 Reference View 1.2. A certification program for IFC4.3 AbRV is not available at the time of the publication of this document. However, until an official certification program is offered by bSI, State DOTs can still work with software vendors to incorporate the new standard into software applications without requiring official certification by leveraging the bSI IFC Validation Service.

The IFC4.3 schema and bSI standards are open to anyone to implement and deploy in software with no restrictions beyond the appropriate licensing agreements. This means any software vendor can opt to support IFC 4.3 exports using the IFC rules checked by the bSI Validation Service, which are available and shared widely through the bSI Github page https://github.com/buildingSMART/ifc-gherkin-rules/tree/main/features. The bSI Validation Service checks for IFC syntax and schema on all parts of IFC.

Note: It is important to recognize that the bSI Validation Service is an important piece of the overall quality management approach for IFC deliverables, and further development of the service is constrained by the financial resources available to bSI. bSI continues to seek financial support from its members to launch technical projects to further develop the IFC file Validation Service. Sustainability of the standards developed by TPF-5(372) is dependent on the financial support from the U.S.

To this end, it is important to note that the vendors participating in the BIM for Bridges and Structures Pooled Fund Software Advisory Group are committed to supporting openBIM standards. These software vendors have been participating in virtual weekly meetings for several months with the BIM for Bridges Pooled Fund Technical Team to discuss the specific requirements for the AASHTO Design to Construction data exchange using IFC4.3. Further, many of the same software vendors have been actively participating in the bSI Implementers Forum hosted by the bSI Technical Team to discuss the agreements for implementing the IFC4.3 and AbRV and the rules being used by the bSI Validation Service. The collaboration between bSI and software vendors on the implementation of IFC4.3 has been proactive and more successful than any previous version of the standards, but there is still more work to do before a certification program is available. However, a formal software certification program has not been established by bSI due to lack of funding. To create a robust software certification program, bSI will need to get financial support from chapter members to fund a project that will develop test instructions.

The unit test suite produced by the BIM for Bridges and Structures Pooled Fund is one component of the materials that may be used for bSI certification, however, it's not the only aspect of the program. bSI is reviewing the bridge test instructions developed by an international effort sponsored by a few European countries. These international project bridge test instructions were delivered to bSI at the beginning of calendar year 2024. It is highly recommended for bSI to review the TPF-5(372) unit test instructions to assess usability for the certification program.

An official certification program offered for IFC 4.3 AbRV is highly desired by many countries. It is anticipated that the IFC4.3 AbRV certification program will be available in the next two years given the funding becomes available to develop and deploy the program.

There is an ongoing debate whether or not a State DOT should require IFC certification from software vendors. Until an official certification program is offered by bSI, it will be difficult or practically impossible for software vendors to be compliant with a certification contractual requirement. However, State DOTs can work collaboratively with software vendors to look into how IFC 4.3 AbRV support can be incorporated into software. It is highly recommended that State DOTs

1. Continue engaging with software vendors and bSI to define and deploy the IFC4.3 AbRV certification program using the Unit Test Suite and the international project bridge test instructions, so that in the future, requirements for software certification are an option when procuring bridge modeling software. This effort will continue through the TPF-5(523) BIM for Bridges and Structures Phase II.
2. Partner with software vendors in piloting the application of the bSDD and IDS to properly deliver IFC files using the current software that may be capable of connecting to the bSDD service and exporting and importing IFC files but may not be officially certified.
3. Create partnerships with other State DOTs currently planning pilot projects to apply the openBIM Standards developed by the BIM for Bridges and Structures Pooled Fund using federal grants or state research funds.
4. Incentivize software vendors to actively participate in the bSI IFC4.x Implementers Forum (IF), the bSI General Assembly of Implementers (GA), and the buildingSMART USA Technical Committee Solutions Providers Group (SPG). One option to incentivize software vendors to consider may be assigning points on procurement requirements for participating in these groups.
5. Participate in the SPG of the buildingSMART USA Technical Committee to actively collaborate with the buildingSMART community and software vendors. AASHTO bSI Principal membership provides the benefit for any State DOT employee to participate in activities sponsored by the buildingSMART USA Chapter. Activities may include technical committee meetings and/or

webinars and chapter summits. A cost may be associated with attending chapter summits and in-person events.

Documentation and Support

There are multiple types and levels of documentation available to State DOTs, as well as support for modeling and data exchanges. Three core resources are the Unit Test Suite (developed by the TPF-5(372) study), software-specific documentation and support agreements, and support provided by bSI and the buildingSMART USA Chapter (bSUSA).

Unit Test Suite

The Unit Test Suite (UTS) provides software vendors with a set of detailed criteria for creating bridge models and enhancing the model components with the required semantic data, and correctly mapping the data to the IFC4.3 schema for export. The information within the UTS enables verification of the results from export to import demonstrating the software's adherence to the data exchange requirements. Software vendors will use the UTS to help develop and debug the needed model authoring and exchange functionality in their products.

End users of the software (e.g., bridge engineers, contractors, fabricators, owners, etc.) can use the UTS to determine the expected data modeling requirements and exchange results for their processes, software, and projects. It is a resource for developing the minimum model development requirements. The UTS includes guidance on levels of data and geometric detail, appropriate mappings of elements and data to the IFC4.3 schema and expected results to satisfy the Design to Construction exchange and supported workflows. The individual test instructions of the UTS are not software-specific, as they are meant to address the user requirements for data modeling and exchange.

Software-specific Documentation and Support

Each software application supporting the openBIM standards typically has documentation authored by the vendor to explain how the functionality works in their specific software. The documentation may not describe a specific data exchange or modeling process (e.g., Design to Construction) but should provide enough guidance on how to correctly use IFC through the description of modeling elements, associated IFC semantics, enabled customization where needed, connections to the bSDD, exporting or importing of IFC files, and/or using IDS files to validate data in an IFC file.

buildingSMART Support

buildingSMART does *not* provide technical support to the industry regarding the use of specific software. Each software vendor is responsible for documenting how openBIM standards work specifically in their product. buildingSMART, at both international and chapter levels, may provide support to the vendors in creating such documentation, but does *not* have strict guidelines to do so. The buildingSMART community *does* help software users (e.g., designers) on understanding the usage of openBIM standards, including IFC, bSDD, IDS, etc.

Preparing Training and Presentation Materials

A technical advancement of this magnitude relies on the development of concise and easy-to-understand training and presentation materials. A clear and comprehensive training and presentation framework is instrumental in bridging the knowledge gap among stakeholders, ensuring that technical personnel and end-users alike grasp the intricacies of these standards effortlessly. Well-crafted materials enhance the efficiency of the rollout process, minimizing the potential for errors and misunderstandings. Additionally, they empower teams to swiftly adapt to new standards, fostering a collaborative environment conducive to innovation. By prioritizing clarity and simplicity in training materials, organizations can promote widespread understanding, adoption, and successful implementation of open data exchange standards, thereby unlocking the full potential of technological advancements in information exchange.

Comprehensive Needs Assessment

Begin by conducting a thorough needs assessment to identify the specific requirements and challenges of the target audience. Understand the existing knowledge base, potential areas of confusion, and the preferred learning styles of the audience. This insight will inform the development of tailored training materials that address the unique needs of both technical and non-technical stakeholders.

Clear Articulation of Standards

Clearly articulate the open data exchange standards, breaking down complex technical jargon into easily digestible concepts. Utilize visual aids, diagrams, and real-world examples to illustrate key principles. Emphasize the practical implications of adhering to these standards, highlighting the benefits and potential pitfalls to enhance comprehension and motivate active engagement.

Interactive Learning Platforms

Implement interactive learning platforms that cater to diverse learning styles. Develop hands-on exercises, simulations, or workshops that allow participants to apply theoretical knowledge in a practical context. By providing opportunities for hands-on experience, you reinforce understanding and build confidence among participants, ensuring they are well-equipped to navigate the intricacies of the open data exchange standards.

Feedback Mechanism and Iterative Improvement

Establish a robust feedback mechanism to gather insights from participants throughout the training process. Regularly solicit feedback on the clarity and effectiveness of the training materials. Use this input to iteratively refine and improve the content, ensuring that it remains aligned with the evolving needs and understanding of the audience. This iterative approach not only enhances the quality of the training materials but also demonstrates a commitment to continuous improvement in the rollout process.

Piloting the Use of Open Data Standards

A well-defined pilot project program is essential for the successful implementation of open data exchange standards for US bridge projects. These programs not only act as steppingstones for testing and refining initiatives but are also a key element in fostering innovation, efficiency, and overall success in standardizing the digital delivery of US bridge projects. This section describes four key factors to consider when preparing a pilot project program.

Project Planning and Risk Mitigation

Pilot projects provide a controlled environment for trying new tools, methods, and deliverables. So, it is important to select a project that has a low-risk scope of work, and a team that is motivated and excited to learn new methods and technologies. It is recommended that the project team prepares a BIM Execution Plan (BEP) that describes communication and collaboration protocols, data management practices and tools to be used, quality management of the design deliverables, and details about how and when the IFC files will be created, validated and delivered.

Another recommendation for the project team is to participate in a risk management workshop to identify actual and perceived risks and establish mitigation strategies at the beginning of the project. The information captured during the workshop should be used to prepare a risk management plan (RMP) that lists the risks, mitigation strategies, and the owners of the identified risks. The project team should revisit both the BEP and the RMP on a regular basis, and update it as needed.

Lastly, it is important to recognize that a prerequisite for piloting open data standards is the use of BIM processes and technologies. Thus, it is highly recommended to use a phased approach for implementing open data standards with the first phase being a strategy for implementing BIM.

Training and Technical Support

Just-in-time training for the project team is highly recommended. A training course should be developed to educate the project team members about open data standards, 3D modeling tools and techniques, creating IFC files in the authoring software and validating in a third-party software application, accessing and viewing IFC files, and importing into the contractor software. Further, it is important to have a technical team available to answer questions during the project and provide timely software support. It is also recommended for the project teams to work closely with the modeling software vendor to find opportunities for improvement and to document procedures, gaps in the software, and workaround solutions to current software shortcomings.

Stakeholder Engagement and Feedback

Learning opportunities within the pilot phase are vital for teams to refine their strategies, troubleshoot challenges specific to data exchange, and adapt to evolving standards. Early identification and resolution of issues contribute significantly to the seamless implementation of open data exchange standards. The following recommendations are provided for consideration:

- Identify key stakeholders involved in the pilot project and how their jobs may be impacted by the use of open data standards. Identifying the various stakeholders ahead of deploying the pilot project will help in determining the type of training, communication and engagement that may be needed to make the project successful.

- Create a communication and engagement plan to assist the State DOT and project teams with communicating roles and responsibilities, opportunities for participation, and providing and receiving feedback. A proactive approach to communication and engagement is a strategy to foster a sense of ownership and commitment and establish a collaborative framework that is crucial for the successful integration of open data exchange standards.
- Establish a way to document challenges and lessons learned and share the information with stakeholders. Pilot projects are the testing ground for evaluating the effectiveness of data exchange protocols, enabling organizations to make data-driven decisions for broader implementation.
- Collaborate with other State DOTs through peer exchanges and technology transfer activities to further the use of BIM and open data standards.

Measuring Success

Another important factor is to establish metrics to measure success. Performance metrics provide a way to understand what success looks like and inform the team about how they may need to change their strategy for successfully delivering the project. At the end of the day, the pilot projects are the basis for refining standards, optimizing performance, and ensuring that US bridge projects benefit from interoperability and standardized data exchange, contributing to the long-term sustainability of infrastructure initiatives.

The development and execution of pilot project programs stand as a strategic imperative for US bridge projects seeking to implement open data exchange standards. These programs offer a controlled environment for addressing challenges, engaging stakeholders, optimizing resources, and laying the foundation for scalable and sustainable delivery of files in a neutral non-proprietary format that will enhance interoperability. The transition from pilot to full-scale implementation becomes not only well-informed but also aligned with the transformative potential of open data exchange standards in shaping the future of bridge projects in the United States.

Examples of performance metrics to consider include:

- Number of states piloting TPF-5(372) products
- Number of published case studies documenting the use of TPF-5(372) products on bridge projects
- Number of collaborative partnership agreements between State DOTs and software vendors
- Number of software vendors including support of IFC 4.3, AbRV and bSDD as part of their product roadmaps

Appendix 20: AASHTO National BIM Standards Governance Technical Memorandum

BIM FOR BRIDGES AND STRUCTURES

TPF-5(372)

AASHTO National BIM Standards Governance Technical Memorandum

Recommendations for a Governance Strategy for National BIM Standards

Date: March 2024

Version: Final

Table of Contents

BIM FOR BRIDGES AND STRUCTURES TPF-5(372)

Background Information

This document provides a short background on the AASHTO Administrative Resolution (AR-1-19) (1)to adopt the Industry Foundation Classes (IFC) Schema, and it provides recommendations to TPF-5(372) BIM for Bridges and Structures members regarding a governance framework for the American Association of State Highway and Transportation Officials (AASHTO) to oversee the development and implementation of a national data standard for the adoption of building information modeling (BIM).

AASHTO AR-1-19

The AASHTO Administrative Resolution (AR-1-19)[1] to adopt the Industry Foundation Classes (IFC) Schema was approved in October 2019. Specifically, the AR-19 was approved to:

- Adopt the IFC Schema as the national data standard for AASHTO States.
- Establish an internal, cross-committee, multi-disciplined group within AASHTO to coordinate schema adoption, identify gaps, resolve any conflicts, and avoid duplication of efforts.
- Investigate AASHTO membership in buildingSMART International to provide representation and participation for the state DOTs in schema development.

AASHTO buildingSMART Membership

AASHTO joined buildingSMART International (bSI) as a Principal Member on October 21, 2022. These openBIM® standards are developed through international consensus via bSI organizational structure. Members of bSI have direct input into the development and implementation of openBIM standards, and their support provides longer term data governance and support of openBIM. There are many levels of membership within bSI, with the Principal Membership being the most influential given its granted benefits.

The bSI Principal Membership will enable AASHTO members to actively participate as follows:

- One voting member in the bSI Standards Committee (governance body), which oversees the overall Standards process
- One voting member in the Infrastructure Domain Steering Committee (IDSC), which oversees international projects for multiple activities to advance the openBIM standards
- Direct and indirect representation as a member of the Technical Committee. This committee oversees US Chapter technical work in advancing the development of openBIM standards and the implementation of such standards by software developers and technology providers. The committee oversees the work of two working groups:

[1] https://data.transportation.org/wp-content/uploads/sites/44/2022/05/AR-1-19-IFC-Schema-Resolution-Board-Adopted-FINAL.pdf

- US Data Dictionary Working Group – responsible for developing and approving content to be uploaded to the buildingSMART Data Dictionary Service that is made available to software vendors
- Solutions Providers Working Group – responsible for working directly with software vendors to help advance deployment of openBIM standards in commercial-off-the-shelf software.

- Participation in technical committees, working groups, regional summits, and educational programs
- Access to webinars, collaboration forums, and technical resources

Without bSI membership, AASHTO members have no voice to influence the direction of openBIM standards and how software developers implement them.

The use of openBIM standards is a critical piece in enabling State Departments of Transportation advance their digital delivery initiatives. Today, exchanging digital information is very difficult because the data is typically developed through proprietary technologies that do not talk to each other. openBIM standards allow State DOTs and their stakeholders interoperability to freely share information regardless of software being used.

The AASHTO AR-1-19 and the AASHTO bSI Principal Membership serve as the basis for the proposed governance strategy presented herein. The organizational roles and responsibilities of AASHTO, Federal Highway Administration (FHWA), bSI, State DOTs and Industry at large were also considered in preparation of the recommendations presented in this document. These organizational roles and responsibilities are fully described in Appendix A of this technical memorandum.

Proposed Governance Strategy

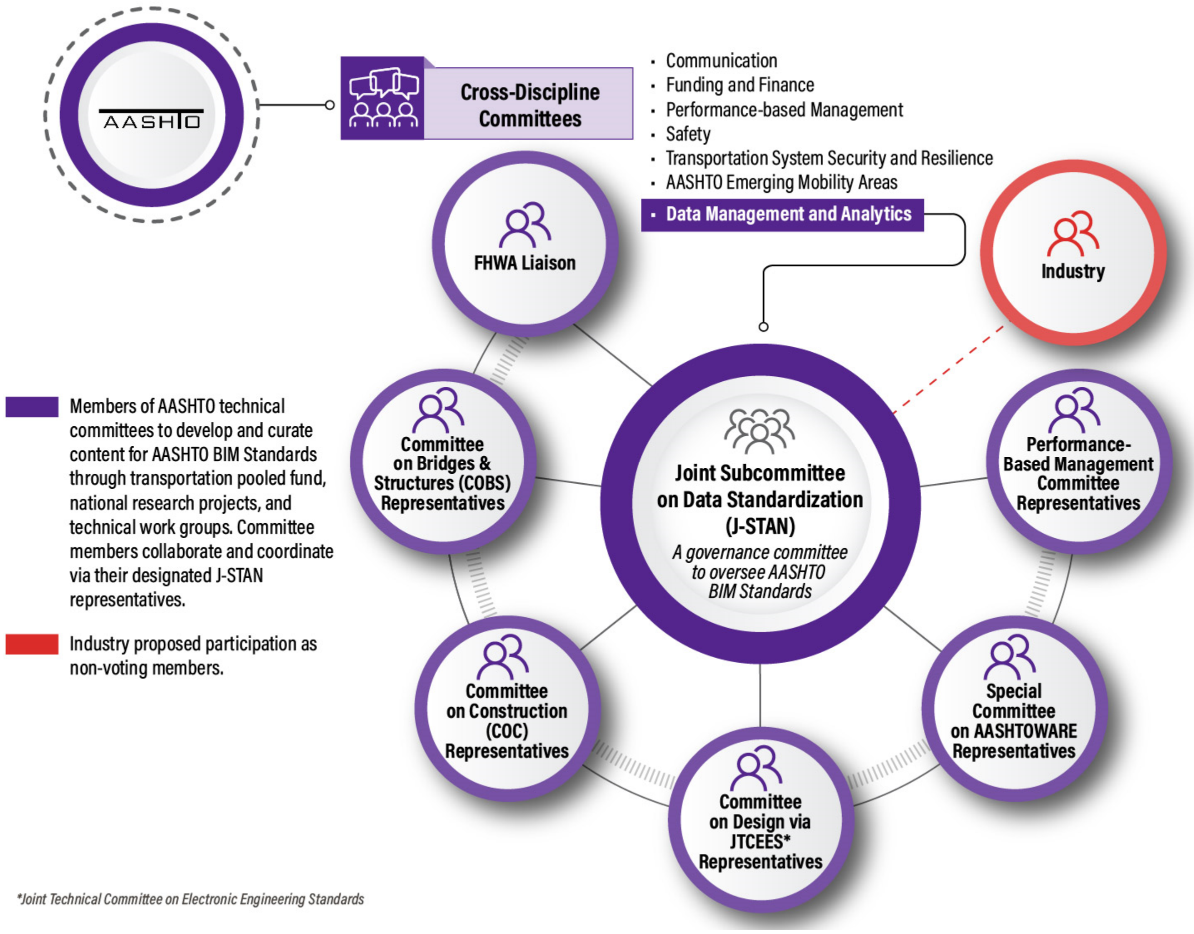
The proposed governance strategy presented herein provides a framework that will enable AASHTO members and other transportation agencies to adopt and manage State Departments of Transportation (DOT) BIM standards through a variety of individual, regional, and national efforts.

Both the adoption of IFC as the standard schema for the exchange of electronic engineering data, and the creation of the Joint Subcommittee on Data Standardization (J-STAN) were established by AR-1-19. The role of J-STAN was never intended to be the author of discipline-specific State DOT BIM standards but rather to work with each of the disciplines to identify complementary industry standards and coordinate the work to implement those standards or develop new standards to meet the needs of AASHTO members.

The proposed governance strategy is based on two key elements: 1) the roles and responsibilities of AASHTO's various committees and 2) the coordination and collaboration with buildingSMART to enable State DOT adoption of industry standards and best practices for BIM adoption.

Roles and Responsibilities

Figure 1. Current Governance Committee Structure with Proposed External Stakeholders



Roles and responsibilities for each group illustrated in Figure 1 are described as follows:

- **J-STAN:** governance body for all BIM standards (including open data standards). Responsibilities as a governing body may include but are not limited to:
  - Identify the BIM Standards to be governed by AASHTO; current suggestions include:
    - AASHTO Domain Data Dictionary hosted on the buildingSMART Data Dictionary (bSDD) Service
    - Information Delivery Manuals (IDM)
    - Information Delivery Specifications (IDS)
    - Classification Systems (e.g., UniFormat, MasterFormat, OmniClass, UniClass)
    - Open geospatial standards published by Open Geospatial Consortium (OGC) (a strategic partner with bSI)

- Define roles and responsibilities for each of the J-STAN committee members
- Coordinate the development, maintenance, and use of AASHTO adopted openBIM® standards
- Establish long-term funding sources for annual bSI Principal Membership fees to ensure continued governance and bSI involvement
- Define minimum criteria for selecting the AASHTO representative to each bSI committee
- Coordinate with bSI to determine protocols for replacing the selected AASHTO representative to the IDSC (in the event the chosen representative may not be able to complete the required four-year term)
- Provide direction on coordinating efforts with industry representatives to help prioritize input into the development and implementation of openBIM standards and technology applications of those standards.

Specific Discipline Technical Committees: The main responsibility as it relates to AASHTO adopted openBIM standards is to develop and curate content for guide specifications, define best practices, manage the AASHTO domain data dictionary (DD) content, conduct webinars and publish educational material related to individual disciplines. Examples may include:

- Development, balloting, and publication of IDMs
- Creation of software test instructions for certification and validation services provided by bSI. The intent is to share test instructions with bSI to be evaluated and updated for sharing with the international community as part of official bSI Certification and Validation Services. These test instructions would help reduce the cost of certification, which in turn will increase participation by software vendors.
- Development of IDS for AASHTO data exchanges
- Development of content for the AASHTO Domain Data Dictionary
- Identification, coordination and creation of educational material regarding best practices related to each specific discipline.
    - BIM execution plans (BEP)
    - Model element breakdown structure (MEBS)
    - Level of Development (LOD) for geometric representation of 3D objects
    - Level of Information Need (LOIN) for information requirements defined in IDMs and verified by IDS technology
    - Guidelines for 3D model-based quality management and documentation
    - Process improvements and training documentation
    - Level of geospatial positioning accuracies and metadata. It is important to note that there is no technical committee within the AASHTO organization that oversees survey matters. It is highly recommended that a Subcommittee on Geomatics within the Committee on Construction (COC) is created to assist AASHTO with National BIM Standards. The COC

Technology Subcommittee already has a few members currently engaged. In 2022, this group drafted a resolution to:

- Establish a national surveying and mapping standard
- Create a cross-committee, multi-disciplined group within AASHTO to coordinate surveying and mapping standards and avoid duplication of efforts
- Establish a permanent group to guide the development and maintenance of surveying and mapping standards

- Coordination and collaboration with other external bodies responsible for other BIM Standards, such as the National Institute of Building Sciences (NIBS), BIM Forum, Construction Specifications Institute (CSI), etc.
- Provide direction to project teams working on national efforts through transportation pooled funds, NCHRP research projects, and FHWA national research projects
    - Recommendations for representing each discipline of the engineering community on NCHRP panels and national technical working groups working with FHWA
    - Coordination of scope of work, budget, and schedules for transportation pooled fund efforts

Coordination and Collaboration with buildingSMART International

AASHTO Membership Benefits

The proposed relationship between AASHTO and bSI is illustrated in Figure 2. Figure 3 is buildingSMART USA interpretation of their relationship with AASHTO (as posted on their website). As a principal member, AASHTO receives benefits with the international organization and the US chapter as described below.

International benefits:

- One voting member in the bSI Standards Committee (governance body), which oversees the overall Standards process
- One voting member in the IDSC, which oversees international projects for multiple activities to advance the openBIM standards

US Chapter benefits:

- Representation as a member of the US Chapter Executive Committee, via the US Roads & Bridges Committee
    - Chair of the US Roads & Bridges Industry Committee to be an elected J-STAN representative
    - Vice Chair of the US Roads & Bridges Industry Committee to be an elected industry representative

- Direct and indirect representation as a member of the Technical Committee. This committee oversees US Chapter technical work in advancing the development of openBIM standards and the implementation of such standards by software developers and technology providers. The committee oversees the work of two working groups:
  - Data Dictionary Working Group
    - The participation from AASHTO technical committee members is highly encouraged. It is recommended for the AASHTO Committee on Bridges and Structures, Technology Technical Committee, to serve in the role of AASHTO representative in this working group until other AASHTO technical committees create, review, and reach consensus on specific discipline content to be uploaded to the bSDD service. This working group may serve as a collaboration forum in which AASHTO can work with other organizations to reach consensus on the content that should be considered by the various AASHTO technical committees and transportation pooled funds for incorporation into the AASHTO Domain DD. Currently, there is no direct participation from AASHTO technical committee members. All input related to the AASHTO Domain DD is being provided indirectly by the BIM for Bridges and Structures consulting team developing the content for the AASHTO Bridge Data Dictionary as part of the TPF-5(372) Pooled Fund scope of work.
    - The participation from representatives from the Special Committee on AASHTOWare is also recommended to work directly on technical matters as member of the Data Dictionary Working Group.
  - Solutions Providers Group (SPG)
    - It is also recommended for AASHTO technical committees actively working on development of openBIM standards directly managed by buildingSMART to select one representative to participate in this working group. This interaction would enable State DOTs investing in the development of national openBIM standards to have the proper level of engagement with software vendors outside of pooled fund efforts.
    - Special Committee on AASHTOWare members should also consider being an active member of this working group given they are the governing body for AASHTOWare products and services. This interaction would support AASHTO members' interoperability goals for AASHTOWare products.
- Participation in technical committees, working groups, regional summits, and educational programs
- Access to webinars, collaboration forums, and technical resources

Figure 2. AASHTO's Current Relationship with buildingSMART USA with Minor Proposed Changes

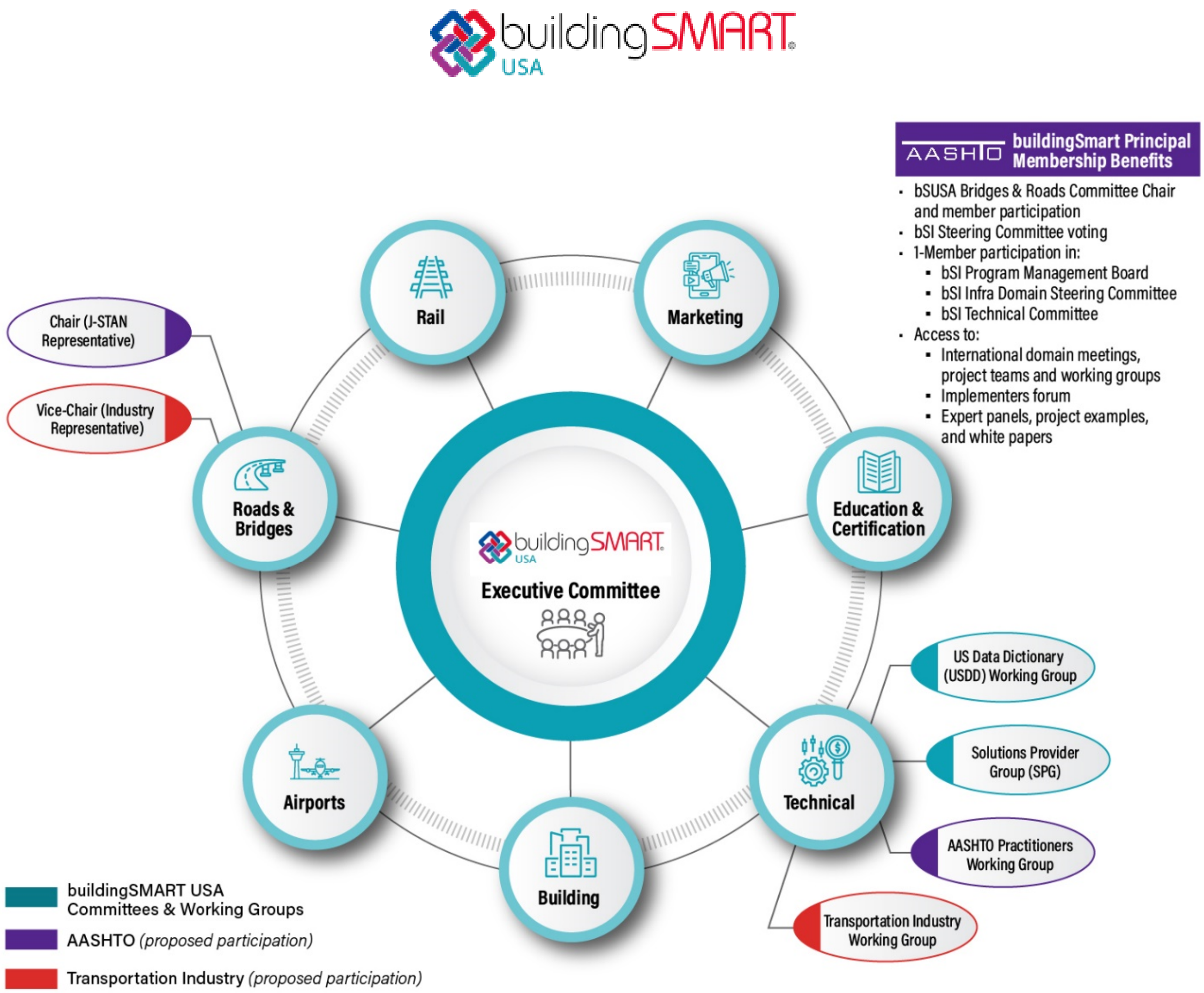
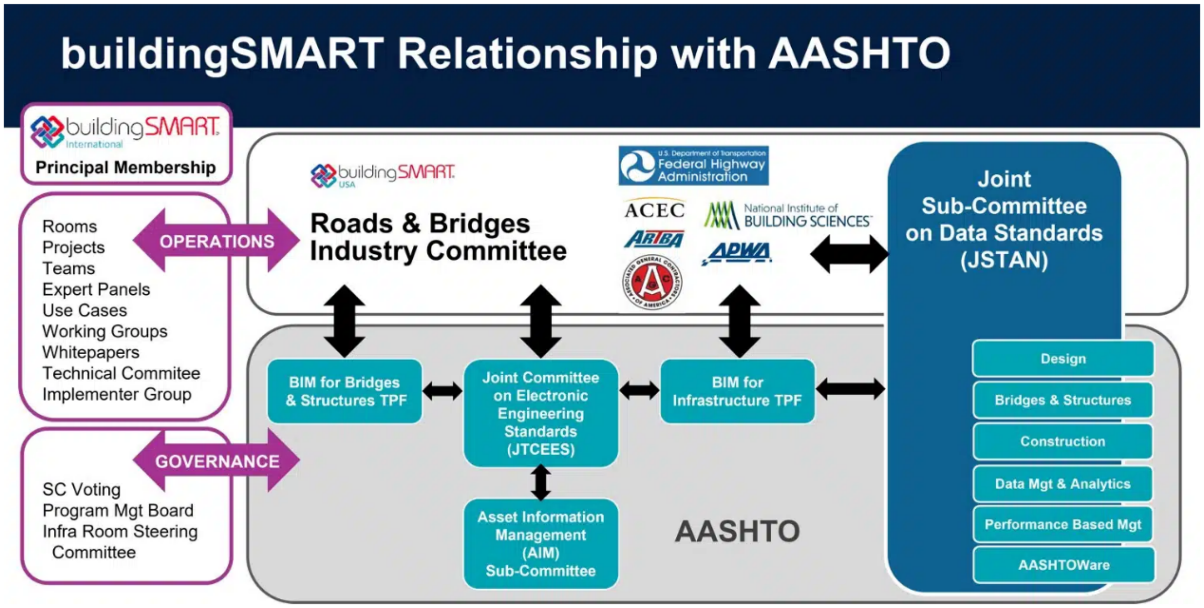


Figure 3. Relationship Diagram as published on the buildingSMART USA Website



Considerations for Development and Updates to AASHTO National BIM Standards

As new National BIM Standards are identified and adopted by AASHTO, it is important to evaluate dependencies on bSI Core Standards, as well as level of effort and activities required for successful implementation. It is recommended that each AASHTO technical committee oversees the prioritization and development of its specific discipline standards while considering the need for National BIM Standards and the discipline co-dependencies with each other. Each technical committee has two representatives in J-STAN who would be responsible for submitting the needs of each specific discipline and creating the business case for each of the proposed new standards. As a governance body, J-STAN would then prioritize development and implementation of new National BIM Standards using AASHTO balloting and voting protocols. It is also important for J-STAN to develop a National BIM Standards Roadmap to assist with communication, coordination, and collaboration of priorities and activities for advancing the state of the practice.

Since the National BIM Standards adopted by AASHTO will have some dependencies on bSI Core Standards, it is important to establish the protocols to address changes. Changes may be initiated by bSI or by AASHTO.

- **Changes made by bSI**
  - If bSI Core Standards change, for example changes to base MVDs, i.e., Alignment-Based Reference View (AbRV), bSDD and IDS, those changes would propagate directly to the

AASHTO National BIM Standards. In this case, the affected AASHTO National BIM Standard should be reviewed by the appropriate technical committee or designate technical expert to assess impacts and develop solutions. If reviewers agree changes impact the current AASHTO National BIM Standards, a recommendation for updates should be prepared to reflect such changes to the content of one or more IDM and IDS, AASHTO Domain Data Dictionary, certification, and validation requirements; and updates to application programming interfaces (APIs) and functionality related to the BIM Collaboration Format (BCF).

  - Omissions or errata in bSI Core Standards (e.g., IFC schema and schema documentation) should be submitted following current bSI protocols using community forums.

- **Changes made by J-STAN (via technical committees)**
  - If a change is made to AASHTO National BIM Standards, (e.g., updates to IDMs, AASHTO Domain Data Dictionary, IDS, etc.), J-STAN should work with the appropriate technical committee(s) or designate technical expert to assess impacts and develop solutions. The following scenarios have been identified for consideration:
    - Changes to AASHTO National BIM Standards necessitating changes to bSI core standards (e.g., IFC schema changes, base MVDs, BCF implementation changes, etc.) would be submitted to buildingSMART US Chapter through the Roads & Bridges Industry Committee in collaboration with the bS USA Technical Committee. The IDSC, J-STAN and US Chapter representatives would be responsible for communicating the need for these items to be added as high priorities for IDSC business to be shared with bSI and its Standards Committee Technical Executive.
    - Changes to National BIM Standards that do not require updates to bSI Core Standards would be implemented by the appropriate AASHTO technical committee or designate technical expert.

Appendix A. Organizational Roles and Responsibilities

AASHTO

AASHTO is an educational organization and serves as a liaison between state departments of transportation and the Federal government. AASHTO is also the authority in setting technical standards for all phases of the highway system, including design and construction of highways and bridges, as well as materials, safety, operations, and many other technical areas. As an organization, AASHTO is guided by a Board of Directors, led by an Executive Committee, and supported by paid staff. However, much of the work is conducted by forums, councils, committees, and task forces made of member department personnel who serve voluntarily through the AASHTO committee structure (Figure A-1). Each of the committees may also be subdivided into technical subcommittees or task forces that focus on specific topics of interest to the parent committee.

FHWA

As a federal government agency within the U.S. Department of Transportation, FHWA is responsible for supporting State and local governments in the design, construction, and maintenance of the National Highway System through the Federal Aid Highway Program. FHWA also supports various federally and tribal owned lands through the Federal Lands Highway Program. Historically, FHWA has collaborated with AASHTO and its members through a variety of technical committees, national transportation pooled funds, Transportation Research Board, and FHWA sponsored programs (e.g., Every Day Counts and Turner-Fairbank Highway Research Center). Most recently, FHWA has funded many technology transfer activities (e.g., peer exchanges) and research projects to advance the national BIM state of the practice. The need for this financial and technical support continues to be a foundational enabler for State DOTs to develop and implement National BIM Standards and best practices.

State Departments of Transportation

State DOTs are responsible for planning, design, construction, and operations and maintenance of the transportation assets within their state jurisdiction. Each State DOT allocates resources from various Federal-aid and State-funded programs. Within the context of BIM deployment activities, State DOTs develop and implement initiatives to advance the state of the practice within their jurisdiction and collaborate with their state industry representatives. The role of State DOTs in the development and deployment of National BIM Standards is to contribute technical resources to represent the interests of their state within transportation pooled funds, AASHTO technical committees, and national research technical working groups. At the local and regional level, State DOTs coordinate and collaborate with their state specific industries, business, and technology partners and exchange best practices with their peers via peer exchanges, regional summits and national conferences.

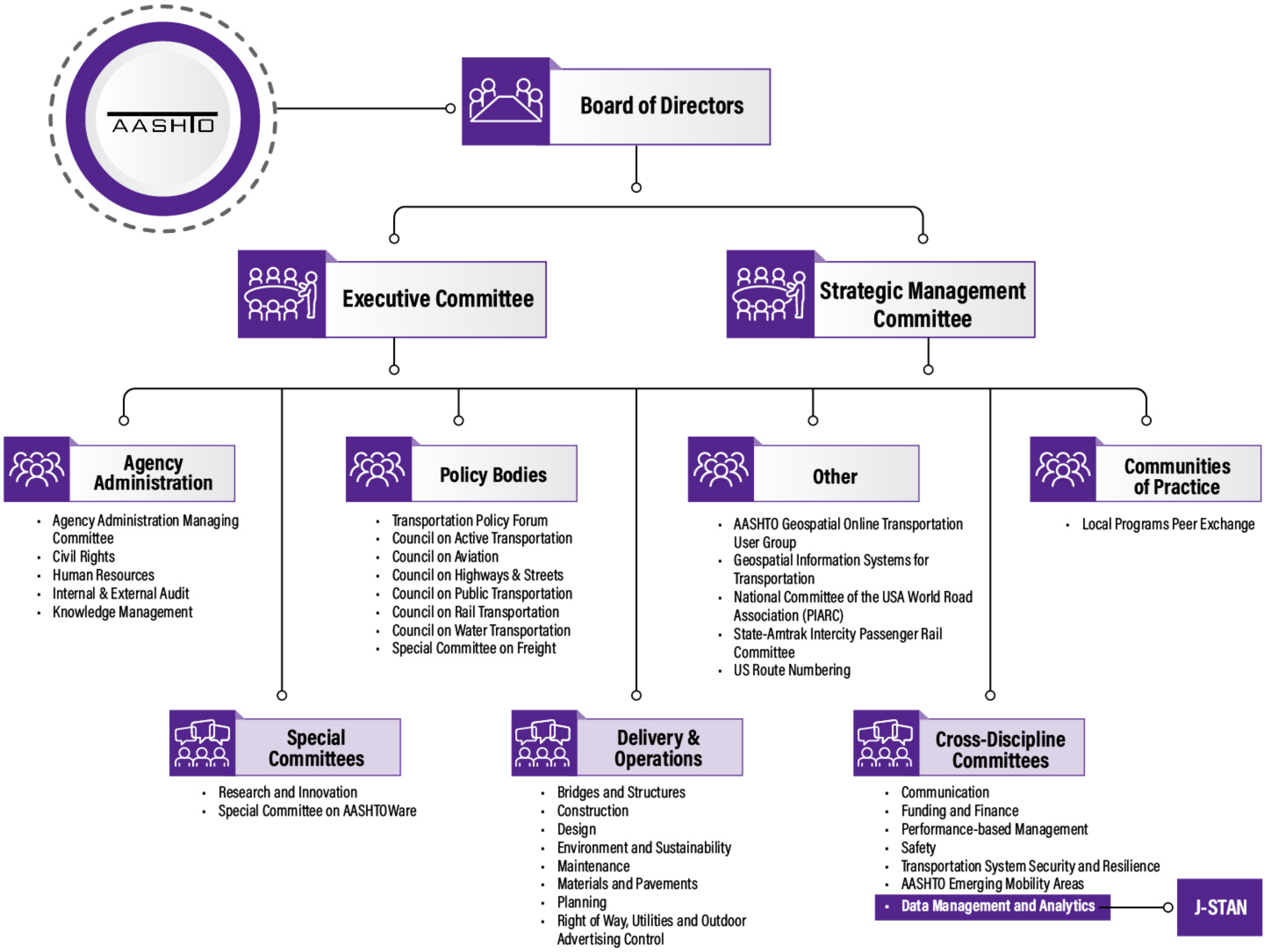
Industry

Industry also plays a critical role assisting State DOTs in the design, construction, and longer-term management and operations of infrastructure. In the context of BIM and national data standards, Industry includes technical experts external to the States DOTs and FHWA including design consultants, contractors, fabricators, and others. For immediate collaboration, an Industry Advisory Group (IAG) is proposed under the BIM for Bridges and Structures Phase II pooled fund effort to provide focused industry input and feedback for BIM pooled fund efforts at the national level. Initial members of the IAG are anticipated to include representative members from Association of General Contractors (AGC), American Roadway and Transportation Builders Association (ARTBA), the American Council of Engineering Companies (ACEC), the National Steel Bridge Alliance (NSBA), the National Concrete Bridge Council (NCBC), the National Institute of Building Sciences (NIBS), buildingSMART USA, and buildingSMART International, and we expect this group will evolve over time.

The IAG is being initially established by the TPF efforts and includes coordinating with leadership of these industry groups to confirm active participation and designating one to two representatives for participation in the IAG, developing an IAG mission statement, and having periodic meetings with industry representatives. The IAG will provide a conduit for getting proactive industry input in the development of national open data standards.

The membership and composition of the IAG may evolve over time as new data exchanges are defined and developed by AASHTO Technical Committees. Long term collaboration may take place via a national digital delivery stakeholder group being coordinated by FHWA.

Figure A-1. AASHTO Organizational Structure

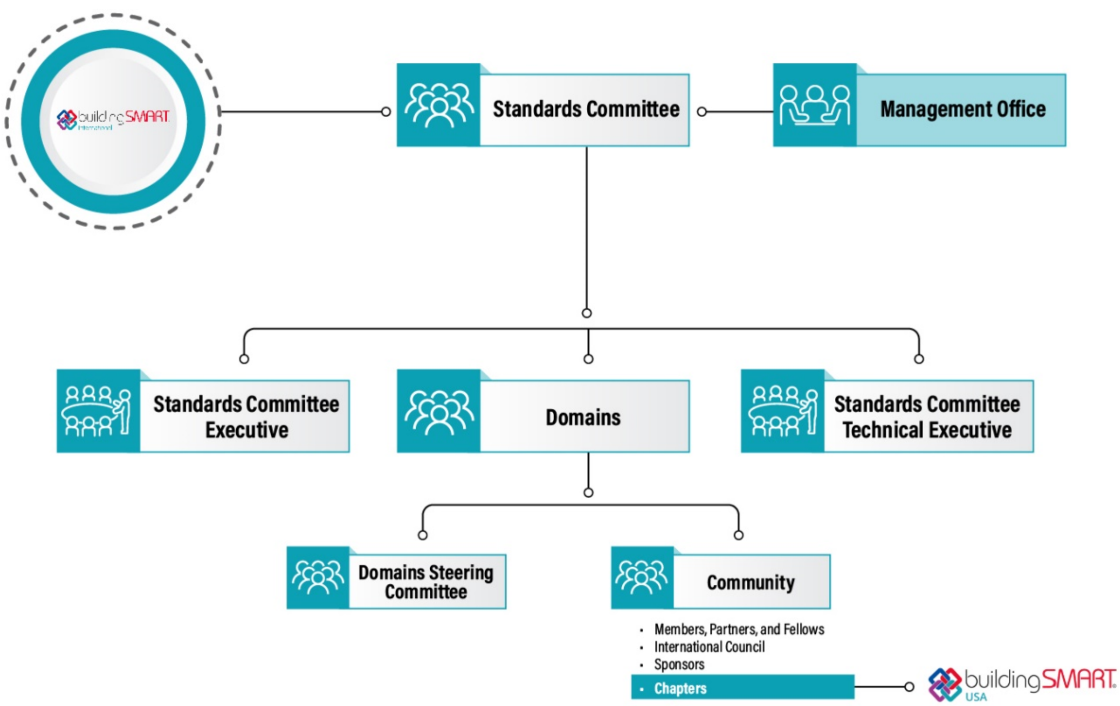


buildingSMART

buildingSMART International is a not-for-profit, vendor neutral, international open standards organization and serves as the authority for setting and managing a key set of openBIM standards. bSI is guided by a Board of Directors, led by a Chief Executive Officer with a Management team of four Directors and supported by paid staff. The work is conducted by volunteers (typically domain experts) from the buildingSMART Membership supported by hired technical consulting teams through "projects" that are sponsored by members, industry stakeholders and research funding. Projects are guided by an appointed professional project manager who is responsible for managing to an agreed budget and achieving milestone deliverables by coordinating both paid consultants and volunteer member representatives through the bSI committee structure, as illustrated in Figure A-2 (2).

buildingSMART USA is a separate 501(c)6 non-profit entity which is designated as the official US Chapter of buildingSMART International.

Figure A-2. buildingSMART International Organizational Structure



Below is a description of each bSI group illustrated in Figure A-2:

- **bSI Standards Committee** (governance body) oversees the overall bSI Standards process.
- **Standards Committee Executive** is responsible for establishing and managing solutions and standards programs.
- **Standards Committee Technical Executive** provides technical assurance that standards and solutions being produced by the international projects and domains are following appropriate technical approach to meet the needs of the community. This committee serves as a liaison with the Compliance Program.
- **Domains** oversee the development of standards and solutions to support industry needs, including a strategic roadmap for the domain that complements the overall bSI strategic roadmap. These are groups of industry experts and practitioners with an expertise in a focused area (i.e., Infrastructure). Each domain prioritizes activities and initiates and oversees international projects related to its domain. Anyone can participate in the domain activities, but each domain is governed by a Steering Committee whose member are elected from the community at large and serve a term of four years. bSI assigns a Domain Coordinator to help administer each Domain.
- **Project Teams** comprise volunteers from the membership coordinated by a professional project manager plus technical consultants hired by bSI to assist with the development of open standards and services through international sponsored projects. Each project has a Project Steering Committee made up of key stakeholders and sponsors with oversight from the bSI Director of Operations.Fi

bSI oversees the governance and development of many openBIM standards, including (3):

- **Industry Foundation Classes (IFC)** is a standardized, digital description of the built asset industry. It is an open, international standard (ISO 16739-1:2018) and promotes vendor-neutral, or agnostic, and usable capabilities across a wide range of hardware devices, software platforms, and interfaces for many different use cases. See a more detailed explanation at https://technical.buildingsmart.org/standards/ifc
- **Base Model View Definitions (MVD)** is a specific implementation level of IFC to describe and facilitate a specific use or workflow that is a subset of the IFC schema. Examples include the Coordination, Reference View (RV) and the Alignment-Based Reference View (AbRV). See a more detailed explanation at https://technical.buildingsmart.org/standards/ifc/mvd/
- **Building Collaboration Format (BCF)**, allows different BIM applications to communicate model-based issues with each other by leveraging IFC data that have been previously shared among project collaborators. See a more detailed explanation at https://www.buildingsmart.org/standards/bsi-standards/bim-collaboration-format-bcf/

- **Information Delivery Specifications (IDS)** is a computer interpretable document that defines the Exchange Requirements of model-based exchange. It defines how objects, classifications, materials, properties, and even values need to be delivered and exchanged. This is often done based on Industry Foundation Classes (IFC) and additional classifications, materials, and properties (national agreements or company-specific ones; either stored in bSDD or somewhere else). See a more detailed explanation at https://www.buildingsmart.org/standards/bsi-standards/information-delivery-specifications-ids/
- **Information Delivery Manuals (IDM),** The ISO 29481-1:2010 "Building Information Modelling - Information Delivery Manual - Part 1: Methodology and Format" standard has been developed by buildingSMART in order to have a methodology to capture and specify processes and information flow during the lifecycle of a facility. See a more detailed explanation at https://technical.buildingsmart.org/standards/information-delivery-manual/
- **Open Common Data Environment (openCDE)** is a portfolio of API standards that enables interoperability between different collaboration platforms (common data environments).

bSI also provides a series of tools and services to assist users with implementation and adoption of openBIM standards, including:

- **buildingSMART Data Dictionary (bSDD):** The buildingSMART Data Dictionary (bSDD) is an online service hosting classes (terms) and properties, allowed values, units, translations, relations between those and more. It provides a standardized workflow to enable data quality, information consistency and interoperability. BIM modelers use the bSDD for easy and efficient access to all kinds of standards to enrich their models. BIM Managers use the bSDD to reference Information Delivery Specifications (IDS) and check BIM data for validity. Content creators benefit from having one entry point to various BIM tools and platforms. bSDD supports national and international classification systems[2] (e.g., Uniclass, CCI) and domain-specific standards (e.g. ETIM, IfcAirport) and also company-specific standards. bSDD implements the ideas from ISO 12006-3, ISO 23386 and Linked Data standards.
- **Use-Case Management (UCM) Service**, a library of "best practice" use-cases. See a more detailed explanation at https://ucm.buildingsmart.org/ .

[2] While industry standard classification systems, such as Uniclass and others are supported by the bSDD, it should be noted that currently they do not apply to bridges or horizontal infrastructure in general. Tables to include bridges and horizontal infrastructure classes have not been developed by the standards organization overseeing these classification systems.

- **IFC Validation Service**, is a free, online platform for validating IFC files, developed by buildingSMART – with the help of software vendors and bSI projects. Given an IFC file, the Validation Service provides a judgment of conformity for such file against the IFC standard (schema and specification). See a more detailed explanation at https://technical.buildingsmart.org/services/validation-service/ . The IFC Validation is available at https://validate.buildingsmart.org
- **Global Software Certification,** a new global software certification program is currently under development. This program will allow software vendors to get a bSI Certification that informs users about the quality of support for IFC for each of their commercial products/applications.
- **Accelerator Program** is a new initiative from bSI to support and encourage uptake of open standards and services to organizations that want to improve their open and neutral digital workflows. Some of the services include proofs of concept (PoC) for a buildingSMART Data Dictionary (bSDD) domain, Validation Service, Information Delivery Specification (IDS), and other Industry Foundation Classes (IFC) related workflows. Clients can tailor the standards and services to their needs, and a long-term plan is in place for this program to be made available via the Chapter network.
- bSI also provides a series of training courses and professional certification to support workforce development to ensure that DOT employees, consultants and contractors are able to acquire the knowledge and skills they need to implement openBIM on DOT projects as follows:
  - Entry Training – introducing openBIM (new)
  - Foundation Basic – “the What” - a body of knowledge and learning objectives explaining concepts and vocabulary (existing course and exam is currently being provided by 21 Chapters worldwide including the US Chapter)
  - Management – “the Why” – informing users about the benefits of using openBIM workflows for project delivery (coming soon)
  - Practitioner – “the How” – demonstrating how to apply openBIM (under development)

More information on the availability and registration for these professional certification (PCert) courses is available at https://education.buildingsmart.org/our-program/.

References

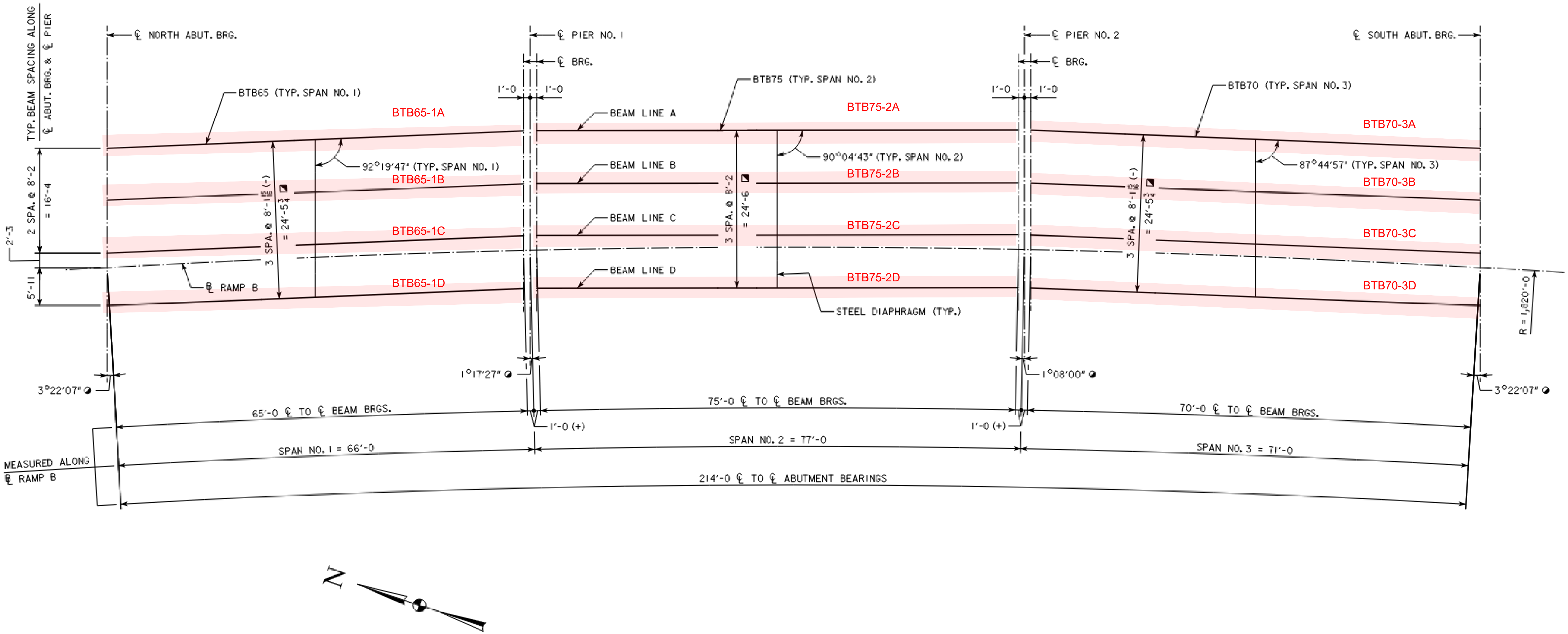
1. **American Association of Highway and Transportation Officials.** AASHTO. *Committee on Data Management and Analytics* . [Online] October 9, 2019. https://data.transportation.org/wp-content/uploads/sites/44/2022/05/AR-1-19-IFC-Schema-Resolution-Board-Adopted-FINAL.pdf.

2. **buildingSMART International.** buildingSMART International. *Standards Organization.* [Online] [Cited: October 26, 2023.] https://www.buildingsmart.org/standards/organisation/.

3. —. buildingSMART International. *bSI Standards.* [Online] [Cited: October 26, 2023.] https://www.buildingsmart.org/standards/bsi-standards/.

Appendix 21: Sample Unit Test Instructions

The suite of unit test instructions includes both annotated PDF plans and a spreadsheet. A sample of the PDF content (i.e., Level 2 instructions for a girder) is included in the appendix. The PDF is the relevant content for bridge domain experts whereas the spreadsheet is intended only for software developers.



BEAM LAYOUT

NOTES:

1. For the full plan set and additional structure information, see Br1-Precast and Cast Concrete-Iowa DOT.pdf.
2. FOR BEAM BTB65 DETAILS SEE SHEET L1-BR01-Girder01.
3. Modeling and export of reinforcing is optional for Level 2.

NOTES:
◐ MEASURED PERPENDICULAR TO LOCAL TANGENT OF ℄ RAMP B.
◪ MEASURED PERPENDICULAR TO ℄ BEAM.

Unit Test Instruction for the Design-to-Construction Data Exchange		
1	12/14/23	
No.	Date	Issue / Revision Notes

BIM FOR BRIDGES AND STRUCTURES TPF-5(372) — HDR — jō consulting

Unit Test Description: Level 2 Prestressed Concrete Beams
Drawn By: AMN
Reviewed By:
Unit Test / Sheet No.: L2-Br01-Girders01 / 01

BTB BEAM DATA

BTB BEAM	SPAN LENGTH ℄-℄ BEARING	OVERALL BEAM LENGTH (L)	CONCRETE STRENGTH		STRAND SIZE DIA. (in)	NO. OF STRAND		TOTAL INITIAL PRESTRESS kips ③	HOLD DOWN FORCE-kips	CAMBER (in)		DEFLECTION (in) Δ_D		PERMISSIBLE MAXIMUM SPACING HL-93 LOADING	WEIGHT (TONS)	CONCRETE (CU YD.)	REINFORCING STEEL (WEIGHT-LBS)
			f'ci (ksi)	f'c (ksi)		STRAIGHT	DEFLECTED			AT RELEASE	AFTER LOSSES	IMMEDIATE ① (ELASTIC) Δ_I STEEL DIAPHRAGM	TIME ② (PLASTIC) Δ_T STEEL DIAPHRAGM	STEEL DIAPHRAGM			
BTB65	65'-0	66'-4	4.5	5.0	0.60	18	2	851	8.0	1.13	2.01	0.83	0.21	8'-2	21.8	10.8	1586
BTB70	70'-0	71'-4	5.0	5.5	0.60	20	2	936	7.4	1.32	2.35	1.06	0.26	8'-2	23.5	11.6	1674
BTB75	75'-0	76'-4	5.5	6.5	0.60	22	4	1106	13.0	1.65	2.92	1.28	0.32	8'-2	25.1	12.4	1764

① DEFLECTIONS AT MID-SPAN DUE TO WEIGHT OF SLAB AND DIAPHRAGM. THE DEFLECTIONS SHOWN ARE FOR A SLAB (8.5 in) AND HAUNCH (1.5 in) WEIGHT OF:

0.92 kips/ft FOR 8'-2 BEAM SPACING

AND ONE STEEL DIAPHRAGM (0.500 kips) AT ℄ OF SPAN. FOR DIFFERENT SLAB AND DIAPHRAGM WEIGHTS, DEFLECTIONS WILL BE DIRECTLY PROPORTIONAL.

② DEFLECTIONS DUE TO THE COMBINED EFFECT OF CREEP DUE TO WEIGHT OF SLAB AND SHRINKAGE OF SLAB.

TOTAL BEAM DEFLECTIONS AT ℄ OF SPAN, Δ_D , DUE TO WEIGHT OF SLAB AND DIAPHRAGMS FOR DETAILING PURPOSE:

(A) $\Delta_D = \Delta_I + \Delta_T$ FOR SIMPLE SPAN.

(B) $\Delta_D = \Delta_I + \frac{3}{4}\Delta_T$ FOR END SPANS OF CONTINUOUS BRIDGE.

(C) $\Delta_D = \Delta_I + \frac{1}{2}\Delta_T$ FOR INTERIOR SPANS OF CONTINUOUS BRIDGE.

③ TOTAL INITIAL PRESTRESS IS BASED ON 72.6% f's, f's. = 270 ksi. AND As = 0.217 in^2.

CALCULATED DESIGN CAMBERS HAVE BEEN REDUCED FROM THEIR THEORETICAL VALUES BY 15% TO AID CONSTRUCTABILITY.

NOTE:
THE EXTERIOR SURFACES OF THE EXTERIOR (FASCIA) BEAM ENDS OVER THE PIER SHALL NOT BE ROUGHEND.

NOTE:
FOR MODIFIED STIRRUP EXTENSIONS, SEE "BENT BAR DETAILS" AND BEAM DETAILS SHEET FOR DIMENSIONS AND LOCATIONS.

BEAM NOTES:

THESE BEAMS ARE DESIGNED FOR AASHTO LIVE LOADS AS INDICATED IN ABOVE TABLE WITH AN ALLOWANCE OF 20 LBS PER SQUARE FOOT OF ROADWAY FOR FUTURE WEARING SURFACE.

ALL PPC BEAMS SHALL USE HIGH PERFORMANCE CONCRETE (HPC) IN ACCORDANCE WITH THE STANDARD SPECIFICATIONS.

HOLD DOWN POINTS FOR DEFLECTED STRANDS MAY BE MOVED TOWARD ENDS OF BEAM A DISTANCE OF 0.05 L MAXIMUM AT PRODUCER'S OPTION.

ALL PRESTRESSING STRANDS EXCEPT LIFTING LOOP STRANDS SHALL BE 0.60 in. NOMINAL DIAMETER (NOMINAL STEEL AREA = 0.217 in^2) AND CONFORM TO ASTM A416 GRADE 270 LOW RELAXATION STRANDS. MINIMUM STRAND BREAKING STRENGTH SHALL BE 58.6 kips.

TOPS OF BEAMS ARE TO BE STRUCK OFF LEVEL AND FINISHED AS PER MATERIALS IM570.

BEARINGS SHALL BE AS DETAILED ON OTHER DESIGN SHEETS.

BEAMS TO BE USED IN BRIDGES MADE CONTINUOUS BY THE POURED IN PLACE FLOOR, ARE TO BE AT LEAST 28 DAYS OLD BEFORE THE FLOOR IS PLACED UNLESS A SHORTER CURING TIME IS APPROVED BY THE BRIDGE ENGINEER.

THE PORTIONS OF THE PRESTRESSED BEAMS THAT ARE TO BE EMBEDDED IN THE ABUTMENT AND PIER DIAPHRAGMS SHALL BE ROUGHENED FOR A DISTANCE OF 10" FROM THE BEAM END BY SANDBLASTING OR OTHER APPROVED METHODS TO PROVIDE SUITABLE BOND BETWEEN THE BEAM AND THE DIAPHRAGM IN ACCORDANCE WITH ARTICLE 2403.03, I, OF THE STANDARD SPECIFICATIONS.

ALL BEAMS ARE TO BE INCREASED IN LENGTH TO COMPENSATE FOR ELASTIC SHORTENING, CREEP AND SHRINKAGE.

FOR TRANSPORTING, THE ALLOWABLE OVERHANG IS SHOWN IN THE LIFTING LOOP AND OVERHANG TABLE.

HOLES MUST BE CAST IN THE WEB TO ACCOMMODATE THE STEEL DIAPHRAGM ATTACHMENTS AS DETAILED ON THE STEEL DIAPHRAGM DETAIL SHEET.

MINIMUM CONCRETE f'c (AT 28 DAYS) AND MINIMUM f'ci AT RELEASE ARE LOCATED IN THE BTB BEAM DATA TABLE ABOVE.

FOUR 0.60 IN. DIAMETER STRANDS STRESSED TO NOT MORE THAN 5000 lbs EACH MAY BE USED IN LIEU OF BARS 5a1 AND 5a2 IN THE TOP FLANGE.

NOTES:

1. Modeling and export of reinforcing is optional for Level 2.

Unit Test Instruction for the Design-to-Construction Data Exchange

BIM FOR BRIDGES AND STRUCTURES TPF-5(372)

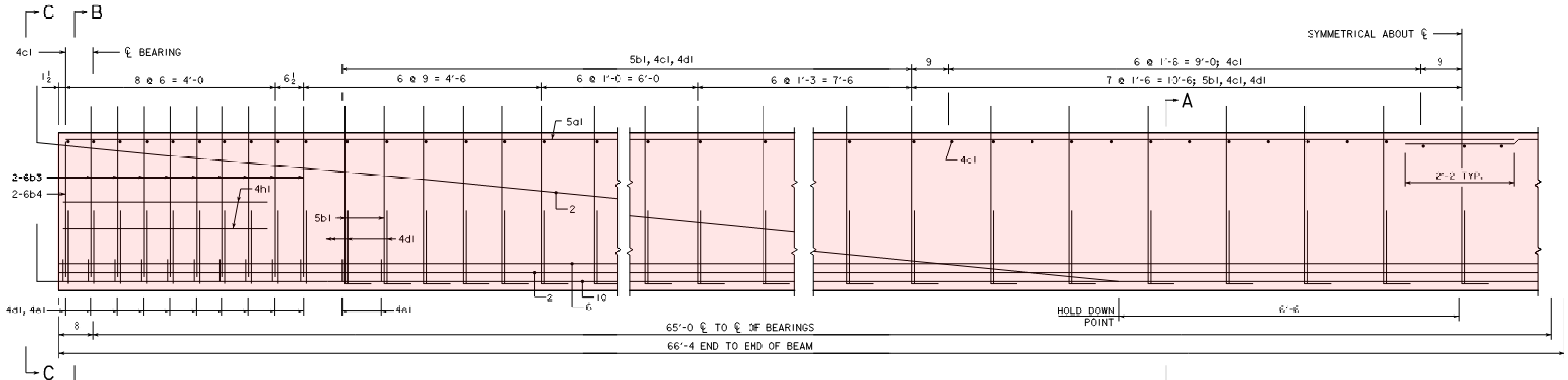
HDR | jō consulting

No.	Date	Issue / Revision Notes
.	.	.
.	.	.
.	.	.
1	12/14/23	.

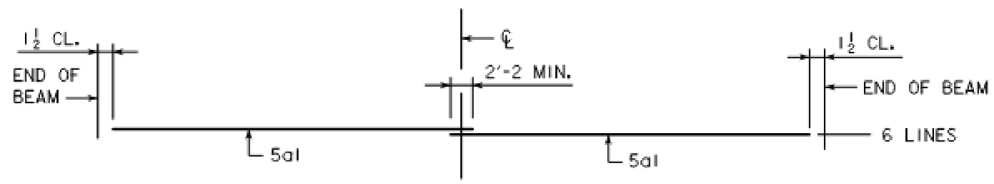
Unit Test Description: Level 2 Prestressed Concrete Beams

Drawn By: AMN | Reviewed By: .

Unit Test / Sheet No.: L2-Br01-Girders01 / 02



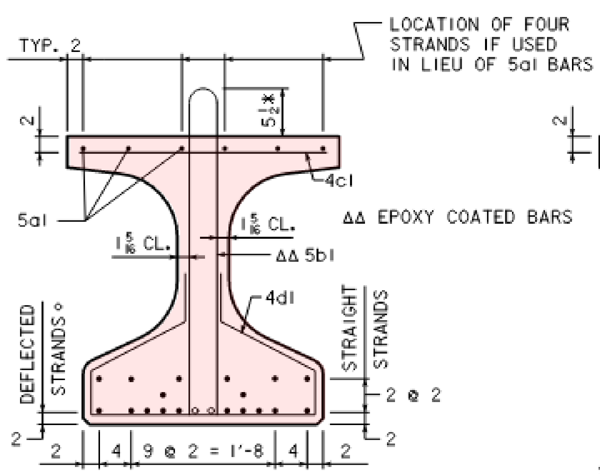
BTB65



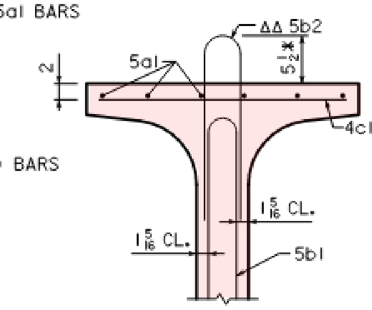
TOP FLANGE LONGITUDINAL BAR LAYOUT

NOTE: STIRRUP EXTENSION

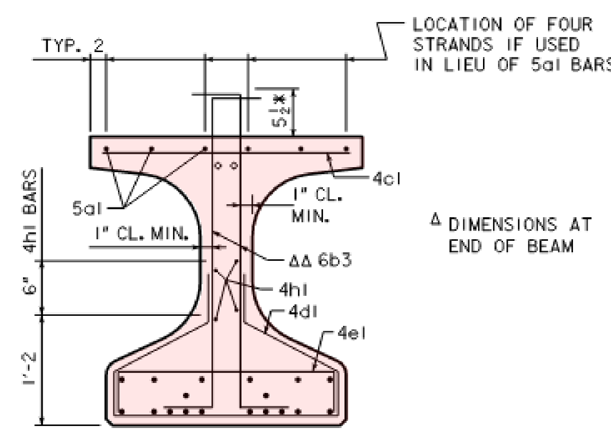
* THE STANDARD 5" PROJECTION HAS BEEN INCREASED.



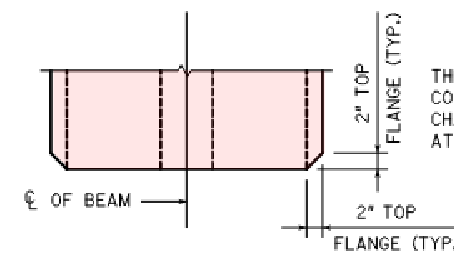
SECTION A-A


SECTION A-A (ALTERNATE)

SEE ALTERNATE BAR NOTE ON DESIGN SHEET 19.

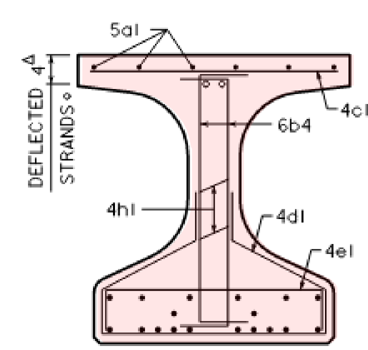


SECTION B-B



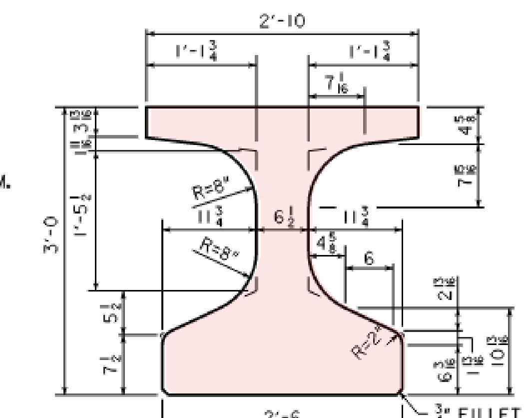
TOP VIEW

THE TOP FLANGE BEAM CORNERS ARE TO BE CHAMFERED 2" AS SHOWN AT BOTH ENDS OF THE BEAM.


SECTION C-C

AREA = 631.7 in²
$\bar{y}_b$ = 17.14 in.
I = 99,980 in⁴

BEAM SECTION PROPERTIES



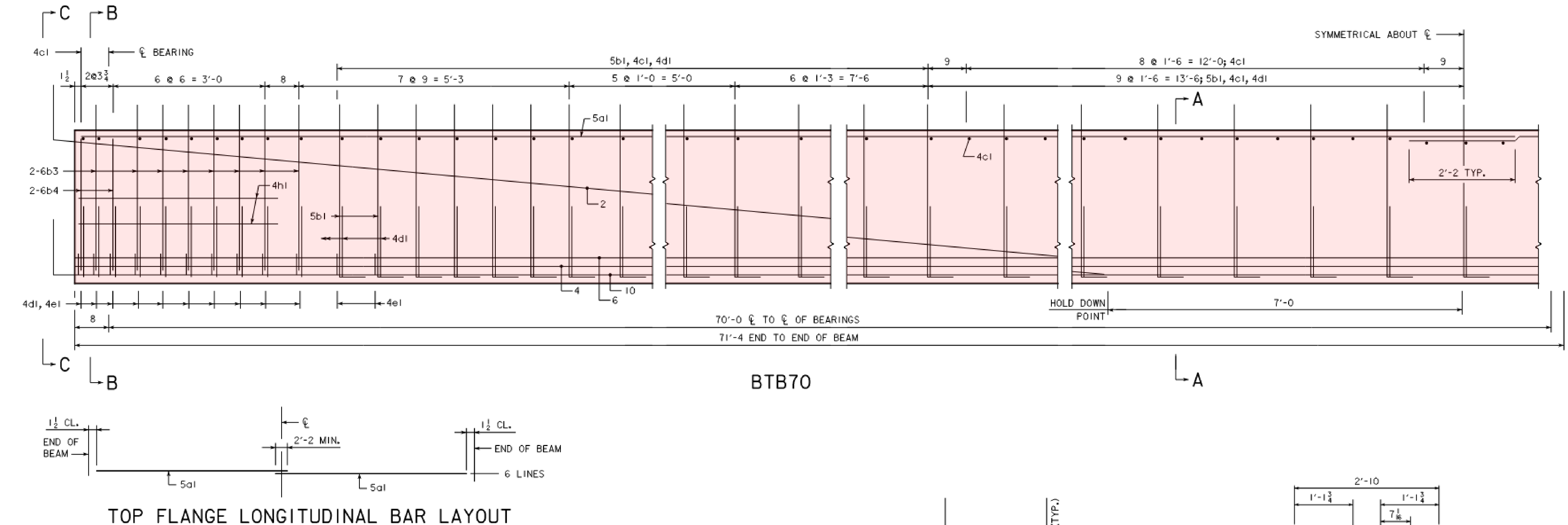
BTB BEAM CROSS SECTION

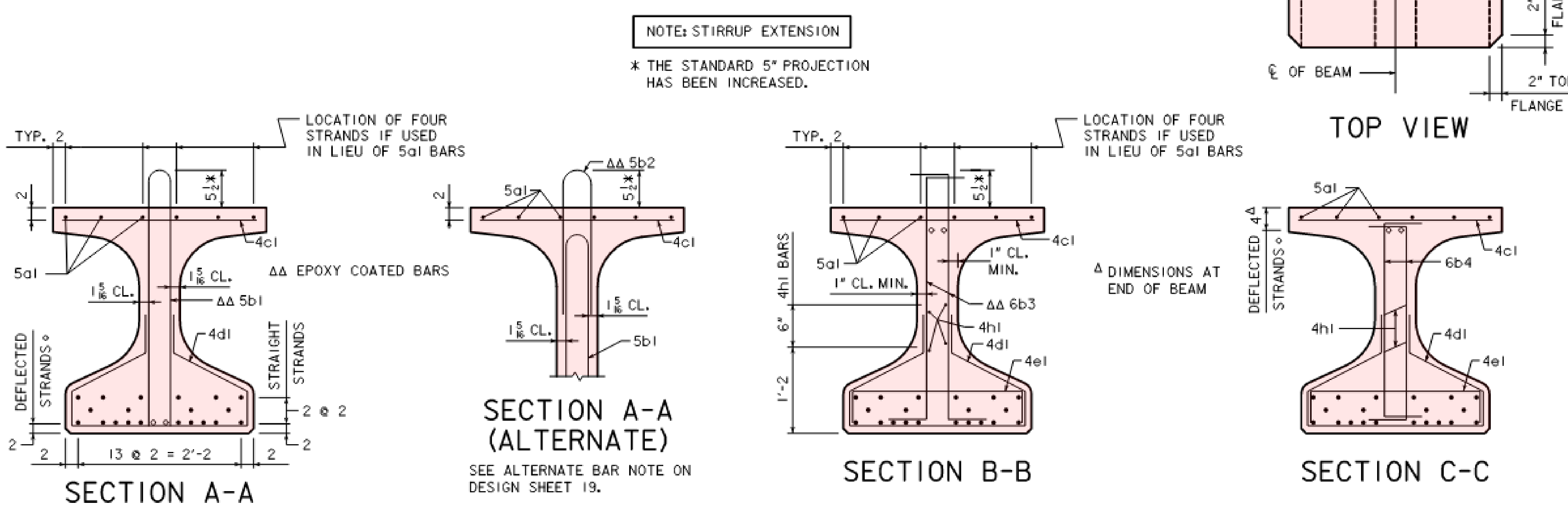
BTB65 BEAM DETAILS

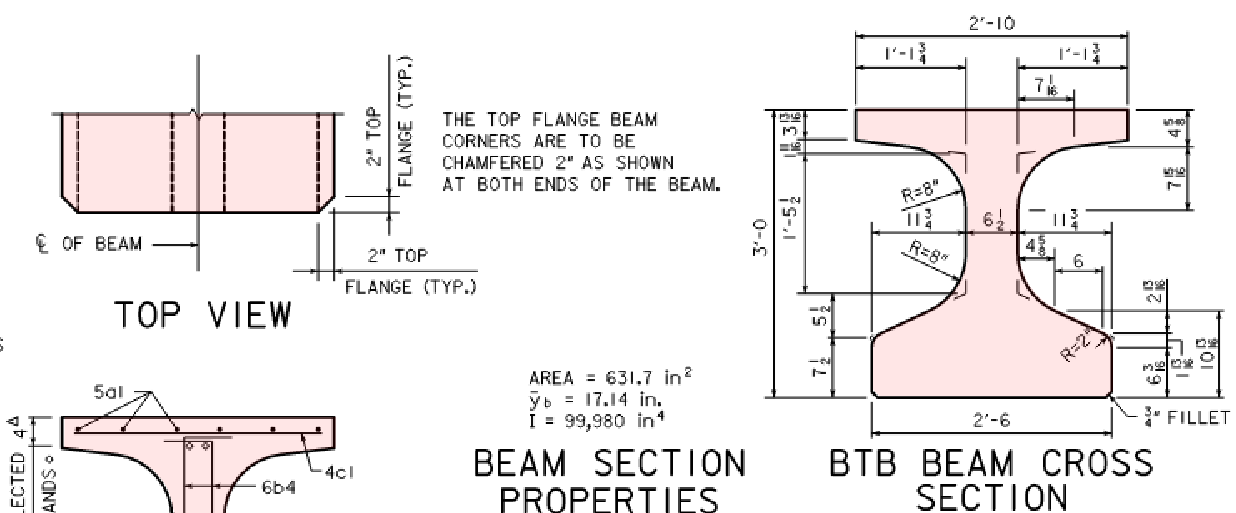
NOTES:

1. Modeling and export of reinforcing is optional for Level 2.

Unit Test Instruction for the Design-to-Construction Data Exchange		BIM FOR BRIDGES AND STRUCTURES TPF-5(372) / HDR / jō consulting
No.	Date	Issue / Revision Notes
1	12/13/23	
Unit Test Description: Level 1 Prestressed Concrete Beam		Unit Test / Sheet No.: L2-Br01-Girders01 / 03
Drawn By: AMN	Reviewed By:	







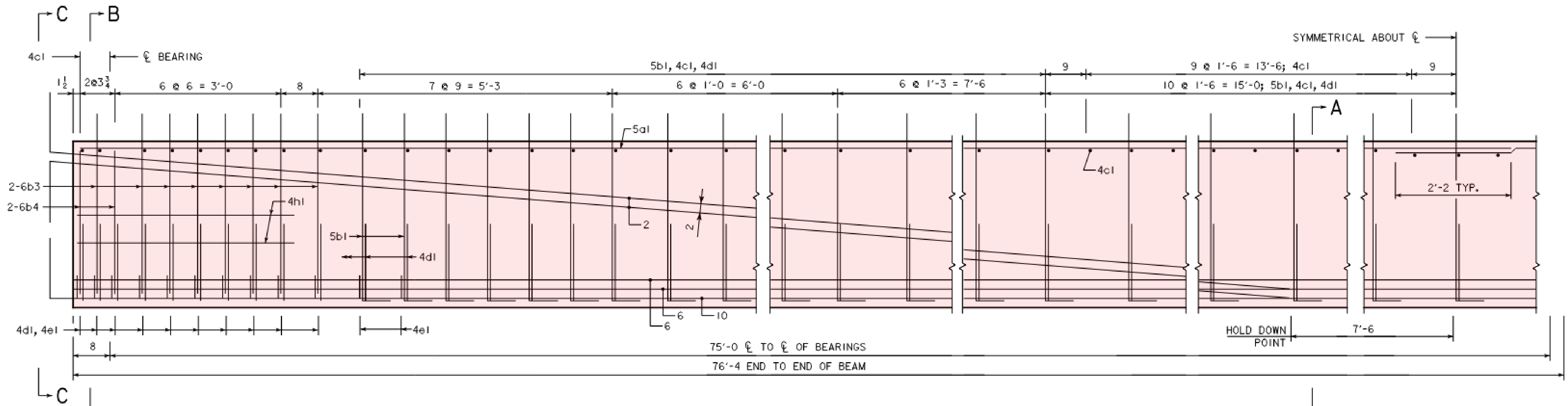
BTB70 BEAM DETAILS

NOTES:

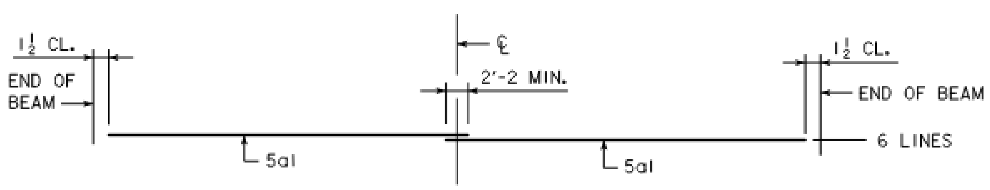
1. Modeling and export of reinforcing is optional for Level 2.

Unit Test Instruction for the Design-to-Construction Data Exchange		BIM FOR BRIDGES AND STRUCTURES TPF-5(372)
1	12/14/23	
No.	Date	Issue / Revision Notes
Unit Test Description: Level 2 Prestressed Concrete Beams		Unit Test / Sheet No.: L2-Br01-Girders01 / 04
Drawn By: AMN	Reviewed By:	

HDR jō consulting



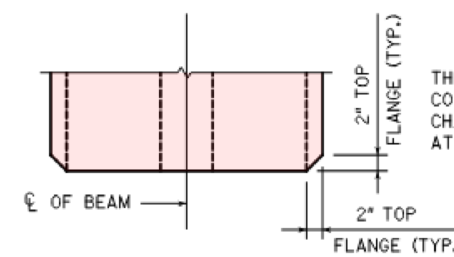
BTB75



TOP FLANGE LONGITUDINAL BAR LAYOUT

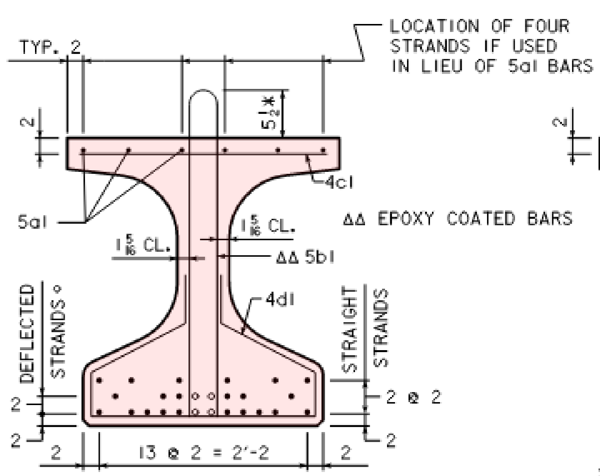
NOTE: STIRRUP EXTENSION

* THE STANDARD 5" PROJECTION HAS BEEN INCREASED.

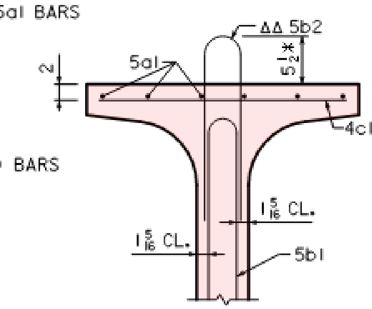


TOP VIEW

THE TOP FLANGE BEAM CORNERS ARE TO BE CHAMFERED 2" AS SHOWN AT BOTH ENDS OF THE BEAM.

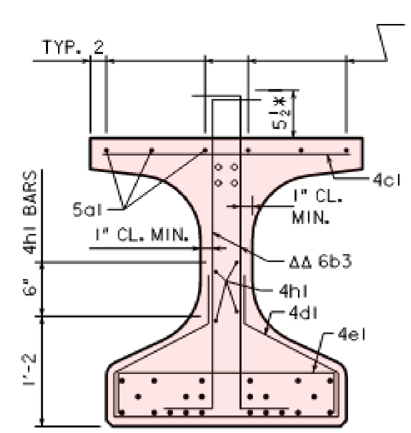


SECTION A-A



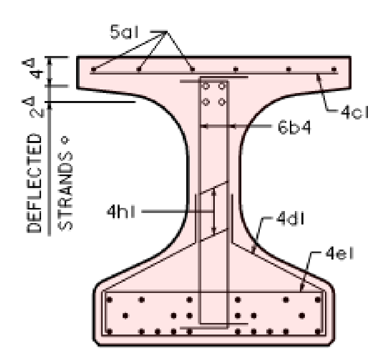
SECTION A-A (ALTERNATE)

SEE ALTERNATE BAR NOTE ON DESIGN SHEET 19.



ΔDIMENSIONS AT END OF BEAM

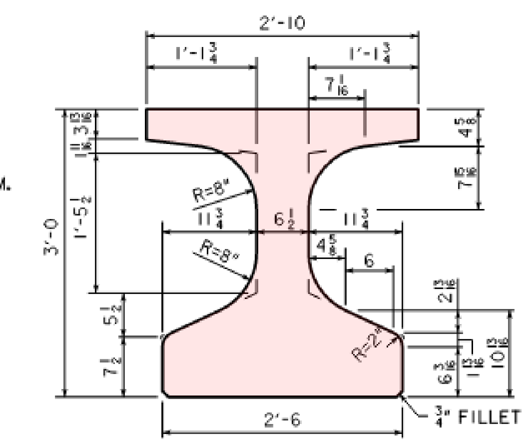
SECTION B-B



SECTION C-C

AREA = 631.7 in²
$\bar{y}_b$ = 17.14 in.
I = 99,980 in⁴

BEAM SECTION PROPERTIES



BTB BEAM CROSS SECTION

BTB75 BEAM DETAILS

NOTES:

1. Modeling and export of reinforcing is optional for Level 2.

Unit Test Instruction for the Design-to-Construction Data Exchange			BIM FOR BRIDGES AND STRUCTURES TPF-5(372)
1	12/14/23	.	HDR / jō consulting
No.	Date	Issue / Revision Notes	
Unit Test Description: Level 2 Prestressed Concrete Beams		Unit Test / Sheet No.	L2-Br01-Girders01 / 05
Drawn By: AMN	Reviewed By: .		

Appendix 22: Frequently Asked Questions Handout

1. Can I use IFC to support ALL of my bridge data exchanges?

Not reliably, yet. IFC is a comprehensive schema that supports all industries in the built environment. The schema is too large for software vendors to implement the complete schema in their software products. Software products typically support a limited purpose and a specific domain, such as bridges. Therefore, software vendors need to support a limited subset of the IFC schema. These subsets are called Model View Definitions (MVDs). At this time, the IFC technical solutions for the bridge domain have only been developed for the design-to-construction data exchange. While it's possible that IFC could support other bridge data exchanges, the technical solutions have not yet been developed.

2. Why do I need an IDM?

An IDM is a document that defines, in both human and machine-readable format, the exact information to exchange for one or more specific exchanges during the lifecycle of built assets within a specific domain. The IDM is then used as a basis for developing other technical solutions including a suite of test instructions, data dictionary, and Information Delivery Specification (IDS) that collectively facilitate a complete and properly structured information exchange. Once the software has been tested, an agency can use an IDM to ensure that their standards (e.g. model development standards) require the complete information needed to support the exchange.

3. Who uses a data dictionary? What is it for?

A data dictionary is used by people who plan for or participate in information exchanges. This includes people setting up software workspaces, people creating software import/export utilities, and even people who create or receive datastets. A data dictionary helps to understand data assets by providing information such as data type, size, classification, and relationships with other data assets. If data is organized into a table, then the data dictionary would describe precisely what type of data goes into each column. If data is organized into a form, then the data dictionary would describe precisely what type of data goes into each field. For a zip code field, the data dictionary would describe whether the zip code is entered as a five-digit integer or as a string that is ten characters long and comprised of integers and a dash, e.g. 90210-1234. In a table of addresses, the data dictionary would similarly describe the data in the zip code column. Data dictionaries are primarily technical and machine-readable; however, the human-readable components help users to understand a dataset.

Data dictionaries are particularly important for information exchanges. A sender and receiver may call a piece of data the same thing, like a zip code, but store the data differently. The sender may store a zip code as a string of five digits, a dash, and four more digits, whereas the receiver may store a zip code as a five-digit number. The receiver's software cannot accept a string entry in a number field, and there would be errors parsing the file. However, by referencing the data dictionary, the import utility could anticipate the format of the zip code and manipulate the string to truncate it at five characters and then convert that to a number and successfully import the data.

The TPF-5(372) project has developed the AASHTO Bridge Data Dictionary, a standard definition of all the data that is defined in the *Information Delivery Manual (IDM) for the Design to Construction Data Exchange for Highway Bridges*. These data definitions support vendors implementing tools for bridge design-to-construction IFC exports. Agencies may choose to develop their own data dictionaries for additional data that is required for their deliverables. This could be unique state bridge ID, pay item numbers, or any localizations of the AASHTO Bridge Data Dictionary.

4. How do I know if an IFC file is correct?

It depends what you mean by "correct." buildingSMART International (bSI) has a selection of services that can help validate the information in an IFC file.

The IFC Validation Service is a free service where an IFC file can be uploaded and checked to ensure that it is stored with the correct syntax according to the specific version of IFC or a specific MVD. This only checks how the data is organized and stored. At the time of authoring of this document, bSI's validation service is in the process of being refined.

An IDS is a tool to check that the specific information requirement has been fully provided. This will check that all the required data is populated and that it is populated in accordance with the data dictionary requirements. It could check that a text field of up to 50 characters contains a string of letters and/or numbers up to that length or that an integer field within the range of 0-1000 contains an integer within that range. A designer would use an IDS to ensure that the model is complete in terms of geometric detail and attached properties before export. The recipient would use an IDS after import to ensure that the data was not corrupted in the importing process.

There are different ways to model bridge geometry in software. The Unit Test Suite is a suite of test instructions, including bridge drawings and IFC mapping information, that software vendors use to understand how the bridge information as described by the IDM is intended to be represented in software. The test instructions can be used to certify that a particular software product can export and import IFC files that construct the bridge models as intended. Using certified software and checking models before export and after import with an IDS would give a high degree of confidence that the recipient's model matches what was in the original model before it was exported.

Other checks, such as calculations that depend on software features, that the geometry in the model matches the geometry in the calculations, or that the structural design is code compliant, cannot be automated using IFC or bSI services.

5. Can I specify IFC deliverables now?

Yes, but they would currently be of limited use. A few things need to happen before an IFC deliverable could be used on a construction project. First, the AbRV MVD can be finalized and software vendors can conclude their testing with the test instructions. Next, software vendors can release new versions of their products that support the export and import of bridge design models using IFC 4.3. Finally, all participants in the exchange would have to switch to the new versions of the software. Additionally, bSI needs to finalize the IDS standard, and then AASHTO needs to finalize the bridge design-to-construction IDS and upload the AASHTO Bridge Data Dictionary to the buildingSMART Data Dictionary (bSDD), which are planned outcomes of the TPF-5(372) project. bSI also needs to finalize the software certification program so that software vendors can certify their products.

It will take some time for the whole construction supply chain to adopt new versions of existing software, or even new software products. Once agencies adopt new software versions that support IFC, they can start requiring IFC files to use for archiving their design models. The IFC files will be in a standard, open format and therefore they will be more readily accessible decades in the future (e.g., when an agency needs to access the design documents to prepare for a major rehabilitation project) than today's proprietary model formats that depend on today's software. Some software products currently claim to support IFC, but these are not IFC 4.3, which is the basis of the AbRV MVD that has been developed in coordination with the bridge design-to-construction IDM. Any IFC files exported with different versions of IFC (e.g. 4.1, 4.0, 2x3) are unlikely to be useful and there is no way to ensure that they accurately store bridge geometry.

6. If I import an IFC, can I edit the bridge geometry?

The AbRV MVD is a reference view. It is not intended to store the parametric properties of the bridge geometry, such as how the deck geometry and girder alignment might change with a change to the roadway alignment or how a girder cross-section might change with a change in the length or depth property. Once an IFC file has been imported into software, it depends on the software design and implementation whether the geometry could be changed. For example, a software product could allow for an imported concrete element to be used to design the reinforcement within that concrete. The resulting reinforcement design, as well as its relationship to the imported concrete element, would be part of the new, proprietary file. If that were exported to IFC, the parametric relationship between the concrete element and the reinforcement would not be preserved in the IFC file.

Glossary of Terms

Certified Software	Software that has been thoroughly tested by a third party to verify that it meets the requirements of that third party.
Data Dictionary	A structured repository of metadata that helps describe the data being used. In other words, a data dictionary provides additional context and information about each piece of data so that software developers and people who create or use the described data can understand it better.
Data Validation	A procedure to analyze the content of a file and verify that it is structured according to a specified standard and contains all required data fields. In order to validate the data in a file, the requirements for that data need to be defined in a machine-readable format.
Industry Foundation Classes (IFC)	A schema specification for the structure of model-based construction data to facilitate information exchange sharing between proprietary modeling software applications. This bSI standard is governed by the ISO 16739 standard, which has gone through multiple updates over the years, with the ISO 16739-1:2024 expected to be published in early 2024 as the most recent version.
Information Delivery Specification (IDS)	A new standard being developed by buildingSMART International. An important aspect in the development of IDS was that it should be easy to use and simple to implement. It provides a technical solution to check properties and quantities, IFC schema attributes, object classification, material names, and selected relationships such as containment, grouping and aggregations. More complex types of checks such as element connections, logical combination of requirements, mathematical functions or not to forget object geometry are outside of the scope for this standard.
Information Delivery Manual (IDM)	A standardized methodology for documenting a common understanding of the processes involved during the development of model-based data of the built environment within the asset management lifecycle. ISO 29481-1: 2016 Building Information Modeling – Information Delivery Manual Part 1: Methodology and Format specifies the methodology that links the business processes undertaken during the construction of built assets with information requirement specifications, and a way to create data flow diagrams that describe the information processes within the boundary of business process. ISO 29481-2: 2012 Building Information Modeling – Information Delivery Manual Part 2: Interaction Framework specifies a methodology and format for describing coordination activities between stakeholders in a construction project during all lifecycle stages.
Information Requirement	An organized list of the information to be provided at an exchange. Typically, an information requirement is a classified, hierarchical structure of categories (or systems) that identifies the data properties for each object within each class.
Model View Definition (MVD)	A standardized subset of the IFC schema for software vendors to implement so that their products can exchange information for a specific purpose. The Alignment-based Reference View is an MVD for IFC version 4.3.

Appendix 23: AASHTO Administrative Resolution AR-1-19

Administrative Resolution AR-1-19
Title: Adoption of Industry Foundation Classes (IFC) Schema as the Standard Data Schema for the Exchange of Electronic Engineering Data

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Whereas, Several data schema exist for the exchange of electronic engineering data, among them Trans XML, Land XML, and various industry schemas; however, there is no single standard data schema recognized by the industry;

Whereas, Transportation agencies need to implement asset management more efficiently throughout the lifecycle of the asset, which requires the ability to exchange data seamlessly;

Whereas, Transportation agencies are progressing toward Building Information Models as the successor to the standard plan set for highway infrastructure projects;

Whereas, Transportation agencies are utilizing a variety of tools and equipment from multiple vendors and manufacturers to gather, display, and work with the data necessary for infrastructure project development, and interoperability of the models is a critical feature so that the agencies have the ability to transfer data seamlessly across these platforms;

Whereas, Seamless data transfer necessitates a single data schema that is recognized as the industry standard, otherwise there is a potential loss of data when translated from one device or one application to another; however, there has been a lack of consensus for adoption of a single schema;

Whereas, To date efforts to establish a national standard data schema have not been successful, in large part due to the inability to identify an agency or entity capable of providing ongoing development, support, and maintenance of the schema, so it would be advantageous to move toward a schema where that support mechanism already exists;

Whereas, There is an international effort underway, led by buildingSMART International, to extend their existing Industry Foundation Classes (IFC) standard data schema to incorporate infrastructure projects including IFC Bridge and IFC Road;

Whereas, Adoption of a single data schema by transportation agencies would give vendors and manufacturers the standard we need to facilitate collaboration on their adoption as well;

Whereas, The AASHTO Committee on Bridges and Structures already has several efforts underway to facilitate the adoption of IFC Bridge as the standard data schema for their discipline, and it would be essential in order to ensure and maintain interoperability between these two disciplines that we adopt IFC Road for highway infrastructure projects; and

Whereas, There are other AASHTO committees with interest in this effort, including but not limited to the Committee on Data Management and Analytics, the Committee on Bridges and Structures, and AASHTOWare; now, therefore, be it

Resolved, That the AASHTO Board of Directors recommends the adoption of IFC Schema as the national standard for AASHTO States;

Resolved, That an internal, cross-committee, multi-disciplined group within AASHTO should be formed to coordinate schema development, identify gaps, resolve any conflicts, and avoid duplication of efforts; and

Resolved, That possible AASHTO membership in buildingSMART International should be investigated to provide representation and participation for the state DOTs in schema development.

Approved by the AASHTO Board of Directors
October 9, 2019