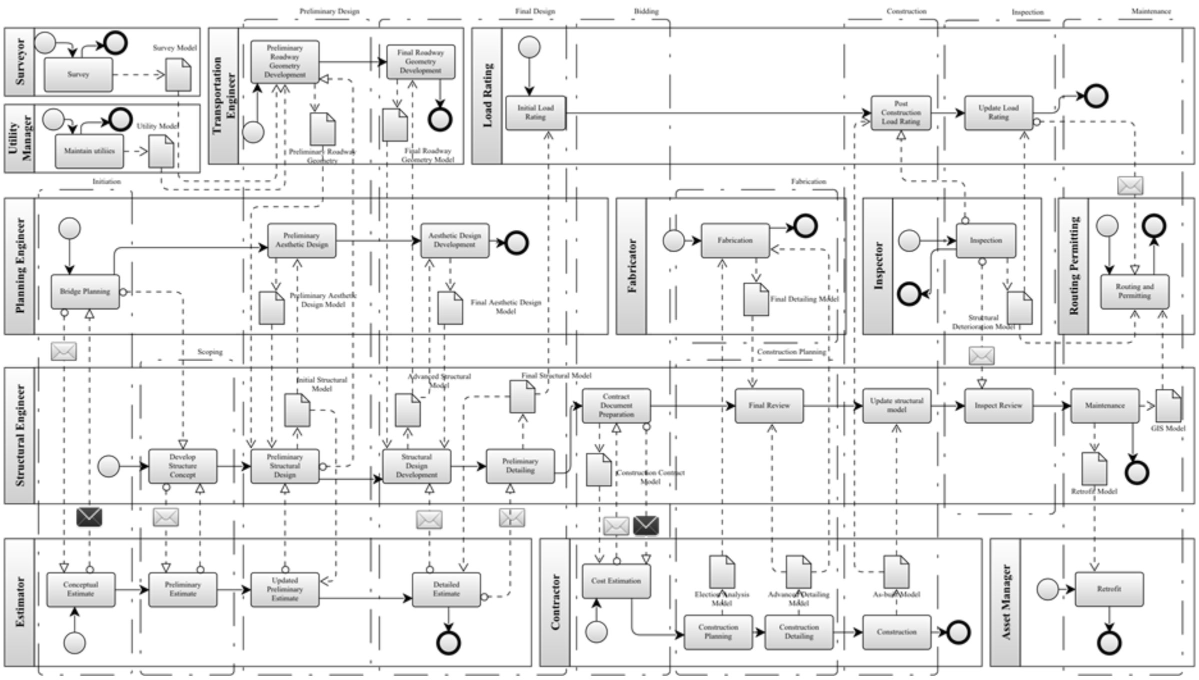
Bridge Information Model Standardization

VOLUME I: INFORMATION EXCHANGES

April 2016



U.S. Department of Transportation
Federal Highway Administration

FHWA-HIF-16-011

Foreword

Advancing the capability of computer modeling and analysis tools and techniques is clearly in the best interest of the U.S. bridge engineering practice. Without industry consensus standards for Bridge Information Modeling (BrIM) and related data exchange protocols, there is no common way to integrate the various phases of a bridge design and construction project and benefit from that information in the inspection, maintenance, and operational phases associated with its asset management. This work seeks to develop, validate, identify gaps, implement, and build consensus for standards for BrIM for highway bridge engineering.

The contributions and constructive review comments received from many professionals across the country are greatly appreciated. In particular, I would like to recognize Scot Becker of Wisconsin DOT, Christopher Garrell of National Steel Bridge Alliance, Danielle Kleinhans of Concrete Reinforcing Steel Institute, Josh Sletten of Utah DOT, Steven Austin of Texas DOT, Brad Wagner of Michigan DOT, Todd Thomson of South Dakota DOT, Ahmad Abu-Hawash of Iowa DOT, Mike Keever of Caltrans, Ali Koc of Red Equation Corporation, Hanjin Hu of Michael Baker International, and all those who participated in our workshops described in the Report.

Joseph L. Hartmann, PhD, P.E.

Director, Office of Bridges and Structures

Notice

Quality Assurance Statement

Technical Report Documentation Page

1. Report No. **FHWA-HIF-16-011**	2. Government Accession No.	3. Recipient's Catalog No.

4. Title and Subtitle Bridge Information Modeling Standardization Report Volume I – Information Exchanges	5. Report Date 6. Performing Organization Code
7. Author(s) Primary - Tim Chipman/Aaron Costin/ Donghoon Yang Contributing – Charles Eastman Editor – Roger Grant	8. Performing Organization Report No.
9. Performing Organization Name and Address National Institute of Building Sciences 1090 Vermont Avenue, NW, 7th Floor Washington, DC 20005	10. Work Unit No. 11. Contract or Grant No. DTFH6114C00047
12. Sponsoring Agency Name and Address Office of Bridges and Structures Federal Highway Administration 6300 Georgetown Pike McLean, VA 22101-2296	13. Type of Report and Period Covered 14. Sponsoring Agency Code

15. Supplementary Notes
This document is the second of a multi-volume set of documents on Bridge Information Modeling Standardization. The volumes can be read individually or sequentially as part of the set. Reading the Introduction first is recommended to provide context and a summary of the work and its findings.

16. Abstract: *Bridge Information Modeling Standardization* is a multi-volume report that analyzes options for standardized approaches for modeling bridges across their lifecycle. The goal of the Report is to identify and evaluate candidate open standards that can be used to document all aspects of bridges to identify viable standards that can be used by bridge owners to specify information delivery requirements and by software providers to meet those requirements. After evaluation of the viable available options, the Report goes on to provide an in-depth analysis based on test cases of real bridge projects of the viable alternative. Accompanying the Report is a comprehensive exchange specification to assist software developers to implement the recommended alternative to the benefit of bridge owners. This volume, Exchange Analysis, the second of four volumes, evaluates process models for the bridge life cycle developed in a previous FHWA project, in use by industry in other domains and represented by existing requirements from state Departments of Transportation, and then recommends a new process map built on the best practices identified in the analysis.

17. Key Words	18. Distribution Statement
bridge, design, construction, modeling, models, open, standards,	No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 22161.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	79	

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

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

APPROXIMATE CONVERSIONS FROM SI UNITS

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

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)
A 508 compliant version of this table is available at http://www.fhwa.dot.gov/publications/convtabl.cfm.

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1 Introduction

Information about a bridge is generated throughout its full life cycle including design, engineering, construction, operation, maintenance, and demolition. The information is used for many purposes and by many different stakeholders. The use may involve many computer software applications, people, and organizations. In order to support such uses, the bridge information should be represented in a neutral, readily understandable, computer interpretable form that remains sufficient and consistent when exchanged and stored.

An Information Modeling Standard aims to specify a digital organization and exchange structure that is in a computer interpretable format used for storing, accessing, transferring and archiving data in a formal manner suitable for communication, interpretation, or processing by human beings or computers. (ISO TC184/SC4, 1992) A modeling standard is not only for supporting neutral file exchange but also for implementing and sharing information databases and archives.

The standard procedures developed by the National Institute of Building Sciences for using the Industry Foundation Classes (IFC) (ISO TC59/SC13, 2010) to specify information modeling standards consist of defining the targeted use case(s), developing a generic process map identifying required information types for a specific activity and purpose, identifying detailed data types for the required exchange information, and finally mapping detailed data types into a neutral computer interpretable form and validating the result. The process is summarized in Figure 1. This Volume describes the development of the process map for the bridge life cycle, which identifies types of information flow (exchange requirements) among activities in the process. Volume II and III further discuss the required information and data types.

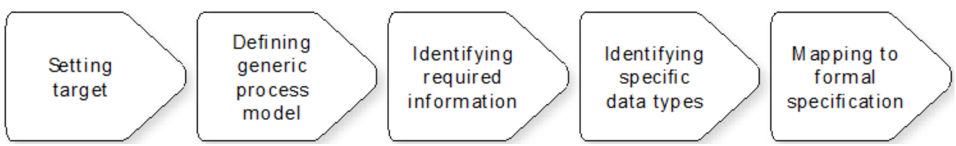

Figure 1. General steps for defining data exchange in IFC

A complete BrIM standardization effort is a large multi-year, national and potentially international, undertaking. The planning and execution of such an undertaking can vary widely in scope, cost and temporal effectiveness. For example, adopting the Precast/Pre-stressed Concrete Institute (PCI) Model View Definition (MVD) took more than half a decade to fully execute. (Eastman, Precast BIM Standard Project, 2012)

The project team has participated in meetings of related organizations that have helped inform and expedite the analysis and development of the resulting bridge process map:

- buildingSMART International, the international organization that manages IFC and reviews the evolution of IFC exchange efforts.

- Three building focused efforts (sponsored by American Institute of Steel Construction (AISC, 2011), Precast/Pre-stressed Concrete Institute (Eastman, Precast BIM Standard Project, 2012), and American Concrete Institute (Eastman, Cast-in-Place National BIM Standard, 2012), respectively).

These earlier building specific efforts adopted the processes and phasing recommended by the National Institute of Building Science (NIBS) (National Institute of Building Sciences, 2015) as outlined in Figure 1, based on extensive involvement of the various user communities. The user communities need to be augmented by software vendor groups that will be the implementers of the exchange software. The development of the process map requires strong leadership because of the front-end costs and generally delayed benefits. Recognizing these issues this project attempted to expedite the national BIM standard process by:

1. Instead of developing a full set of exchanges for various types of bridge projects, the team selected two common representative bridge types to focus efforts.
2. The elements and sequencing of project activities can be different by contract types. The design-bid-build delivery method has different activities and sets of exchanges from the design-build delivery method. This project focused on the design-bid-build approach, the most common delivery method for bridges and the method already identified in the previous work, instead of extending or annexing other approaches to reduce the time.
3. The design-bid-build approach involves data exchange from design to construction, which involves flow of information on a full and detailed bridge model. The BrIM team identified that this exchange is the most well-defined and has the highest potential return from being fully automated out of the whole design-bid-build process for bridge projects.
4. The project team concluded from the previous efforts that having a working exchange in a short time is more beneficial and effective to communicate intent and to get feedback than providing full implementation of multiple exchanges simultaneously over a longer period of time. Therefore, instead of identifying information items from various user communities and augmenting those by software vendors, the project team decided to use the contract document set prepared by the engineer of record (EOR) for the owner in order to identify required information item types.

The full bridge lifecycle can be information intensive and complex, with numerous phases, actors, and activities. In order to help reduce the complexity and make the process more understandable, a process map has been introduced to define the context for specifying objectives. Processes in construction vary because of different contexts, locations, and requirements. No process map is likely to describe completely the activities in the bridge life cycle. A process map generally classifies the information flows between the different actors and activities throughout the project phases. The classification provides a guide for identifying salient exchanges for a given purpose and scope.

Process modeling refers to activities involved in defining what an actor does, who is responsible, to what standard a process should be completed, and how the success of a process can be determined. Its purpose is not to have standardized work flow, but to gain an in-depth understanding of the relationships between the activities to achieve the data exchanges, the actors involved, and the data required, consumed and produced. (buildingSmart International, 2012) This project developed a new, comprehensive bridge process map, Figure 2.

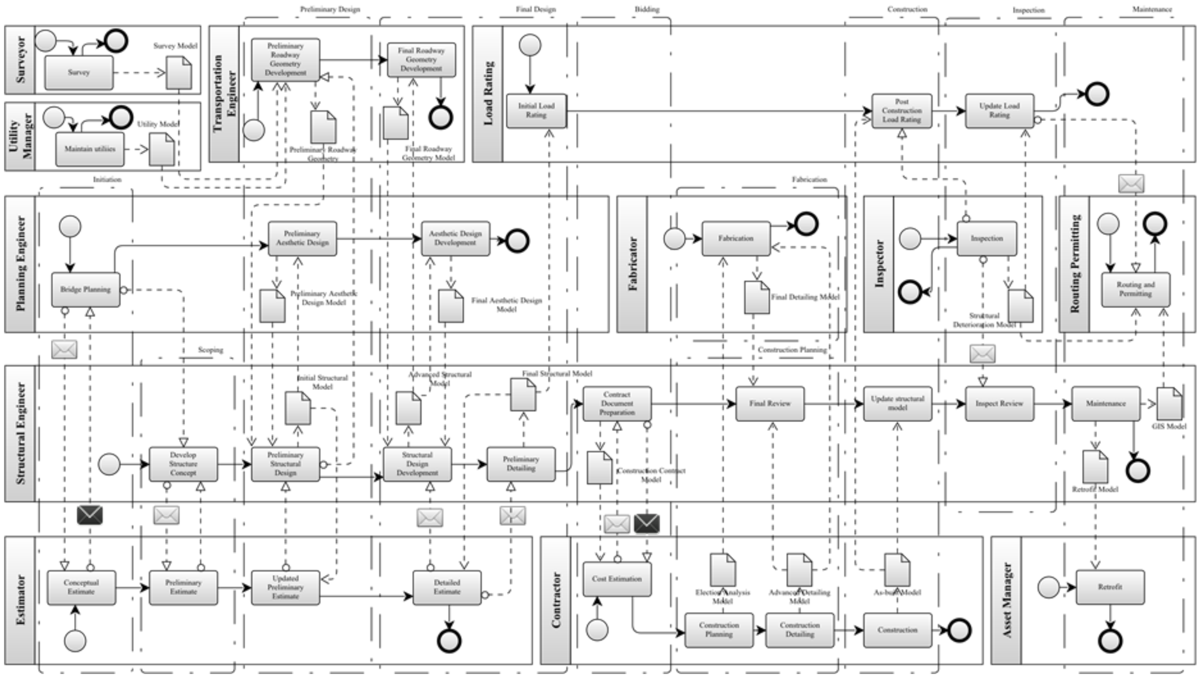

Figure 2. Bridge Lifecycle Management Process Map

The process map characterizes the activities that have specific inputs and outputs. Inputs are typically from other activities and other data sources and the activities generate outputs to other subsequent activities. The outputs from precedent activities (e.g. preliminary design) are inputs for subsequent activities (e.g. final design) of a data exchange (e.g. from preliminary design software to final design software). Exchange requirements further specify the required inputs in a specific data exchange. The process map defined in this Report is based on the Design-Bid-Build delivery approach where design is 100% complete before construction begins. Other delivery methods such as Design-Build could require that some exchanges be modified. What this process map is based on and how it was developed is further explained in the rest of this volume.

2 Bridge Lifecycle Workflows

At the outset of this phase of work, three existing sources of bridge processes were identified for evaluation towards further developing a new, more comprehensive and procedurally correct bridge lifecycle process map that would establish the full exchange requirements for bridges. The three sources of bridge processes evaluated were:

1. FHWA Bridge Map (2013) - The process map generated from the FHWA BrIM Report 2013 by the University of Buffalo (Chen S. S., 2013) (Chen S. S., 2013) was the starting point for the exchange modeling efforts of this phase of work.
2. Industry Product Models - product models from the Architecture / Engineering / Construction (A/E/C) industry for fabrication and engineering by the Precast/Prestressed Concrete Institute (PCI) and the American Concrete Institute (ACI) for concrete framing and detailing, and the American Institute of Steel Construction (AISC) for steel framing and detailing.
3. State Departments of Transportation (DOT) Standards - high-level classes of exchanges used in DOT agencies were identified according to published standards at DOT agencies.

The following sections present background on each of the three process sources evaluated along with the analysis that led up to the development of a new integrated process map in Section 4.

2.1 The FHWA Bridge Process Map (2013)

The FHWA BrIM Report 2013 defined a process map for design-bid-build bridge projects, which identified at which points the data exchanges of interest occur in order to develop future implementations. Within the data exchanges, five high priority exchanges (final roadway geometry model, final structural model, contract model, erection analysis model, and final detailing model) were identified, and information items were collected from TransXML, ISM[1], IFC, and CIS/2[2] to describe geometries, sections, materials, cambers and etc.

The process map, identified exchanges, and information items from the FHWA BrIM Report 2013, were updated based on the review of related works. Details of the updated process model, exchanges and information items are discussed in the corresponding sections of this Report

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[1] ISM (Integrated Structural Modeling) (Bentley, 2012) is a technology for sharing structural engineering project information among structural modeling, analysis, design, drafting and detailing applications. ISM was developed by a commercial software company, Bentley Systems, Inc. It can work with major Bentley software products.

[2] CIS/2 (CIMsteel Integrated Standards Release Two) originated from the CIMsteel (Computer Integrated Manufacture of Constructional Steelwork) (Crowley, 2000) Project from the European Construction Steelwork Industry. It is a set of formal computing specifications that allow software vendors to make their engineering applications mutually compatible. AISC endorsed CIS/2 as the format for data exchange among structural steel related software applications.

leading to recommendations for modification and improvement that are incorporated into the Bridge Lifecycle Management Process Map.

2.1.1 Phases

In construction, four general phases characterize most typical design-bid-build projects: planning, bidding, construction, operation and maintenance (O&M). Phases are temporal discrete segments of time, usually occurring sequentially and not overlapping each other.

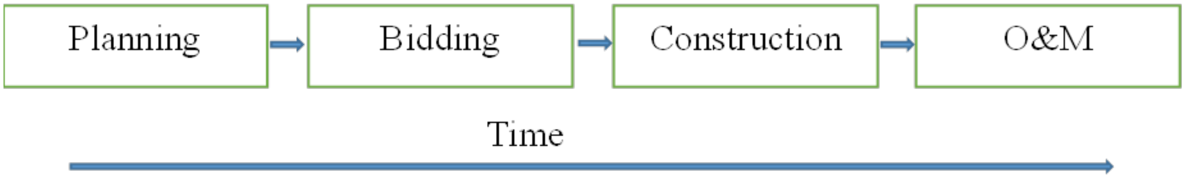

Figure 3. General Phases of Project Development and Asset Management

Each high level phase can then be broken down into smaller, sub-phases. For example, planning can be broken into initiation and design. In order to build a bridge, the plan first needs to be initialized (what the problem is, what the constraints are, etc.). Afterwards, the bridge needs to be designed (type of bridge, capacity, aesthetics, etc.). These sub-phases can further be broken down into smaller sub-phases. Sub-phases are disjointed partitions of the phase or sub-phase they are part of. The FHWA BrIM Report 2013 identified the phases for bridge construction. Below is a list of the phases identified in the bridge lifecycle process, in which each term is followed by its classification number from the OmniClass Construction Classification System (OCCS) (OCCS Development Committee, 2006):

- 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 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

2.1.2 Disciplines

In order to make an activity happen, there needs to be one or more people to carry out the tasks. These people are called 'actors' because they act upon a certain activity in the process. The same person may carry out different activities having different roles for each activity. Anybody that has a role in a process is considered a resource, which can be a person, an organization, or a person acting on behalf of an organization. The FHWA BrIM Report 2013 classified actors into the following disciplines in its process map, , in which each term is followed by the corresponding OCCS number (OCCS Development Committee, 2012).

- 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 00 00
- Inspection (I), 33-21 31 14
- Load Rating (LR), 33-21 31 14
- Routing and Permitting (RP), 33-21 31 11
- Maintenance and Management (MM), 33-55 24 00

2.1.3 Process Map

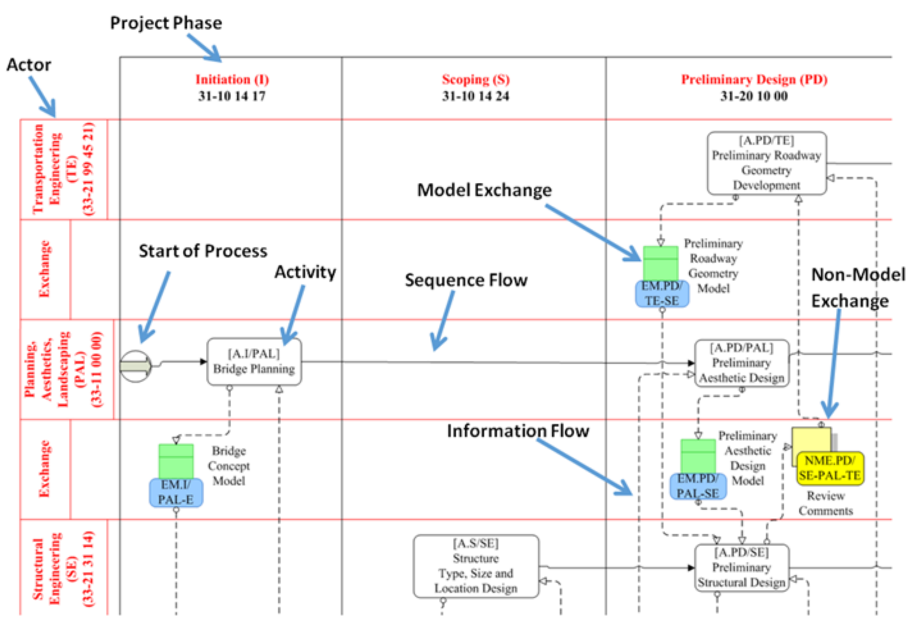

Figure 4. Notation of the process map from the FHWA BrIM Report 2013

Figure 4, a segment of the process map shown in Figure 5displays the notation used in the process map. The map is broken up into lanes (rows and columns). The leftmost column shows the disciplines of actors (stakeholders). The topmost lane identifies the phases (or stages) in the process in order of involvement (i.e. the far left is the start of the project and the far right is the end).

The activity lane, denoted by the actors' disciplines, displays the activity (A) (white rectangles with rounded edges labeled starting with letter A) carried out by the actors at a specific phase in the project. The lanes labeled "exchange" display the exchange maps and are there to facilitate exchange flows. The green box exchange maps (EM) (square edged rectangle attached to rounded edge rectangles labeled starting with letters EM) identify digital maps, and the yellow box non-map exchanges (NME) (square edged rectangle attached to rounded edge rectangles labeled starting with letters NME) are non-map files (e.g. PDF, notes, etc.).

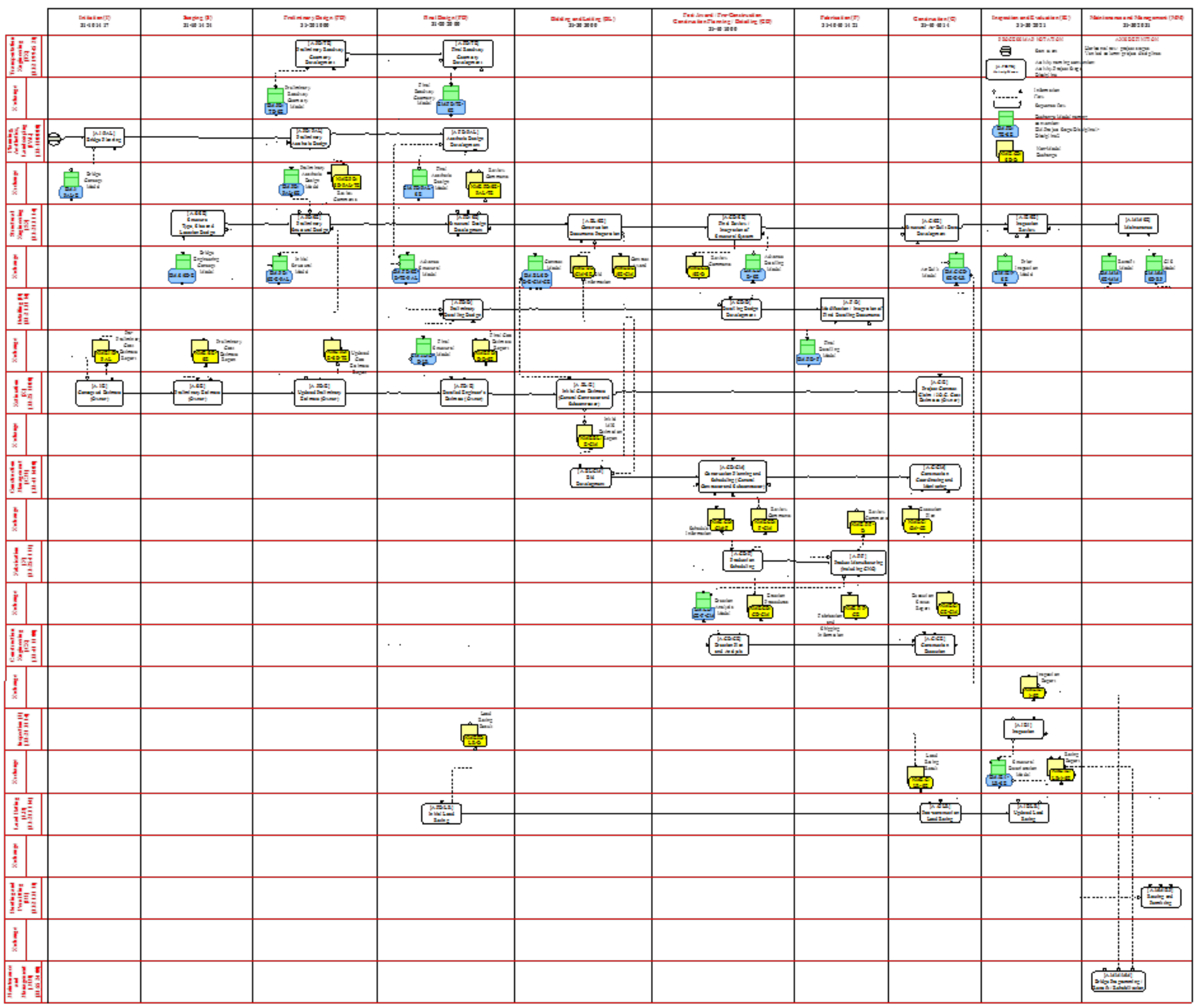

Figure 5. The process map from the FHWA BrIM Report 2013

Since each exchange is potentially unique, they have been named according to phase and disciplines of actors. The format is EM. Phase/Sender-Receiver(s). For example, the "Preliminary Roadway Geometry Model" is in the Preliminary Design (PD) phase and is sent from Transportation Engineering (TE) to Structural Engineering (SE). Therefore the name is EM.PD/TE-SE.

Non-model exchanges are denoted by NME rather than EM. The direction and flow of the activities are shown by solid arrows, and the direction and flow of the exchanges are shown by dashed arrows.

Figure 5 represents the entire process map from the FHWA BrIM Report 2013. The process map identified 34 activities and 18 model based exchanges described in the following sections. Further information on process maps is provided in the section titled Development of a New Integrated Process Map.

2.1.4 Activities

Within each sub-phase, various activities are expected and usually scheduled to reach a specified goal. An activity applies resources (people, time, equipment, computation, expertise, etc.) to complete the activity.

Activities can be repetitive, or iterated until the outcome of that activity is achieved. Often, activities are dependent on conditions that are realized by other activities. The second activity depends on the state of the first activity; the second activity can only be meaningfully applied if the first activity has been completed. In addition, if the first activity is iterated, the second activity may also have to be repeated.

For instance, initiation has two activities: "bridge planning" and "conceptual estimate". The "bridge planning" activity determines the project plan, which may include a description of the problem, preliminary project objectives, a description, project elements to be investigated and a preliminary schedule. The "conceptual estimate" activity creates a preliminary cost estimate report of the bridge plan. Therefore, any changes to the plan will create changes in the cost estimate report, which makes the "conceptual estimate" activity dependent on the "bridge planning" activity. Since there is a dependency, the two activities iterate until a final bridge plan is achieved and the associated cost estimate is generated.

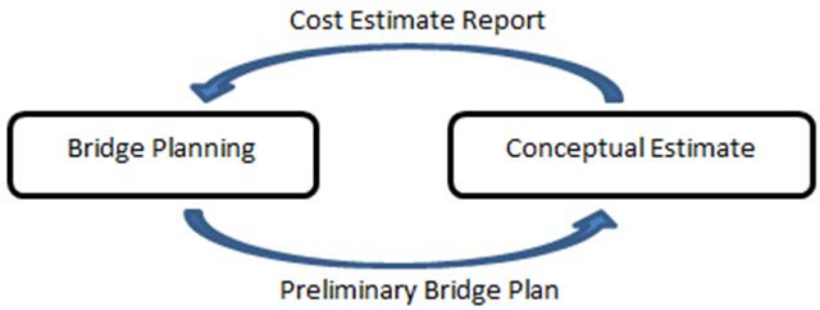

Figure 6. Bridge Planning and Conceptual Estimate Cycle

The FHWA BrIM Report 2013 identified the majority of the activities important in the life-cycle of a bridge. However, it is important to note that the list is not a fully comprehensive list of all the activities needed to model bridges, but addresses the most common cases.

1. Bridge Planning
2. Conceptual Estimate
3. Structure Type, Size and Location Design
4. Preliminary Estimate
5. Preliminary Roadway Geometry Development
6. Preliminary Aesthetic Design
7. Preliminary Structural Design
8. Updated Preliminary Cost Estimate
9. Final Roadway Geometry Development
10. Aesthetic Design Development
11. Structural Design Development
12. Preliminary Detailing Design
13. Detailed Engineer's Cost Estimate
14. Initial Load Rating
15. Construction Documentation Preparation
16. Initial Cost Estimate
17. Bid Development
18. Final Review / Integration of Structural System
19. Detailing Design Development
20. Construction Planning and Scheduling
21. Production Scheduling
22. Erection Plan and Analysis
23. Modification / Integration of Final Detailing Documents
24. Product Manufacturing
25. Structural As-Built Data Development
26. Project Contract Claim / J.O.C. Cost Estimates

27. Construction Coordinating and Monitoring
28. Construction Execution
29. Post-construction Load Rating
30. Inspection Review
31. Inspection
32. Updated Load Rating
33. Maintenance
34. Routing and Permitting

2.1.5 Exchanges

An estimator needs specific and reliable data from the planner in order to make an accurate cost estimate report. If the data are erroneous or unreliable, the cost estimate report is inaccurate, which can cause later problems in the project. To ensure that the estimator obtains the needed reliable information an exchange is established. An exchange is the process of transferring the needed information at a given phase in a process from one actor to another. The information sent from the planner to the estimator, in the form of the bridge plan, is one type of exchange. The information sent back from the estimator to the planner, in the form of the cost estimate report, is a separate exchange.

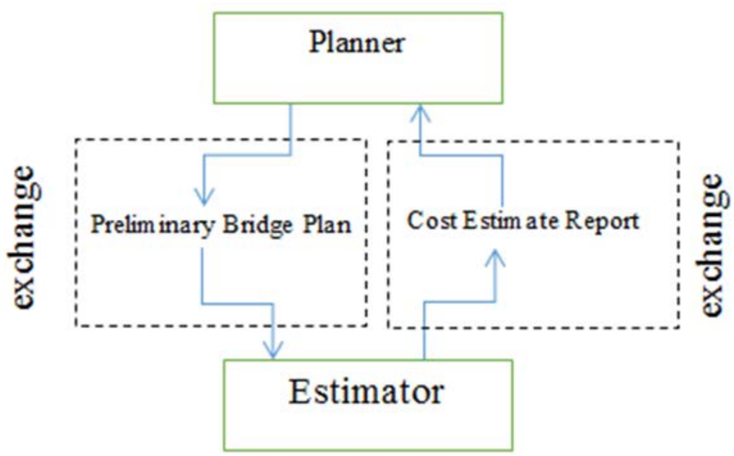

Figure 7. Exchanges Between two Actors; Planner and Estimator

Note that the exchanges below may have multiple actors importing data in an exchange. However, in practice, multiple correct models may not be merged into a single one without using an application supporting the integration or via a manual interpretation. An example is structural analysis models for a structure and the physical representation of the structure. Some applications support the synchronization of the two models internally, while others do not. An emerging technology supporting the coordination of model data between different applications are model servers. Today however, links between separate models are not currently supported in practice. Merging of models must be done within an application.

1. [EM.I/PAL-E] Bridge Concept Model
Sender (33-11 00 00) Planning, Aesthetics and Landscaping
Receiver (33-25 11 00) Estimation
Purpose These models are created by engineers to help define candidate a project based on program goals.

2. [EM.S/SE-E] Bridge Engineering Concept Model
Sender (33-21 31 14) Structural Engineering
Receiver (33-25 11 00) Estimation
Purpose This model helps stakeholders better understand problems and define project scope, cost and schedule.

3. [EM.PD/TE-SE] Preliminary Roadway Geometry Model
Sender (33-21 99 45 21) Transportation Engineering
Receiver (33-21 31 14) Structural Engineering
Purpose This model has been developed to provide minimum safe geometrics for the bridge project.

4. [EM.PD/PAL-SE] Preliminary Aesthetic Design Model
Sender (33-11 00 00) Planning, Aesthetics and Landscaping
Receiver (33-21 31 14) Structural Engineering
Purpose The model contains aesthetic design data.

5. [EM.PD/SE-E-PAL] Initial Structural Model
Sender (33-21 31 14) Structural Engineering
Receiver (33-25 11 00) Estimation
Purpose This model is created to help structural engineer select the most appropriate alternative to be advanced.

6. [EM.FD/TE-SE] Final Roadway Geometry Model
Sender (33-21 99 45 21) Transportation Engineering
Receiver (33-21 31 14) Structural Engineering
Purpose This model contains updated roadway geometry data.

7. [EM.FD/PAL-SE] Final Aesthetic Design Model
Sender (33-11 00 00) Planning, Aesthetics and Landscaping
Receiver (33-21 31 14) Structural Engineering
Purpose This model contains updated aesthetic design data.

8. [EM.FD/SE-D-TE-PAL] Advanced Structural Model

Sender (33-21 31 14) Structural Engineering

Receiver (33-21 31 14) Detailing, and (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.

9. [EM.FD/D-E-LR] Final Structural Model

Sender (33-21 31 14) Detailing

Receiver (33-25 11 00) Estimation, and (33-21 31 14) Load Rating

Purpose This model is used to develop detailed cost estimate and assemble acontract package to enable the bridge owner to advertise, let, and award.

10. [EM.BL/SE-D-E-CM-CE] Contract Model

Sender (33-21 31 14) Structural Engineering

Receiver (33-21 31 14) Detailing, (33-25 11 00) Estimation, (33-41 14 00) Construction Management, and (33-41 00 00) Construction Engineering

Purpose For contractors to develop contractor's cost estimate, construction planning and detailing.

11. [EM.CD/D-SE] Advance Detailing Model

Sender (33-21 31 14) Detailing

Receiver (33-21 31 14) Structural Engineering

Purpose Bridge detailing for bridge owner and designer to review modeling.

12. [EM.CD/CE-F-CM] Erection Analysis Model

Sender (33-41 00 00) Construction Engineering

Receiver (33-25 41 11) Fabrication, and (33-41 14 00) Construction Management

Purpose This model is used for development of a construction schedule.

13. [EM.F/D-F] Final Detailing Model

Sender (33-21 31 14) Detailing

Receiver (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.

14. [EM.C/CE-SE-E-LR] As-Built Model

Sender (33-41 00 00) Construction Engineering

Receiver (33-21 31 14) Structural Engineering, (33-21 31 14) Structural Engineering, and (33-21 31 14) Load Rating

Purpose This model is used by structural engineers to calculate load rating factors and by an inspector for bridge inspection.

15. [EM.IE/I-SE] Prior Inspection Model

Sender (33-21 31 14) Inspection

Receiver (33-21 31 14) Structural Engineering

Purpose This model contains the bridge information from the previous inspections.

16. [EM.IE/I-LR-SE] Structural Deterioration Model

Sender (33-21 31 14) Inspection

Receiver (33-21 31 14) Load Rating, and (33-21 31 14) Structural Engineering

Purpose The model is used for structural engineers to make load rating calculation, and for the bridge owner to permit and route vehicles.

17. [EM.MM/SE-MM] Retrofit Model

Sender (33-21 31 14) Structural Engineering

Receiver (33-55 24 00) Maintenance and Management

Purpose This model is used for development of a bridge retrofit /rehabilitation program.

18. [EM.MM/SE-RP] GIS Model

Sender (33-21 31 14) Structural Engineering

Receiver (33-21 31 11) Routing and Permitting

Purpose This model is used for development of a bridge GIS model.

2.1.6 Review of the exchanges

The project team reviewed the exchanges from the FHWA BrIM Report 2013 and identified areas to improve in defining model based exchanges. This section identifies the changes made in the development of the new integrated process map described in section 4.

Bridge Concept Model

The bridge concept model defines 1) a description of problem, 2) the preliminary project objectives and descriptions, 3) project elements to be investigated, 4) preliminary environmental classification, 5) issues or circumstances which may arise (e.g. community concerns and environmental issues), and 6) preliminary schedule. (NYSDOT, 2012)

Figure 8 is a part of Table C – Critical Design Elements from the Initial Project Proposal / Final Design Report (IPP/FDR) shell (NYSDOT, 2012) from the New York State Department of Transportation. The IPP template defines design criteria applicable to the bridge design such as design speed, lane width, approach lane width, shoulder width, approach shoulder width, bridge roadway width, approach roadway width, maximum grade, horizontal curvature, super elevation, stopping sight distance, horizontal clearance, vertical clearance, pavement cross slope, rollover and others. This type of information prescribes the design criteria but not the actual design of a roadway that can be transferred. There is no physical design model that has explicit shape (such as terrain, alignment, section and etc.) defined in the bridge concept model as given in the IPP. Therefore, this exchange can be represented as a non-model based exchange.

Element		Standard	Existing Condition	Proposed Condition[2]
1	Design Speed	50 mph (80 km/h)		
2	Lane Width	11 ft (3.3 m)		
3	Shoulder Width	4 ft (1.2 m) BM Section 2.3.1 Table 2-1, and App. 2A Tables & [OR] HDM Section		
4	Bridge Roadway Width	Undivided Arterial Approach roadway width=2(11+4)=30 ft (9 m) Existing traveled way plus 4 ft min. shoulders=2(10+4)=28 ft (8.4 m) Wider of the two is 30 ft (9 m) =std. BM Section 2.3.1 and Table 2-1		
5	Maximum Grade	7% HDM Section		
6	Horizontal Curvature	758 ft (229 m) Min (at e_{max}=8%) HDM Section		
7	Superelevation	8% Max. HDM Section		

Figure 8. Excerpt from the table C – Critical Design Elements of NYS DOT IPP

Bridge Engineering Concept Model

Structural engineers generate the bridge engineering concept model in the scoping phase based on the bridge concept model. The information items contained in the bridge engineering concept model are 1) project area's information, 2) project objective(s), 3) design criteria, 4) feasible alternative(s), and 5) key environmental issues.

The project scoping report template (NYSDOT, Project Scoping Report / Final Design Report (PSR/FDR), 2015) from New York State Department of Transportation also indicates that these information items are lists of textual descriptions that specify the criteria, which does not necessarily involve a model based exchange. Therefore this exchange needs to be represented as a non-model based exchange.

Prior Inspection Model and Structural Deterioration Model

The Inspection activity identified in the FHWA BrIM Report 2013 produces two types of models, a Prior Inspection Model and a Structural Deterioration Model. The Structural Engineering discipline uses the Prior Inspection Model in the Inspection Review activity, and it also uses the Structural Deterioration Model in the Inspection Review activity. The Structural Deterioration Model is used in two other disciplines. The Load Rating discipline uses it for the Updated Load Rating activity. The Routing and Permitting discipline uses it for the Routing and Permitting activity.

Inspection happens periodically throughout the lifecycle of the bridge. Inspection level and frequency criteria are established for such inspections as underwater, scour critical, fracture critical members, complex, damage, in-depth and special inspections. (U.S. Department of Transportation Federal Highway Administration, 2009)

The Prior Inspection Model is in fact the Structural Deterioration Model from the previous Inspection. The FHWA BrIM Report 2013 describes how the inspectors identify areas where defects were found in previous inspections, which allows them to determine if the defects previously identified have been repaired or have increased in size and severity. The defects found in the previous inspection are recorded in the Structural Deterioration Model from the previous inspection. Because of this, it is recommended to modify to the process model to represent looping of recurring Inspections and consolidate the Prior Inspection Model and the Structural Deterioration Model into one exchange.

2.2 Industry Exchanges

This section is an initial assessment of the integration of product models from the Architecture / Engineering / Construction (A/E/C) industry for fabrication and engineering in the bridge construction process, the roles of the participants involved, and the specific data required.

An important opportunity exists to recognize and take advantage of already defined exchanges and software workflows identified in closely related fields. The objective is based on not re-inventing processes already studied and adopted by other groups, and on adopting existing processes being developed in the construction industry, for other structures that are highly overlapping. There is significant overlap of process and information between buildings, bridges, process plants and power lines. For contracting and related processes, it is important to take advantage of these business, industry and practice activities where appropriate. The following analysis reviews three sets of exchanges with bridges:

- Section 2.2.1 reviews exchanges in the Precast/Prestressed Concrete Institute (PCI) Model View Definition (MVD)
- Section 1.1.1 reviews exchanges in the American Institute of Steel Construction (AISC) Model View Definition (MVD)
- Section 2.2.3 reviews exchanges in the American Concrete Institute (ACI) Model View Definition (MVD)

Each of these three exchange sets was created largely independently, but with well-defined linkages with each other. For example, reinforcing and pre- and post-tensioning elements are integrated in concrete and steel detailing; steel decking is typically defined by the steel detailer, but strongly coordinated with two way exchanges in the concrete layout and the structural analysis. Connections between systems (foundations, shear plates) for concrete-steel connections are directly related or linked to each other. At a detailed implementation level, functional libraries are defined that often need to reflect their fabrication.

The material attributes for steel structures and rebar and mesh are the same in most cases. An objective of reviewing these three domains was to assess the effort involved in integrating them with bridge engineering to determine the effort needed to support or improve current practice to identify differences and resolve them where needed. In general, properties and attributes are easy to include or drop; missing entity types with distinct functions or geometry are much larger gaps.

2.2.1 Exchanges in the Precast/Prestressed Concrete Institute (PCI) MVD

PC1. Building Concept (BC)

Phase	Preliminary Project Description
Disciplines	Architecture, Structural Engineering, and Precaster
Purpose	BC consists of the architectural concept model or engineering concept model passed to the detailer for further preliminary precast structural and fabrication detailing

BC consists of the concept design layout of precast pieces optionally composed into assemblies. Geometry is nominal, without camber or twisting. It lacks surface or structural detailing. It includes structural- and other grid-controls. It optionally includes major architectural finishes, and site analysis. It identifies interfaces with other structural elements and curtain wall systems.

PC2. Precast Concept (PC)

Phase	Preliminary Project Description
Disciplines	Architecture and Precaster
Purpose	Precaster’s preliminary feedback based on design review and concept modeling

PC is the precaster's review of the Building Concept model from architects and specifies major architectural/structural precast components. This may deal with the precast structural system, panelization, architectural finishes and site logistics.

PC3. Precast Contract Development (PCD)

Phase	Preliminary Project Description and Design Development
Disciplines	Architecture, Structural Engineering, Precaster, and General Contractor
Purpose	PCD is a general detailed precast design model; with editable geometry; it reflects the detailed design intent of the precast concrete and structural requirements of the building for use in integration with all other systems. It also consists of the total building cost estimate based on the early schematic design.

The model provides precast design intent dealing with both structural and architectural intent. It defines the structural requirements of the building. It may include loads reactions, precast connection designs, precast-to-structural steel connection design, foundation design and connection element capacities.

Precast finishes may be defined and optionally doors, windows, interior wall partitions, and curtain wall systems embedded in or related to the precast. It is passed between different parties for review to ensure the building design intent and the structural adequacy is preserved. It is further refinement of the concept model, providing a basis for the precast cost estimate based on early schematic design models.

The general contractor adds budget, schedule and specifications for the entire building received from several precasters / subcontractors to be passed to the owner/architect group to make a go/no-go decision about the project.

PC4. Engineering Design Development (EDD)

Phase	Construction Documentation, Procurement and Product Development
Disciplines	Architecture, Structural Engineering, Precaster, and General Contractor
Purpose	EDD is based on the architectural and engineering designs that are then detailed and made production and erection worthy by the precaster. It provides the detailed BRep precast design model sent for review. It supports multiple Source-Recipient workflows.

EDD is the detailed precast design model. It includes high-level description of precast piece detailing and all connection details. It provides assembly and piece layout for review to the architect and engineer. The architect's response then identifies those aspects and parts of the design where design intent has not been met to ensure consistency between the architectural design and precast detailing models. The general contractor can use the model for the bid preparation or for coordination merged with other trade models.

PC5. Architectural Contract (AC)

Phase	Design Development and Construction Documentation
Disciplines	Architecture, Structural Engineering, Precaster, and General Contractor
Purpose	This model is a construction stage precast model used for coordination of all precast components with the rest of the building. It integrates the building layout of all precast pieces with all other building systems to support production of a contract construction model and for structural and logistical consistency review.

The model integrates the building layout of all precast pieces with all other building systems. It identifies the shape and logical connectivity of all precast pieces. It includes the layout of surface finishes, molding, reveals and other decorative features. Other systems interacting with precast are also represented.

Based on the architectural and engineering designs, this exchange model is used for coordination of all precast components includes precast slabs, beams, columns, and connections. It conveys detailed model descriptions of all precast structural elements, using BRep geometry. The model together with the drawings and specifications are also submitted to the general contractor in order to be assembled with other models and used for the bid preparation.

PC6. Engineering Contract (EC)

Phase	Construction Documentation
Disciplines	Architecture, Structural Engineering, Precaster, and General Contractor
Purpose	The exchange is prepared as a construction drawing set or construction-level model. It is focused on the structural design and integrates the structural layout with other building systems.

The model includes structural elements, connections and details. Both the precast and other structural systems are fully designed.

PC7. Precast Detailed Coordination (PDC)

Phase	Construction Documentation, Procurement, Fabrication Phase
Disciplines	Architecture, Structural Engineering, Precaster, and General Contractor
Purpose	The model is developed by the precaster to be used by the GC for review and with other trade models which includes building cost estimate, spatial coordination, optionally 4D temporal sequencing and simulation. Structural engineers also include the result of structural design and reinforcement. It relies on assembly-level layout in BRep geometry.

PDC is a general purpose multi-workflow exchange model defined by diverse sources for different recipients for detailed coordination. It may be used for the total building cost estimate based on the early schematic design models. It includes descriptions of all connection details, finishes, joints, embeds, reinforcing, tensioning cable layout and blockouts, pre-tensioned pieces, and lifting hooks for lifting and transporting.

Structural design of logical connections is specified. This model also conveys the results of structural design and reinforcement review by the engineer of record to the precast fabricator during the fabrication phase with information about design constraints, design loads and structural design.

PC8. Structural Review & Coordination (SRC)

Phase	Procurement and Fabrication
Disciplines	Structural Engineering, Precaster and Plant Management
Purpose	The model contains the precast structural system, to verify it maintains structural intent. This model is developed by the precaster and contains all the fabrication model of all precast pieces and assemblies that are required for structural design and reinforcement review.

The model includes geometry and assembly relations of buildings and spaces. Common categories of information for various types of products are included like layout, related shape and material information; both at the piece and assembly level.

Connection relations of the pieces except for non-load bearing pieces are specified. Assembly and nested relations except for connections, and non-load bearing pieces are included. Related identification information and concrete mixes are included. Layout and grid geometry of facades, slab toppings, and reinforcement specifications are designated. More low level, detailed information about products is included. Characteristics of thermal and acoustic insulation are defined. Nested relations of both field applied and plant applied connections are specified.

Finally, related specifications of other building parts and systems are included. It includes detailed description of precast piece detailing, all connection details, finishes, joints, embeds, reinforcing, tensioning cable layout and blockouts, pre-tensioned pieces, and lifting hooks for lifting and transporting. Connections, design constraints, design loads and structural design are defined, using BRep geometry.

PC9. Engineering Analysis Results (EAR)

Phase	Procurement, Product Development and Fabrication
Disciplines	Structural Engineering, Precaster, and General Contractor
Purpose	Detailed analysis review of the precast concrete structural model. This model conveys the results of structural design and reinforcement review by the engineer of record and also the detailed fabrication model of precast pieces and assemblies provided by the precast fabricator.

EAR includes all structural precast elements. Slab layout and topping are defined. Assembly, nested and connection relations of load bearing and voided pieces are specified. Assembly and nested relations of logical connections and both field and plant applied connections are defined. Related identification information and concrete mixes are included. Reinforcement specifications and layout are designated. Structural design for load-bearing pieces and design loads for slabs are specified. Important common categories of information include layout, shape, and material types and surface treatment, both in the piece and assembly level. Openings and opening frames are defined. Detailed information for some types of products is included. Layout and grid geometry of facades are designated. For load-bearing, non-load bearing and voided pieces, joint and connection relations are specified also. Logical and physical connections are defined. Lifting devices are indicated. Thermal and acoustic insulation characteristics are defined. Structural design of logical connections is specified.

PC10. Final Precast Detailing & Coordination (FPCD)

Phase	Fabrication and Erection
Disciplines	Precaster, General Contractor, and Plant Management
Purpose	This is the fully detailed model of precast elements, as assembled in the project, prepared by the precast fabricator for coordination with precast and other systems, mostly by the contractor.

FPCD includes fully detailed information about products and their assembled composition in the project - layout, shape, geometry and finishes of all precast products. Assembly relations of the pieces and connections are specified. Connections with other systems, including embeds, are included. Openings and opening frames are defined (not opening fillers). Identification and related production information for different pieces are included. Reinforcement specifications are defined. Relevant information for different types of products is provided. Facade layout and grid geometry are defined. Voided pieces, nested, connection and joint relations are specified. Nested relations of both field-applied and plant-applied connections are specified. Specifications of other related building parts and systems are included. Concrete mixes and finish material types are defined. Lifting devices are included. Surface treatment areas are included.

PC11A. Production and Erection Data (PED)

Phase	Product Development and Erection
Disciplines	Precaster, General Contractor, and Plant Management
Purpose	In this exchange model the fabricator passes the model of precast pieces and assemblies to the general contractor for coordination and then during the erection phase, the general contractor sends the orders for piece delivery to the plant manager.

In this exchange, important common categories of information are provided including layout, shape, material types, and information about product finishes both at the piece and assembly level. Also, assembly relations of products except for foundation parts are specified. The piece marks for identification are included. Detailed information for some types of products is included. Layout and grid geometry of facades are designated and slab topping thickness, material and surface treatment are defined. For load-bearing and non-load bearing pieces, assembly, nested, joint and connection relations are specified. Relevant information about reinforcement is included. Nested and assembly relations of both field applied and plant applied connections are specified. Specifications of other building parts and systems like lifting devices that are affected, are indicated.

PC11B. Architectural Review and Coordination (ARC)

Phase Product development and Fabrication

Disciplines Architecture and Precaster

Purpose This exchange is for the transfer of coordination action items to the fabricator from the architect for piece detailing. This exchange passes back to the precast fabricator a report of the design intent issues identified by the architect for precast assembly-level piece layout, based on information supplied by the precast fabricator for the architects' review/approval.

In this exchange, design constraints of buildings and spaces are indicated, where relevant. Product information that raises issues about the design intent are reported, including layout, shape, material types, geometry and material finishes of products, both in the piece and assembly level. Also, assembly and connection relations of pieces are specified. For load-bearing and non-load bearing pieces, assembly and joint relations may be identified as problems. The specifications of joints are defined. Nested and assembly relations of both field applied and plant applied connections are specified. The piece marks for identification are included. Detailed information for different types of products is included. Facade layout and grid geometry may be designated; slab topping thickness, material and surface treatment may be returned. Related specifications of other building parts and systems are indicated.

2.2.2 Exchanges in the American Institute of Steel Construction (AISC) MVD

EM1: Concept Model

Concept Model is for the architect to provide information of shapes and dimensions of steel structures in the preliminary design stage. This model is related to both the Preliminary Roadway Geometry Model and the Preliminary Aesthetic Design Model of the FHWA BrIM Report 2013.

Phase Preliminary Project Description

Disciplines Sender: Architecture
Receiver: Structural Engineering, Steel Product Manufacturing

Description Function of the model is to present a schematic architectural model with enough information about physical geometry to design the basic structural system by structural engineer and to do an initial estimate of materials to allow the fabricator to do the preliminary estimate of the material and fabrication costs for concept analysis and/or budget purposes.

EM2: Initial Structural Model

Initial Structural Model is an output of the initial status of the structural engineering. The contents and the level of detail correspond to the Initial Structure Model identified in the FHWA BrIM Report 2013.

Phase	Preliminary Project Description
Disciplines	Sender: Structural Engineering Receiver: Architecture, Steel Detailing Engineering
Description	The function of the model is to present the preliminary design of the structural system which has been developed using general assumptions for member sizes and the lateral restraint system. The model is exported into detailing software to provide the preliminary steel system detailing information.

EM3: Initial Steel Structural Model

Initial Steel Structural Model in the AISC MVD is similar to Preliminary Structural Design of the FHWA BrIM Report 2013, which only represents the simple steel structure without connection details. This model has enough information to finalize a preliminary estimate.

Phase	Preliminary Project Description
Disciplines	Sender: Steel Detailing Engineering Receiver: Plant, Scheduling and Management
Description	Function of the model is to provide a simple design of steel systems using general assumptions for member sizes and the lateral restraint system to let the plant manager develop the initial production schedule. The resulting model will be exported into project management software to do a preliminary estimation.

EM4: Architectural Design Model

Architectural Design Model is similar to the Preliminary Roadway Geometry model and the Preliminary Aesthetic Model of the FHWA BrIM Report 2013.

Phase	Design Development
Disciplines	Sender: Architecture Receiver: Structural Engineering
Description	The purpose is to provide the Architectural design model and to pass physical geometry to the structural engineer for reference in creation of the Engineering Design Model. The structural engineer sends back review comments regarding structural design restraints. The Engineering Design Model is also passed back to the Architect for reference and spatial coordination.

EM5: Structural Analysis Model

In the AEC / FM and structural steel domains, structural analysis and structural design are usually separated. The structural analysis model is used to define physical structural member design and is related to the Initial Structural Model of the FHWA BrIM Report 2013, while it does not differentiate structural analysis and structural member design. This needs clarification from domain experts if the differentiation is required and if there is need for data exchange between structural analysis and structural member design.

Phase	Design Development
Disciplines	Sender: Structural Engineering Receiver: Architecture
Description	The structural engineer has created the analytical model by taking the physical geometry of the structure and load information to generate an analysis program for structural analysis, design, and optimization. This exchange is part of an iterating round loop between architect and structural engineer, finalizing the design content. The resulting structural model with updated steel member sizes and end reactions will be sent to the steel detailing engineer for connection design in the next phase.

EM6: Architectural Contract Model

This exchange is related to the Final Roadway Geometry Model and Final Aesthetic Design Model of the FHWA BrIM Report 2013. While it only addresses the architectural aspect of design, the Architectural Contract Model has the same level of detail as the Contract Model.

Phase	Construction Documentation
Disciplines	Sender: Architecture Receiver: Structural Engineering, Steel Detailing Engineering
Description	The function of the model is to reflect the detailed design intent related to steel system as integrated with all other systems. The building model and documentation provides the structural engineer and detailer the framework regarding steel design intent. It also provides the general contractor with design intent sufficient for bidding. Finally, the model is sent to the steel detailer as one of the inputs needed to design the steel structure layout.

EM7: Structural Contract Model

Structural Contract Model is one of the further detailed exchanges in AISC MVD that identifies all information items for this specific exchange. The Structural Contract Model has the same level of detail as the Advanced Structural Model and the Construction Contract Model in the FHWA BrIM Report 2013.

Phase	Construction Documentation
Disciplines	Sender: Structural Engineering Receiver: Architecture, Steel Product Manufacturing, Construction Management

Description	The purpose of the model is to provide a detailed structural model with enough information to help the steel detailer to design the final steel structure layout, to help the steel manufacturer provide the detailed material take-off and also to help the contractor develop the bid document.

EM8: Mill Order Model

Mill Order Model contains enough information for fabrication planning of the inventory of raw material and the factory operation schedule. This exchange is represented as a non model based exchange in the FHWA BrIM Report 2013, where it is modeled as a non model exchange from construction planning and scheduling to production scheduling. In structural steel, it is important to identify member size in order to plan fabrication.

Phase	Construction Documentation
Disciplines	Sender: Steel Detailing Engineering Receiver: Structural Engineering, Plant and Scheduling Management
Description	The function of the model is to provide detailed steel structure layout for manufacturing and erection of the steel system. It is also sent to the plant manager to develop the detailed production schedule. In the process of finalizing the mill order model, it is sent to structural engineer to provide comments.

EM9: Final Structural Analysis Model

Final Structural Analysis is a further developed Structural Analysis Model, similar to the Structural Analysis Model, there is no corresponding exchange in the FHWA BrIM Report 2013. This needs clarification from domain experts if differentiation is required.

Phase	Design Development
Disciplines	Sender: Structural Engineering Receiver: Steel Detailing Engineering
Description	The function of the model is to provide the final structural system information to allow the detailing engineer to design and detail the structural members for shop fabrication. One thing to consider is that connection design can be handled as an engineer mandated connection design or as member and load data passed downstream.

EM10: Advanced Steel Detailing Model

Advanced Steel Detailing Model is similar to the Advance Detailing model in the FHWA BrIM Report 2013.

Phase	Product Development
Disciplines	Sender: Steel Detailing Engineering Receiver: Construction Management, Structural Engineering
Description	The function of the model and model content is further developed from “Mill Order Model”. The difference is to gain the comments of structural engineer after

final review and integration of structural system. The model provides detailed steel structure layout for advanced connection design and detailing

EM11: Final Steel Detailing Model

This model contains the fully detailed information that is used directly to drive CNC machines that can interpret this model. This exchange is the only fully defined exchange and is implemented in structural detailing software and CNC machine control software. Structural steel bridge components can utilize this exchange without any limitation. The structural steel member can be either an AISC profile shape, custom shape or composite section such as a three plate beam.

Phase	Fabrication
Disciplines	Sender: Steel Detailing Engineering Receiver: Steel Production Automation, Plant and Scheduling Management
Description	The function of the model is to provide enough detailing information about the steel members to enable the fabricator to manufacture and shop assemble the steel pieces. The model is the finalized version of the Advanced Steel Detailing Model which is provided as the output for any modification and integration of the final detailing model. During the steel fabrication the plant management software will add member status to the model.

Following is the list of high level information items in the Final Steel Detailing Model. The full list can be found at the AISC BIMsteel initiative website (https://www.aisc.org/bimsteel)

- Product Information
  - Assembly
  - Main Piece
  - Accessory
- Connection
  - Weld
  - Bolt assembly
- Features
  - Bolt hole
  - Slotted hole
  - Cope
  - Opening
  - Skewed end
- Reused Categories
  - Quantity information
  - Surface treatment
  - Scheduling information
  - Status information
  - Drawing number
  - Version information
  - Tolerance for layout
  - Piece Identification

- Material

2.2.3 Exchanges in the American Concrete Institute MVD

The following exchanges were defined and approved by the ACI-131 committee at the IDM process model level of definition

EM1: Architect's mass structural model

Phase	Design Development, Construction Documentation
Disciplines	Sender: Architecture Receiver(s): Structural Engineer
Description	Provides the structural engineer with base layout to determine structural design. The structural engineer may have previously reviewed the project in earlier phases. Includes major structural concrete elements, major load placements, elevators and stair shafts concrete walls, and foundations. This exchange is iterated until all reinforced concrete aspects are identified and resolved when the model is exported as the architect's contract model.

EM2: Formwork finish & detail geometry

Phase	Design Development
Disciplines	Sender: Architecture Receiver(s): Concrete Contractor, Concrete Formwork Contractor, Finish Contractor
Description	Identify formwork requirements for CIP work including for concrete finishes. Associated finish specification a materials and procedures are available

EM3: Site plan & foundation layout

Phase	Design Development
Disciplines	Sender: Civil Engineer Receiver(s): Structural Engineer, General Contractor, Concrete Contractor
Description	Site plan with general layout of complete facility with concrete improvements and a foundation functional model.

EM4: Mechanical system model (merged)

Phase	Construction Documentation
Disciplines	Sender: Mechanical Engineer Receiver(s): Structural Engineer, Concrete Contractor, Reinforcing Detailer, Reinforcing Fabricator
Description	Provides placement of major mechanical system components sufficient to define connections, pass-throughs and other aspects requiring spatial coordination with mechanical system. Also identifies insulation needs and areas where it is needed.

Defines connection and other embeds, pads and curbs needed for mechanical equipment

EM5: Architect's contract model

Phase Construction Documentation

Disciplines Sender: Architecture

Receiver(s): Structural Engineer, General Contractor, Mech. Engineer

Description Provides a variety of users with concrete layout, as iterated and approved by the structural engineer and serves as a construction document model. Includes all structural concrete elements, load placements, elevators and stair shafts concrete walls, and foundations identified in construction documents.

EM6: Structural design model

Phase Construction Documentation

Disciplines Sender: Structural Engineer

Receiver(s): General Contractor, Concrete Contractor, Site Contractor, Reinforcing Detailer

Description Provides report of the detailed structural analysis to determine steel reinforcing sections, lap standard details, and special connections. Optionally provides an early mill order for reinforcing and identifies early shoring needs.

EM7: Blockout & Insulation placement

Phase Construction Documentation, Concrete Placement & Resource

Disciplines Sender: Mechanical Engineering

Receiver(s): Concrete Contractor, General Contractor

Description Identifies placement of blockouts for pass-through in concrete placement. Also identifies where insulation is to be placed over or within concrete for thermal or vibration insulation purposes.

EM8: Reinforcing & tendon review model

Phase Construction Documentation

Disciplines Sender: Reinforcing Detailer

Receiver(s): Reinforcing Fabricator, Reinforcing Contractor, Concrete Contractor

Description Provides reinforcement layout to all reinforcing disciplines with consideration of structural requirements and concrete placement.

EM9: Detailed reinforcing & tendon integrated layout (merged)

Phase Concrete Resource & Placement Planning

Disciplines Sender: Rebar Detailer

Receiver(s): Structural Engineer, Concrete Contractor, Reinforcing Contractor, Reinforcing Fabricator, Reinforcement Distributor

Description Integrates placement and reinforcement and tendon layout with both integrated structure and pour sequence. (tendons may be a separate model)

EM10: Structural embeds & plates

Phase Concrete Resource & placement planning

Disciplines Sender: Reinforcing Fabricator
Receiver(s): Structural Engineer

Description Identifies all plates, reinforcing, and embeds for all concrete pieces. Also to identify special formwork considerations such as decking for placement and connections. Reviewed by the structural engineer. Reinforcing fabricator work may be done by steel fabricator.

EM11: Formwork piece model

Phase Construction Documentation

Disciplines Sender: Formwork Contractor
Receiver(s): Concrete Contractor, General Contractor

Description Identifies prefabricated or fabricated formwork pieces, a re-use schedule, associated finish specification and materials.

EM12: Construction coordination model

Phase Concrete Placement & Resource Planning

Disciplines Sender: General Contractor
Receiver(s): Site Contractor, Mechanical Engineer, Concrete Contractor, Formwork Contractor, Reinforcing Contractor, Structural Engineer

Description Coordinates CIP concrete with all other building systems for constructability and clash resolution; takes place multiple times throughout the project process; relies on concrete element objects.

EM13: Site planning model

Phase Concrete Placement& Resource Planning

Disciplines Sender: Site Contractor
Receiver(s): Civil Engineer, General Contractor, Concrete Contractor

Description Coordinates site development resources, for delivery of concrete, storage areas for rebar, formwork, other concrete related resources, as reviewed and coordinated with other subcontractors.

EM. 14: Detailed concrete model

Phase Concrete Resource & Placement Planning

Disciplines Sender: Reinforcing Contractor
Receiver(s): Reinforcing Contractor, Finish Contractor, Reinforcing Detailer, Formwork Contractor, General Contractor

Description Provides reinforcing contractor detail layout, with all members defined and rebar placed. Connections to non-concrete elements: wall systems vertical circulation, mechanical equipment are defined. Used for structural review, finish contractor coordination, schedule coordination.

EM15: Reinforcement placement sequence

Phase Concrete Resource & Placement Planning

Disciplines Sender: Reinforcing Detailer

Receiver(s): Formwork Contractor, Reinforcing Fabricator, Reinforcing Contractor

Description Coordinates reinforcement and tendon placement with placement sequence and schedule.

EM16: Formwork placement model

Phase Concrete Placement & Resource Planning

Disciplines Sender: Concrete Formwork Contractor

Receiver(s): Finish Contractor, Concrete Contractor, General Contractor

Description Defines formwork placement plan; which areas use movable formwork; which require custom work and metal decking, which need form inserts for patterning; also includes formwork and shoring placement planning and scheduling.

EM17: Finish work package model

Phase Concrete Placement & Resource Planning

Disciplines Sender: Finish Contractor

Receiver(s): Concrete Contractor, General Contractor

Description Defines the finishing plan based on the concrete placement and curing plan and concrete pour geometry.

EM18: Final structural design model

Phase Concrete Placement & Resource Planning

Disciplines Sender: Structural Engineer

Receiver(s): General Contractor

Description Applies the changes in the structural design based on the feedback from the general contractor and subcontractors regarding constructability and other issues and to provide the complete and final structural design.

EM19: Site excavation as-built

Phase Concrete Execution

Disciplines Sender: Site Contractor

Receiver(s): General Contractor

Description Purpose: document final site modifications made for concrete work, as carried out and coordination with all reinforced concrete BIM roles: for placement, queuing, access points, temporary storage. Also, document all site condition details, for landscaping, walk concrete paving and other later works.

EM20: Construction reference schedule

Phase Concrete Placement & Resource Planning

Disciplines Sender: General Contractor

Receiver(s): Concrete Contractor, Finish Contractor, Structural Engineer, Reinforcing Contractor, Formwork Contractor, Site Contractor

Description Coordinates layout of all systems for clashes and coordinate schedule of installation, especially with formwork and finishing tasks; optionally using a 4D configurator, also used to verify coordination with mechanical systems and architectural intent.

EM21: Formwork as placed model

Phase Concrete Execution

Disciplines Sender: Formwork Contractor

Receiver(s): General Contractor, Concrete Contractor, Reinforcing Contractor, Reinforcing Fabricator

Description Fully coordinates formwork and shoring schedule with general contractor.

EM22: Actual placement submittals

Phase Concrete Execution

Disciplines Sender: Concrete Contractor

Receiver(s): General Contractor

Description Records the actual pour breaks vs. those planned, for archival documentation and planning.

EM23: Reinforcement as-built

Phase Erection Phase

Disciplines Sender: Reinforcing Contractor

Receiver(s): Concrete Contractor, General Contractor

Description Documents all changes to the rebar, post-tensioning specification, and all placement sequence adjustments due to installation and tensioning operations to report changes to testing agency.

EM24: Client as-built model

Phase Erection Phase

Disciplines Sender: General contractor

Receiver(s): Owner/client

Description Hand over as-built model of project to client for use in facility management, operations and maintenance, and for later remodeling.

2.3 State DOT Standards

As a check on the FHWA BrIM Report 2013's process map and the industry process models, high-level classes of exchanges currently used in DOT agencies were identified. The exchanges listed are by no means comprehensive; rather, they are enumerated according to published documents at DOT agencies. They reflect information exchanged outside of DOT agencies, and do not reflect some of the more specific exchanges that may happen within a DOT agency. Ultimately, 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. These include the following:

1. Requirements Model
2. Survey Model
3. Structural Model
4. Documentation Template
5. Construction Contract Model
6. Bid Information Model
7. Fabrication Model
8. Construction Status Model
9. Inspection Model

The full support for the delivery of the information listed above has been taken as the priority target exchanges to be supported in this project. Some of these are well addressed by IFC. But in the same way that bridge engineering codes are different in the aggregate from building codes, the specific requirements needed for bridges require careful reviews with those for buildings. It is also important to note that while there is a history of more than ten years of effort towards full building model automation, mainstream successful implementation is still a future goal.

With this recognition, one of these contract exchanges has been elaborated in detail herein, 6 Construction Contract Model. Volume III of this report describes the modeling of components in detail taken from the actual plans for two example bridges. Each description of these contract exchanges below has a section entitled "Preliminary Mapping to Process Models" that identifies which previous information exchanges these contract exchanges can be mapped to.

This effort will focus on identifying various exchanges and describing general information to be exchanged, and will go into detail on one of the exchanges – arguably the one most recognizable in industry and also the most complex – issuing construction plans/specifications at the conclusion of the design phase. This exchange was recommended for several reasons:

- Transportation agencies have the ability to create information in this format, or require such a format from engineering firms.
- Contractors bidding a job have incentive to use this information.
- Because of its role, this information is usually well documented and usually complete providing a good example for early implementation'

Initially, such digital formats may be provided as "informational" until agencies and contractors become comfortable with the data formats and they have been thoroughly tested and validated. Later, such formats will likely become legally binding.

It should be anticipated that there are likely additional costs and risks incurred upon initially switching to such formats to support automation. While automation of information delivery may reduce opportunities for human error on a per-project basis, it also increases opportunities for human error made system-wide. Software vendors make errors, as do authors of specifications. Achieving lower costs associated with digital delivery formats may take multiple iterations of specifications over a large number of projects. Fortunately, for the more common bridges there is substantially less variation and substantially fewer domain participants, compared to the building industry. Careful review and full pursuit of standards setting practices is essential before implementation and deployment.

2.3.1 Requirements Model

In producing design documents, the engineer must follow guidelines and templates specified by the issuing authority, which in the U.S. is typically a State DOT agency. Such templates may also be digitally defined within a separate exchange – see 5 Documentation Template.

A bridge is identified using parameters consistent with the *National Bridge Inventory*, and is located according to geo-location standards defined by the *Open Geospatial Consortium*.

Phase	Initiation
Disciplines	Sender: Public Entity Receiver(s): Bridge Engineer
Description	This exchange describes the location and requirements of a proposed bridge, for which an engineer may produce detailed design documents.
Major Information Items	Project identifying information; geographic location and right-of-way boundaries; route identifying information; use requirements such as number of lanes in each direction, and minimum vertical clearance; structural requirements such as load capacity, and ability to withstand seismic events; and construction requirements such as allowable closures and timeframes for affected routes

The contents of this exchange are similar to the Bridge Concept Model and the Bridge Engineering Concept Model. The Bridge Concept Model deals more with requirements for the goals and objectives of the project as a whole. The Bridge Engineering Concept Model deals more with requirements from the environment (location, environmental issues, and etc.). The contents of the IPP as described in the Bridge Concept Model and Bridge Engineering Concept Model also conforms to the descriptions of the Requirements Model.

2.3.2 Survey Model

The Survey Model contains geographic information for the project site. This exchange is not identified in the process map of the FHWA BrIM Report 2013. The new process map needs to include this exchange.

Phase Initiation

Disciplines Sender: Surveyor

Receiver(s): Transportation Engineer

Description This exchange captures terrain elevations and soil conditions, which may be produced by a surveyor and delivered to an engineer. Such an exchange may be formally contracted between companies or performed in-house.

Major Information Items Project identifying information; geographic location and surveying boundaries; and soil layers at drill points, with classification and associated structural properties

2.3.3 Utility Model

The Utility Model addresses the information related to utilities on the project site. This exchange is not identified in the process map of the FHWA BrIM Report 2013. The new process map needs to include this exchange.

Phase Initiation

Disciplines Sender: Utility Manager

Receiver(s): Transportation Engineer

Description 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 Information Items Project identifying information; geographic location and utility survey boundaries; distribution systems, classifications, and authorities; and pipes or cables assigned to each system, with locations, axis paths, and profiles

2.3.4 Structural Model

The Structural Model in the FHWA BrIM Report 2013 is further categorized by the phase of structural design activities ranging from conceptual structure model to retrofit model.

Phase Initiation

Disciplines Sender: Structural Engineer

Receiver(s): Public Entity

Description This exchange provides a structural analysis model for a bridge design. It may be generated as part of the design and review process for original construction, or may be generated later in evaluating or maintaining existing bridges.

Major Information Items Project identifying information; bridge identifying information; physical model of bridge elements and connections (see Plan Exchange); bridge systems organizing bridge elements (e.g. deck, superstructure, substructure); structural analysis models corresponding to bridge systems; structural members (curves, surfaces, volumes), shape properties, material properties; structural connections and boundary conditions; structural loads (point, curve, or surface-based forces and moments); structural load cases and combinations; structural design methodology applied, load factors, resistance factors, finite element intervals; structural results (deflections and maximum stresses in each member); and physical elements selected and placed according to load requirements

2.3.5 Documentation Template

The Documentation Template describes tables of information to be presented consisting of one or more columns in a specified order, where each column indicates units and the precise query into the bridge model data.

From a pure information modeling perspective, formatting may be considered superfluous, it is foreseen as critical for parties transitioning between tabular formats in use today and all-digital formats. It defines standardized conventions for transforming model data into familiar formats. As conventions may vary with each agency, such translation is captured in an exchange, which allows for standardized presentation of bridge information to evolve independently of the underlying data.

Template information for bridge alignment may have relative positioning on an alignment curve (stations and offsets), and conditions that apply at particular offsets or between two offsets. Examples of such information may be found at the following links:

http://www.iowadot.gov/design/tnt/PDFsandWebFiles/CurrentBook/eEntireBook.pdf

Phase N/A

Disciplines Sender: N/A, the format is prepared by public entities (i.e. state DOT agency)
Receiver(s): N/A

Description This exchange describes required information content and tabular data formats to be provided by the bridge engineer upon developing plans and specifications.

Major Information Items Varies by the types of the scope

2.3.6 Construction Contract Model

The Construction Contract Model is the major information exchange in design-bid-build process between the public entity and the contractor. The major information items of this exchange are derived from what traditionally is included in the drawing set of the sample ‘workhorse’ bridge analyzed. The major information items must reflect design results, and may or may not also include design parameters such as formulas and patterns used to arrive at the design results. This exchange is identified as the contract model generated as an output of the Construction Document Preparation activity by the Structural Engineering discipline in the FHWA BrIM Report 2013.

Phase	Bidding and Letting
Disciplines	Sender: Public Entity (from Bridge Engineer) Receiver(s): Contractor
Description	This exchange captures bridge plan details with sufficient information for a contractor to submit a bid and proceed with construction.
Major Information Items	Project identifying information; bridge identifying information; alignment curves separated into horizontal and vertical curves; element placement relative to alignment curves; element shape parameters (paths, boundaries, repetition patterns); element material parameters (cross-sections, materials, properties); element 3D geometric shape; element 3D presentation of colors and textures (for indicating architectural details); element 2D presentation for fill styles and line styles (for deriving plan renderings, lane striping); composition of elements and voids such as rebar, conduit, drains; connections between elements, realizing elements and properties; system connectivity and flow for distribution elements including drainage; bridge elements for abutments, piers, framing, decking; building elements for beams, columns, members, plates; structural elements for footings, piles, reinforcing; plumbing elements for pipes, valves, waste terminals; electrical elements for conduit, cables, light fixtures; geographic elements for land terrain and features; soil boring locations with material layer depths and classification; structural load cases indicating designed loads on elements

In addition to originating model information, derived information such as quantities and structural results are also included in this exchange, as this information is also included in the originating plans. While such information could be generated by software (in the same way that it could by a human based on the plans), it is included according to the same rationale – convenience, verification, or other requirements.

- Quantities applied to elements for count, length, area, volume, gross weight, and net weight
- Quantity schedule with assigned elements, units, and totals
- Structural result cases indicating governing stresses on elements

In addition to originating model information and derived summary information, to assist users in the transition to digital models, it may also be useful to include the following 2D plan information such that the same format as found in plans may be derived from the underlying information.

- Request for bid, indicating bid submission date and qualification requirements
- Bid alternates and combinations, with assigned systems and elements
- Schedule constraints, where bonuses or penalties may be applied according to completion dates
- Index of plan sheets with layout information mapping page contents to the underlying model

The structure of the bid may be defined to reflect varying bid scenarios such as a fixed contract amount, alternates for separate work that may be accepted or rejected independently, combinations of alternates where discounts may be achieved, line items with unit costs provided where the actual quantity may vary within a defined range, line items with quantities provided where the unit costs may vary according to market conditions (e.g. asphalt pricing index), or a combination of all.

Plan information representative of this exchange may be found at the following links for each state DOT agency:

Table 1. Directory of State Departments of Transportation

State	Directory	Example
Alabama	http://alletting.dot.state.al.us/WEBPROPS/2015/20150130/NTCJan3015.htm	http://alletting.dot.state.al.us/Docs/Standard_Drawings/2014%20English/STDUS14_1400.pdf
Alaska	http://www.dot.state.ak.us/apps/contracts?ACTION=BIDCAL&REGION_CODE=ALL	http://www.dot.state.ak.us/procurement/prelim/62638/PRELIMINARYPLANS.pdf
Arizona	http://azdot.gov/business/ContractsandSpecifications/CurrentAdvertisements	http://azdot.gov/business/engineering-and-construction/bridge/structure-detail-drawings
Arkansas	http://www.arkansashighways.com/ProgCon/General/Next_Three_Lettings.pdf	http://www.arkansashighways.com/bridge_division/list_standard_drawings.aspx
California	http://www.dot.ca.gov/hq/esc/oe/weekly_ads/all_adv_projects.php	http://www.dot.ca.gov/hq/esc/oe/project_plans/HTM/stdplns-US-customary-units-new10.htm#bridge
Colorado	https://www.codot.gov/business/bidding/future-bidding-opportunities	https://www.codot.gov/library/bridge/design-standards/structural-worksheets-pdfs
Connecticut	https://www.bidx.com/ct/lettings	N/A
Delaware	http://bids.delaware.gov/	http://www.deldot.gov/information/business/drc/cadd.shtml
District Of	http://app.ocp.dc.gov/RUI/informat	N/A

State	Directory	Example
Columbia	ion/scf/indexopps33.asp	
Florida	http://www.dot.state.fl.us/cc-admin/Lettings/Letting_Project_Info.shtm	N/A
Georgia	https://www.bidx.com/ga/lettings	http://standarddetails.dot.ga.gov/stds_dtls/estds.jsp?Preview=no
Hawaii	http://hidot.hawaii.gov/administration/con/	N/A
Idaho	http://qap.questcdn.com/qap/projects/prj_browse/ipp_prj_browse.html?group=1950787&provider=1950787	http://itd.idaho.gov/bridge/cadd/cadddrawings.htm
Illinois	http://apps.dot.illinois.gov/ChangeOrder/ListStatus.aspx	http://www.idot.illinois.gov/doing-business/procurements/engineering-architectural-professional-services/Consultants-Resources/bridges-and-structures-cadd-downloads-and-guidelines
Indiana	https://ecm.indot.in.gov/bidviewer/default.aspx	http://www.in.gov/dot/div/contracts/standards/drawings/sep14/e/sep700.htm
Iowa	http://www.iowadot.gov/contracts/lettings.html	http://www.iowadot.gov/bridge/standards/english/j24-06.pdf
Kansas	http://ksdot1.ksdot.org/burconsmain/contracts/proposal.asp	N/A
Louisiana	https://www.bidx.com/la/lettings	N/A
Maine	http://www.maine.gov/mdot/contractors/#projecttbl	http://www.maine.gov/mdot/contractor-consultant-information/ss_standard_details_division_500_structures.pdf
Maryland	http://sha.md.gov/pages/contractadschedule.aspx	http://apps.roads.maryland.gov/BusinessWithSHA/bizStdsSpecs/obd/BridgeStandards/index.asp
Massachusetts	https://www.bidx.com/ma/letting?lettingid=20150203	http://www.massdot.state.ma.us/highway/DoingBusinessWithUs/ManualsPublicationsForms/LRFDBridgeManual2013Edition/PartIIandPartIIIStandardDetails/PartIIConventionalConstruction.aspx
Michigan	http://mdotcf.state.mi.us/public/bids/index.cfm?letdate=2015-03-06	http://mdotcf.state.mi.us/public/design/files/englishstandardplans/files/standard_plan_book.pdf
Minnesota	http://bidlet.dot.state.mn.us/advertisement.aspx	http://standardplans.dot.state.mn.us/StdPlan.aspx
		http://www.dot.state.mn.us/bridge/culverts.html

State	Directory	Example
Mississippi	http://sp.mdot.ms.gov/Contract%20Administration/BidSystems/Pages/letting%20calendar.aspx	http://sp.gomdot.com/Roadway%20Design/StandardDrawings/1998-10-01/Bridge_Culvert_Standards_1997.pdf
Missouri	http://www.modot.mo.gov/eBidLettingPublicWeb/viewStream.do?documentType=schedule&key=0	http://www.modot.org/business/consultant_resources/bridgestandards.htm
Montana	http://www.mdt.mt.gov/other/contract/external/reports/future_projects_schedule.pdf	http://www.mdt.mt.gov/business/contracting/bridge/cad_files.shtml
Nebraska	http://www.transportation.nebraska.gov/letting/lettings.htm	http://www.transportation.nebraska.gov/design/bridge/downloads-manuals.html
Nevada	http://www.nevadadot.com/Doing_Business/Contractors/BidLetting.aspx	http://www.nevadadot.com/uploadedFiles/NDOT/About_NDOT/NDOT_Divisions/Engineering/Specifications/english_2010sm.pdf
New Hampshire	http://www.nh.gov/dot/org/administration/finance/bids/invitations/index.htm	http://www.nh.gov/dot/org/projectdevelopment/bridgedesign/sampleplans/documents/Bartlett13043.pdf
New Jersey	http://www.state.nj.us/transportation/business/procurement/ConstrServ/bidopen15.shtm	http://www.state.nj.us/transportation/eng/CADD/v8/index.shtml#SamplePlansEnglish
New Mexico	https://www.bidx.com/nm/lettings	http://dot.state.nm.us/en/Standards.html
New York State	https://www.dot.ny.gov/doing-business/opportunities/const-highway	https://www.dot.ny.gov/main/business-center/engineering/cadd-info/drawings/bridge-detail-sheets-usc
North Carolina	https://connect.ncdot.gov/letting/Pages/Bridge.aspx	https://connect.ncdot.gov/resources/Structures/Pages/Structure-Standards.aspx
North Dakota	http://www.dot.nd.gov/dotnet/eplans/default.aspx	http://www.dot.nd.gov/divisions/design/docs/standards/D255-01.pdf
Ohio	https://www.bidx.com/oh/lettings	http://www.dot.state.oh.us/Divisions/Engineering/Structures/standard/Bridges/Pages/StandardBridgeDrawings.aspx
Oklahoma	http://www.okladot.state.ok.us/cabol/a2015/cabol_201502-feb.pdf	http://www.okladot.state.ok.us/bridge/standards.htm
Oregon	http://www.oregon.gov/ODOT/CS/CONSTRUCTION/Pages/Letting_Schedules.aspx	http://www.oregon.gov/ODOT/HWY/ENGSERVICES/pages/bridge_drawings.aspx#bridge_300___concrete_beams
Pennsylvania	ftp://ftp.dot.state.pa.us/Bureau_of_Project_Delivery/PSSCS/ECMS_Planned_6-Month_Letting_Reports/detailedletschdl.pdf	http://www.dot.state.pa.us/Internet/BQADStandards.nsf/bd-archives?readform
Rhode Island	http://www.dot.ri.gov/contracting/bids/index.php	http://www.dot.ri.gov/documents/doingbusiness/RIDOT_Bridge_Standards.pdf

State	Directory	Example
South Carolina	http://www.scdot.org/doing/doingPDFs/tentativeLetting/Bridge.pdf	http://www.scdot.org/doing/structural_Drawings.aspx
South Dakota	http://apps.sd.gov/HC65BidLetting/ebslettings1.aspx	http://sddot.com/business/design/files/Default.aspx#bridge
Tennessee	http://www.tdot.state.tn.us/construction/Bid_Lettings.htm	http://www.tdot.state.tn.us/Chief_Engineer/engr_library/structures/stdenglishdrawings.htm
Texas	http://www.dot.state.tx.us/business/obt.htm	https://www.dot.state.tx.us/insdtdot/orgchart/cmd/cserve/standard/bridge-e.htm
Utah	http://eprpw.dot.utah.gov/applets-production/ProjectExplorer/ProjectExplorer.asp	N/A
Vermont	http://vtranscontracts.vermont.gov/construction-contracting/advertised-projects	N/A
Virginia	http://cabb.virginiadot.org/	N/A
Washington	https://www.bidx.com/wa/lettings	http://www.wsdot.wa.gov/Bridge/Structures/StandardDrawings.htm#Expansion
West Virginia	http://www.transportation.wv.gov/highways/contractadmin/Lettings/Pages/default.aspx	N/A
Wisconsin	http://www.dot.wisconsin.gov/business/docs/mastercontract.pdf	http://on.dot.wi.gov/dtid_bos/extranet/structures/LRFD/standards.htm
Wyoming	https://ipd.exevision.com/wydot/ws/	N/A

2.3.7 Bid Information Model

The Bid Information Model entails the itemized cost of the bidding for the project, which is represented as a list of costs for the bidding project without any 3D modeling information of the bridge. This exchange is a non-model based exchange and is represented as Bid Information in the FHWA BrIM Report 2013.

Phase Bidding and Letting

Disciplines Sender: Contractor
Receiver(s): Public Entity

Description This exchange comprises a bid submitted by a contractor to perform construction work. It identifies the specific project and plan and provides requested rates and quantities.

Major Information Items Project identifying information; bridge identifying information; and cost schedule with unit prices, quantities, and totals calculated.

2.3.8 Fabrication Model

This exchange would be a place holder for a general fabrication exchange, since each domain may have their own requirements. It is recommended that each domain have their own fabrication exchange. Fabrication exchanges that have been identified by the Precast Concrete Institute (PCI), American Institute of Steel Construction (AISC), and the American Concrete Institute (ACI) were described in 2.2 Industry Exchanges.

2.3.9 Construction Status Model

Construction Status Model provides information used for erection including erection calculation, procedure, method, and crane types. This exchange is a non-model based exchange and modeled as the Execution Status Report in the FHWA BrIM Report 2013.

Phase	Construction
Disciplines	Sender: Contractor Receiver(s): Public Entity
Description	Identifies line items as submitted within the bid, applies values to each item, and may optionally reference specific components within the bridge model to assist the reviewer in verifying task completion.
Major Information Items	Project identifying information; bridge identifying information; cost schedule with assigned tasks; tasks with assigned elements and percentages complete; and modifications to the design model to reflect changes made during the construction process

2.3.10 Inspection Model

The Inspection Model is the same exchange as either Structural Deterioration Model or Prior Inspection Model as identified in the FHWA BrIM Report 2013.

Phase	Construction
Disciplines	Sender: Inspector Receiver(s): Bridge Engineer
Description	This model contains the condition of a bridge at a particular point in time, or multiple points in time.
Major Information Items	Project identifying information; bridge identifying information; performance history identifying information (date recorded, user); performance of bridge systems (deck, superstructure, substructure); and performance of bridge elements

3 Development of a New Integrated Process Map

Based on the review of exchanges defined in the FHWA BrIM Report 2013, industry exchanges and DOT agency exchanges, the project team concluded that the exchanges listed below are those needed during the life cycle of a Design-Bid-Build bridge project.

Table 2. List of Exchanges[3]

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

[3] FHWA : Exchanges from the FHWA BrIM Report 2013, PCI : Exchanges from the PCI MVD, AISC : Exchanges from the AISC MVD, ACI : Exchanges from the ACI MVD, DOT : DOT agency exchanges

The resulting exchange set is based on exchange analyses that have been developed with input from bridge engineers and also separately with steel, concrete and precast fabricators. The functional details of these exchanges have not been reviewed yet by the information receivers of those exchanges. While the new integrated exchange set has had some review through workshops and report reviews in this project, it will still need validation from industry to accept or further modify the process map.

The intents of the exchanges need to be defined in more detail for future implementation. Additional work is needed to develop the new exchanges; an exercise that relies heavily on industry input. Volume II and Volume III provide an example of implementation applied to the Construction Contract Model. An initial integration of these exchanges is shown in Figure 2 and the process map is further discussed hereafter.

3.1 Business Process Modeling Notation (BPMN)

The process map in this Report is defined using Business Process Modeling Notation (BPMN) (Object Management Group (OMG)). BPMN is a graphical notation that depicts the steps in a business process. BPMN depicts the end to end flow of a business process. The notation has been specifically designed to coordinate the sequence of processes and the messages that flow between different process participants in a related set of activities. (Object Management Group (OMG), 2013)

Flow objects, data, connecting objects, swimlanes, and artifacts are the five basic element types in BPMN. Flow objects define the behavior of business process and are the main graphical elements depicting events, activities and gateways. Connecting elements connect flow objects for sequence flow, message flow, association or data association. Swimlanes bound the modeling elements into pools or lane. Artifacts represent additional information about the process by group or text annotation. (Object Management Group (OMG), 2013)

A Pool in a BPMN diagram is the graphical representation of Actors who sequentially executes the activities enclosed in the Pool. The process map groups actors as Pools, which is a practice area or specialty of the actors that carry out the activities and procedures that occur during the lifecycle of the process. The process map categorizes actors throughout the life cycle of a bridge into ten types.

A Process is a sequence of Activities in a discipline with the objective of carrying out work. A Process is depicted as a graph of Activities, Events and Sequence Flows that defines execution semantics. The process map describes Activities in high level in order to focus on collecting meaningful input and output instead of describing Activities in details. The process map is a Collaboration model, which contains a collection of disciplines shown as Pools. Their interactions are shown in Message Flows that connect Data Objects across disciplines.

3.2 BPMN Notation

Following are descriptions of BPMN notation types used in the process map.

Event

Something that happens during the course of a process.

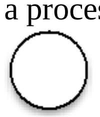

Figure 9. BPMN notation for Event

Task

Activity is a generic term for work that a company performs in a process. A Task is an atomic Activity that is included within a Process.

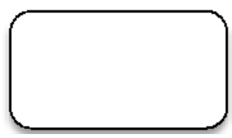

Figure 10. BPMN notation for Task

Sequence Flow

Sequence flow shows the order that activities will performed in process.

Figure 11. BPMN notation for Sequence Flow

Message Flow

Message flow shows the flow of messages between two participants.

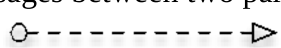

Figure 12. BPMN notation for Message Flow

Association

Association links information and artifacts with BPMN graphical elements. Text Annotations and other artifacts can be associated. An arrowhead can indicate a direction of flow if necessary.

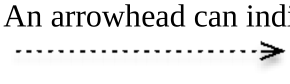

Figure 13. BPMN notation for Association

Pool

Pool represents a participant in a collaboration. It can also act as a swimlane and a graphical container for partitioning a set of activities from other pools.

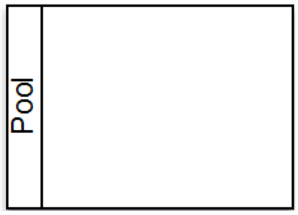

Figure 14. BPMN notation for Pool

Lane

Lane is a sub-partition within a process, sometimes in a pool. Lanes organize and categorize activities.

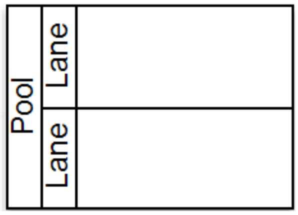

Figure 15. BPMN notation for Lane

Data Object

Data object provides information about what activities require to be performed and / or what they produce.

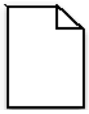

Figure 16. BPMN notation for Data Object

Message

Message depicts the contents of a communication between two participants. Returning message (non initiating message) uses shaded envelope while the first (initiating message) message uses non shaded envelope.

Figure 17. BPMN notation for Message

Group

Groups graphical elements within the same category.

Figure 18. BPMN notation for Group

3.3 Process Map

The process map has been updated from the FHWA BrIM Report 2013, which used Pool for activity name while the updated version uses the actor's name to conform to the BPMN specification. The process map has twelve actors grouped into nine phases of a bridge lifecycle as depicted in the following two views of the process map enlarged for ease of review.

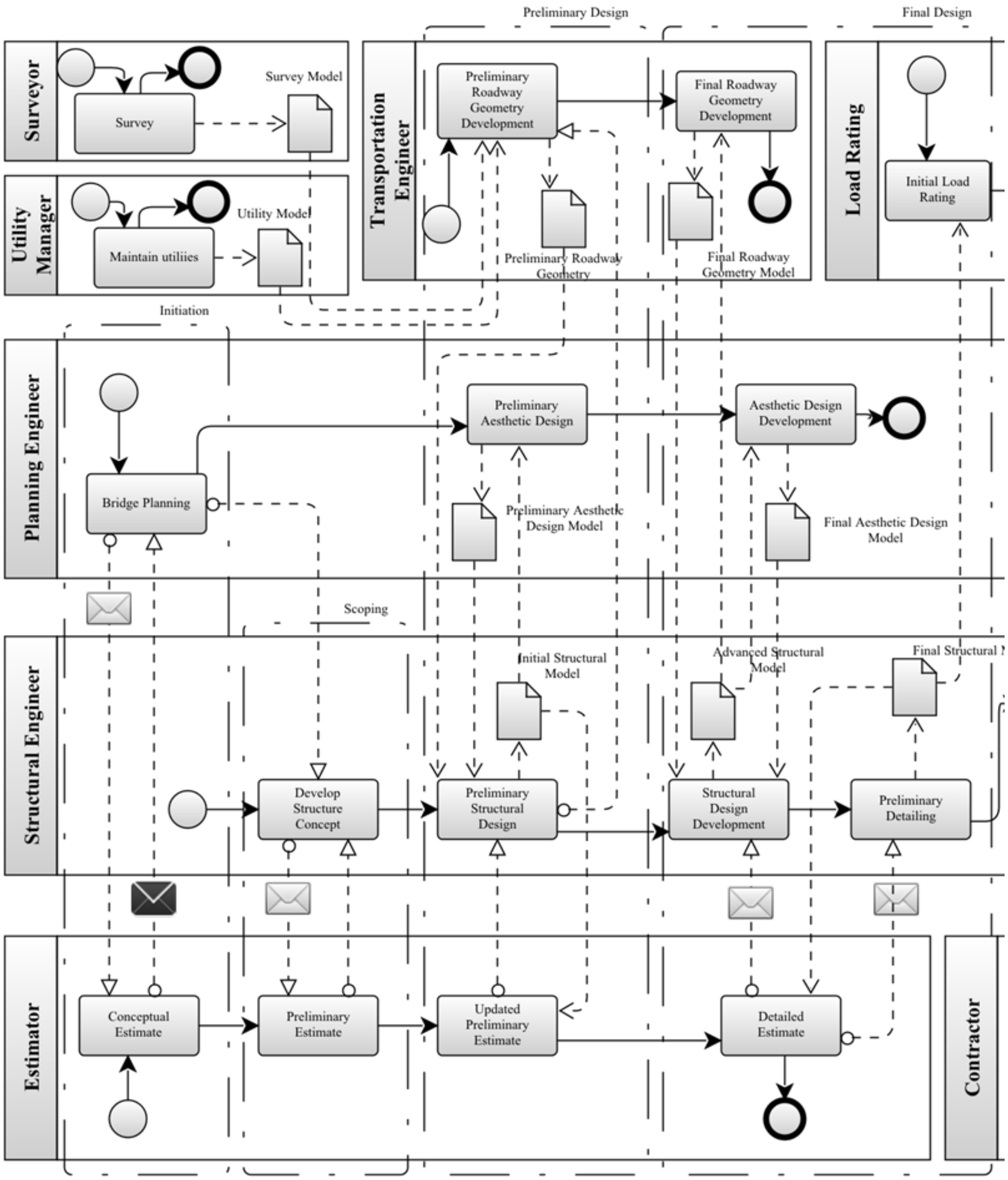

Figure 19. Bridge Lifecycle Management Process map (initiation to final design)

The twelve actors include 1) Transportation engineer, 2) Planning engineer, 3) Structural engineer, 4) Estimator (owner), 5) Contractor, 6) Fabricator, 7) Load rating engineer, 8)

Inspector, 9) Routing and permit engineer, 10) Asset manager, 11Surveyor, and 12) Utility manager. Changes to the Pools were made as follows:

- Construction engineering pool and construction planning pool are merged into Contractor's pool
- Detailing pool is removed
- Preliminary detailing design task is moved to structural engineering pool and renamed to preliminary detailing
- Detailing design development is moved to contractor's pool and renamed to construction detail model
- Modification / integration of final detailing documents is merged into fabrication task in fabricator pool

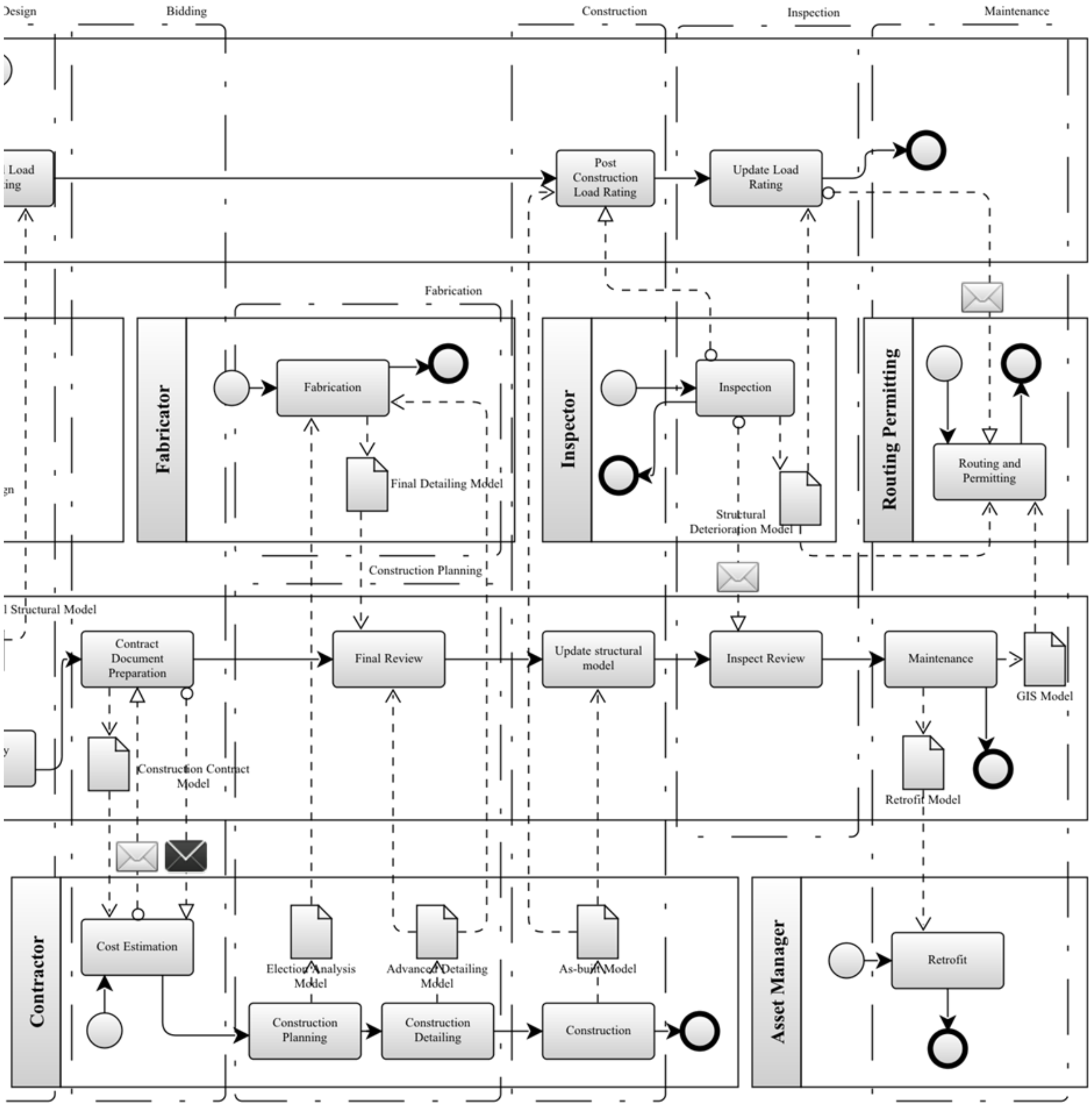

Figure 20. Bridge Lifecycle Management Process map (bidding to maintenance)

Phases are 1) Initiation, 2) Scoping, 3) Preliminary Design, 4) Final Design, 5) Bidding, 6) Construction Planning, 7) Construction, 8) Inspection, and 9) Maintenance. Tasks of Actors belong to one of these phases. The vertical pool in the FHWA BrIM Report 2013 process map is modified to Group symbol in order to conform to the BPMN specification.

Actors are represented with a BPMN Pool that runs horizontally. Tasks of Actors in the Pool are connected with Sequence Flows. A Start Event is represented in a circle, and an End Event is represented in a circle with thicker line. A Task may produce a Data Object that indicates a model based exchange in the BrIM Process Map. A Data Object from a Task can be used in multiple tasks on other Pools. Message Flows with Messages indicate non-model based exchanges. Messages in black indicate they are responding to Messages in white. The phases use the Group artifact of BPMN for their notation.

Figure 19 shows processes for Initiation, Scoping, Preliminary Design and Final Design. Figure 20 shows processes for Bidding, Construction Planning, Construction, Inspection and Maintenance. The Pools can span through multiple Groups or a single Group depending on the existence of Actors' Tasks.

3.4 Actors and activities

Actors can have multiple activities in a process. An activity has specific inputs that are typically generated from other activities or from other data sources and it also has specific outputs used as inputs by other activities. Lists of Activities were adopted from the FHWA BrIM Report 2013 and modified to represent activities relevant to model based data exchanges. They involve three-dimensional shape representations of a bridge. Activities that only generate or consume non-model based exchanges are opted out to facilitate a concise representation of the process model. Descriptions in this section on the processes and activities are based on the descriptions from the FHWA BrIM Report 2013.

3.4.1 Planning Engineer

Bridge Planning

Planning engineer develops the initial bridge program to resolve transportation problems or needs. At the initiation stage, engineers describe a candidate project and how the project addresses the program goals.

Preliminary Aesthetic Design Development

Planning engineer produces the Preliminary Aesthetic Design Model that defines physical geometry. The design model can influence the appearance of the bridge structure and its surroundings when defining the structure's type, size and location. This may influence the bridge geometry, superstructure type and shape, substructure type and shape, appearance of appurtenances, etc.

The preliminary aesthetic design model is used as an input for the preliminary structural design activity. The preliminary aesthetic design can get feedback from and can be updated according to preliminary structural design.

Aesthetic Design Development

Planning engineer continues to develop aesthetic design from the preliminary design and generate the final aesthetic model. Structural engineer uses the model to enhance the structural model and produce the advanced structural model. When the advanced structural model requires revision, the engineers need to repeat the process. The final aesthetic model should have sufficient information for the later stages of the project.

3.4.2 Surveyor

Survey

Surveyor generates the information model of terrain elevations, soil conditions and soil layers at drill points, with classification and associated structural properties. This activity generates the utility model that can be used by bridge engineers. It is noted that the Surveyor may in fact need to be divided into other specialists such as Geotechnical and Hydraulic Engineers but is used to cover these for this iteration of the map. These specializations could be added in the future if deemed necessary.

3.4.3 Utility Manager

Maintain utility

Utility manager generates a utility information model including geographic location, utility survey boundaries, distribution systems, classifications, authorities and pipes or cables assigned to each system with locations, axis paths, and profiles locations. This activity generates the utility model that can be used by the bridge engineer.

3.4.4 Estimator (Owner)

Conceptual Estimation

Bridge owner uses the bridge concept model to prepare the conceptual cost estimate without benefit of detailed field investigations or project design details. Rules of thumb based on experience can be used (cost per mile, cost per square foot, etc.).

This activity uses input from the Bridge Planning activity and outputs cost estimation. Initial Project Proposal (IPP) template lists initial cost by project phases, duration of phase, funding source and obligation date. There is no model-based exchange associated with the conceptual estimation activity.

Preliminary Estimation

Bridge owner updates the conceptual cost estimate according to field investigations, major design elements identified and major quantities estimated. The estimate methods include Benefit-Cost (B/C) analysis and Life Cycle Cost analysis based on the bridge shoulder break methodology that uses a shoulder break square foot unit cost basis. The shoulder break methodology provides reasonable compensation for positioning abutments anywhere within the shoulder break length along the shoulder break slope line, when bridge particulars, such as abutment heights and locations, are not known. (Engineering Division - Office of Structures, 2015)

Updated Preliminary Estimate

Bridge owner updates the preliminary cost estimate according to the bridge structural model, which reflects preliminary design based on detailed field investigation and condition data collection done by the structural engineer.

Detailed Estimate

The detailed engineer's estimate which is done by bridge owners should be created based on the items necessary and quantities calculated for the work to be performed. The detailed cost estimate should be refined throughout detailed design. The estimate at the time of contract plans (model), specifications and estimate (PS&E) should reflect the anticipated cost of the project in sufficient detail to permit an effective review and comparison of the bid received.

3.4.5 Structural Engineer

Structural engineers address structural design and detailing including the structural conceptual design, assigned loads and clearances, load aggregations and combinations and general structural parameters. From the engineering parameters, the sizes and parameters are derived for fabrication.

Develop Structure Concept

Structural engineer considers and investigates various project issues, elements and initiatives which will have an effect on scope, cost, and schedule. At the end of the scoping stage, stakeholders will have a clear understanding of the problems and needs. They will establish consensus regarding the proper scope of the project and will make informed decisions.

Preliminary Structural Design

At the preliminary design stage, structural engineer collects detailed structure condition data, develops feasible alternatives based on the conceptual design, studies social, economic and environmental impacts, collects detailed structure condition data, and finally selects the most appropriate alternative to be advanced to final design.

Structural Design Development

Structural engineer reviews and completes the preliminary structural package, and then adds necessary detailing to the design alternative based on roadway geometry model and aesthetic design model.

Preliminary Detailing Design

Structural engineer modifies and details the design alternative, and finalizes the contract plans (model), specifications and cost estimate package.

Construction Documentation Preparation

Bridge owner collects and produces contract documentation on which various general contractors will in turn bid. The final contract package includes plans (model), specifications and cost estimate regarding transportation, structural design and sometimes landscaping.

Update structural model

Structural engineer modifies contract plans (model) and specifications based on the revisions provided by contractor to reflect changes in construction. As-built plans (model) are a reflection of the existing bridge condition.

Inspection Review

Structural engineer and bridge inspector reviews the as-built data and/or the previous bridge inspections. The inspector identifies areas where defects were found in previous inspections. This allows them to determine which defects previously identified have been repaired or have increased in size and severity.

Maintenance

Cyclical maintenance activities need to be performed by bridge owners to reduce the rate of deterioration of critical bridge elements. These activities are essential for a bridge to reach its maximum useful life and maintain its designed level of service. The activities include bridge cleaning, sealing cracks in the wearing surface, etc.

3.4.6 Transportation Engineer

Preliminary Bridge Geometry Development

Transportation engineer specifies the minimum requirements for bridge roadway, facility widths, and vertical under-clearances for the bridge project. This work is done primarily based on providing a level of geometric consistency between the bridge and the approach roadway and recognizing the highway functional classification and traffic that the bridge serves.

Final Bridge Geometry Development

Transportation engineer uses structural models from structural engineer to modify the preliminary highway geometry design. This revision is based on changes resulting from new information or review comments from the final structure design. At the end of this stage, the highway portion of the contract plans (model), specifications and cost estimate package will be created.

3.4.7 Contractor

Cost Estimate

After receiving the construction contract model, general contractor and subcontractors compile a complete "bid price" for submission by the closing date and time. Bid documents can be based on the quantities of materials, devices, and labor in the completed construction.

Construction Planning

Contractor plans and schedules construction work properly to minimize construction time and cost. Contractor prepares and submits a detailed erection procedure to bridge owner for each structure in the contract. The procedure shall be in conformance with the contract documents.

Construction Detailing

After the project is awarded, general contractor receives the contract (or invited subcontractors) develop bridge detailing calculations and drawings for fabrication, installation and erection.

Construction

Contractor and engineer-in-charge assigned by bridge owner monitor bridge construction to verify Quality Control and Quality Assurance.

General contractor and subcontractors execute bridge construction by following construction plans. Engineer-in-charge assigned by bridge owner is on site for quality assurance.

Contractor generates an as-built model according to the actual construction result.

3.4.8 Fabricator

Fabrication

Manufacturer schedules production process to minimize the production time and cost, by telling a production facility when to make, with which staff, and on which equipment.

Immediately after receiving comments on the preliminary final detailing model, fabricator shall address all changes into the final detailing model and submit them to bridge owner for final approval.

Manufacturer uses the final detailing model to control fabrication machine and produces bridge steel and/or concrete components in plants according to the final detailing model approved by bridge owner.

3.4.9 Load Rating Engineer

Initial Load Rating

Structural engineer makes initial load rating based on final contract plans and specifications before bridge is actually built. The initial load rating includes inventory and operating factors.

Post-construction Load Rating

Structural engineer updates the initial load rating based on the as- built bridge model after bridge construction is completed.

Structural engineer needs to make an updated load rating calculation whenever the capacity of the bridge changes due to the condition of the structure, impact on the bridge due to approach roadway or deck deterioration, or if the dead load of the bridge has been increased.

3.4.10 Inspector

Inspection

Bridge inspectors use a systematic method to observe the bridge and ensure that the entire bridge is inspected. The exact order of the inspection varies depending on the type of bridge being inspected. The bridge inspector documents their findings in the bridge inspection report.

3.4.11 Routing and Permitting Engineer

Routing and Permitting

Based on load rating data in the bridge inventory, transportation agencies permit and route oversize and overweight vehicles

3.4.12 Asset Manager

Bridge Programming / Retrofit / Rehabilitation

When the bridge is structurally deficient or functionally obsolete, bridge engineers plan a retrofit / rehabilitation / replacement project based on the bridge inspection report and load rating factors.

3.5 Exchanges

Descriptions of the exchanges in the process map are provided here.

Survey Model

Phase	Initiation
Creator	Surveyor

Users	Transportation Engineer
Purpose	This model 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 model 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, 3) vertical under clearances, 4) vertical profile of all roads, and 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	This 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
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	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	This 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	This model is 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	This model is for bridge detailing for the 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	This model provides 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	This model is used by structural engineers to make load rating calculation and by bridge owner to permit and route vehicles.
Major Elements	Bridge deterioration data including section loss, strand loss, and crack information
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

4 Summary

This volume of the *BrIM Modeling Standardization* Report summarizes the development of a new process map that captures all aspects of the bridge project development and asset management lifecycle – the Bridge Lifecycle Management Process Map. The process map integrates activities, actors and roles, general and detailed phasing of activities, that together identify, in a general way, the processes used by the industry to carry out its activities (for the most common bridge types). The process map identifies the major activities and how they are tied together through coordination supported by data exchanged between activities. The information flows that support the bridge design process were tested at the information requirements level to determine what elements need to be represented for bridge exchanges. Identifying the exchanges for which standardized documentation can be provided to support open data exchange between parties is critical to the BrIM standardization process.

The development builds upon the process map and exchanges identified by the FHWA BrIM Report 2013 as the basis for a new process map that expands on the previous effort. These efforts are augmented by adding analysis from the exchanges developed for the concrete and steel fabrication industry. Validation against the processes identified in state Department of Transportation documents is also conducted to ensure that the process is supportive of published requirements for which contracts between parties are being drawn. These models and exchanges are all brought together in a new bridge process map that is in line with the process definition procedures established for the U.S. National BIM Standard and following the buildingSMART Information Delivery Manual (IDM) standard procedures. The resulting new process map is a solid platform for the ongoing development of interrelated exchanges that span the full lifecycle of common bridge types. Finally, all components of the most comprehensive exchange, the construction contract model exchange, are put to use in detail in Volume III.

Also in this volume, the ability for design processes and data models to support downstream processes where the labor and resources planning, the construction planning, fabrication, and assembly of the bridge project are executed is examined. An important issue addressed in this Report and detailed in Volume III is what information structures are needed to transfer the construction contract model information from its given form as defined by a set of construction drawings or models into that needed for modeling bridge components and their detailing in sufficient detail to support fabrication. Not addressed yet is schedule planning which is being increasingly used and is described as 4D scheduling of bridge erection modeling.

Integration of the bridge design modeling with different independently defined processes and data models at the fabrication level for precast, steel and reinforced concrete models was undertaken. By reviewing the fabrication models, it appears that integration with design and construction models is practical and cost effective. A further assessment, based on the exchange requirements between the bridge model and the outlined fabrication models found no challenging mapping issues, beyond the varying entity types existing in bridge objects and building objects.

Appendix A:1 – Bridge Modeling Terminology

Terminology applicable to the process maps, models and corresponding exchanges in this Report is identified here. The terminology is from the IFC documentation (buildingSmart International, 2015) unless noted otherwise.

actor (Object Management Group (OMG))

person, an organization, or person acting on behalf of an organization

NOTE A specialization of the general term object.

alignment

a 3D curve segment used for positioning physical structures such as components of bridges, that may be based on a 2D horizontal alignment curve with optional 2D vertical alignment curve relative to the horizontal curve.

NOTE In some specifications and software implementations, the term "alignment" refers only to the horizontal alignment and "profile" refers to the vertical alignment; within this document, "alignment" refers to both.

horizontal alignment

a 2D curve used for positioning physical structures relative to coordinates at a fixed elevation, where such curve segments may include lines, spirals, or circular arcs.

NOTE In some specifications, the term "alignment" refers specifically to the horizontal alignment.

vertical alignment

a 2D curve used for positioning physical structures with elevations relative to a horizontal alignment, where such curve segments may include lines, parabolas, or circular arcs.

NOTE In some specifications, the term "profile" refers specifically to the vertical alignment, whereas in this document the term "profile" refers to any arbitrary cross-section.

Attribute (ISO TC184/SC4, 1991)

unit of information within an entity, defined by a particular type or reference to a particular entity

NOTE There are three kinds of attributes: direct attributes, inverse attributes and derived attributes.

direct attribute

scalar values or collections including Set (unordered, unique), List (ordered), or Array (ordered, sparse) as defined in (ISO TC184/SC4, 1991)

NOTE Similar to the term "field" in common programming languages.

inverse attribute

unit of information defining queries for obtaining related data and enforcing referential integrity

NOTE Similar to the term "navigation property" in entity-relational programming frameworks.

derived attribute

unit of information computed from other attributes using an expression defined in the schema

B-Rep

Boundary Representation describing a 3D solid model by its surfaces, where such surfaces may be flat or arbitrarily curved, may have linear or curved boundaries, and may include holes defined by inner linear or curved boundaries.

classification

categorization, the act of distributing things into classes or categories of the same type

constraint

restriction for a specified reason

NOTE A specialization of the general term control.

control

directive to meet specified requirements such as for scope, time, or cost

NOTE A specialization of the general term object.

dictionary

collection of words, terms or concepts, with their definition

element

tangible physical product that can be described by its shape representation, material representations, and other properties

NOTE A specialization of the general term product.

element occurrence

element's position within the project coordinate system and its containment within the spatial structure

exchange (exchange requirement)

the set of information that is passed between actors at a given stage in a process. The purpose of an exchange requirement is to describe the information that must be passed from one business process to enable another business process to happen.

exchange model (EM)

a software-neutral and semantically rich data definition of the content needed in the exchange requirement.

entity (ISO TC184/SC4, 1991)

class of information defined by common attributes and constraints as defined in (ISO TC184/SC4, 1991)

NOTE Similar to the term "class" in common programming languages but describing data structure only (not behavior such as methods).

external reference

link to information outside the data set, with direct relevance to the specific information the link originates from inside the data set

feature

parametric and property information modifying the shape representation of an element to which it applies

group

collection of information that fulfills a specified purpose

NOTE A specialization of the general term object.

identification

capability to find, retrieve, report, change, or delete specific instances without ambiguity

information delivery manual (IDM)[1]

specifies a methodology that unites the flow of construction processes with the specification of the information required by this flow, a form in which the information should be specified, and an appropriate way to map and describe the information processes within a construction life cycle.

instance

occurrence of an entity

NOTE Similar to the term "instance of a class" in object oriented programming.

library

catalogue, database or holder of data, that is relevant to information in the data set

NOTE It is information referenced from an external source that is not copied into the data set.

model

a data set, governed by the structure of an underlying schema, to meet certain data requirements

NOTE Information models and building information models are examples for a model.

model view

subset of a schema, representing the data structure required to fulfill the data requirements within one or several exchange scenarios

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

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

NOTE The utilization of material definitions for a paticular concept root representing a wall is an example of a concept.

concept template

the specification of a subset of the schema structure to enable a certain unit of functionality

NOTE The identification of the entities, attributes and constraints needed to express a material definition independently on how it is utilized later in the context of a wall is an example of a concept template.

concept root

an entity of a schema used to assign concepts to describe the required functionality

NOTE A root concept often describes a model element, such as wall, air outlet, construction task, or similar, that is the root of a graph of connected entities and attributes defining the specific information items required, such as geometry, material, breakdown structure, etc.

object

anything perceivable or conceivable that has a distinct existence, albeit not material

object occurrence

characteristics of an object as an individual

NOTE Similar to "object", "instance", "individual" in other publications.

object type

common characteristics shared by multiple object-occurrences

NOTE Similar to "class", "template", "type" in other publications.

process

object-occurrence located in time, indicating "when"

process map (Integrated Process for Delivering IFC Based Data Exchange, buildingSMART International, 2012)

A process map is a visual representation of the logical and sequential flow of activities and information exchanges described in use cases.

The purpose of a process map is to gain an understanding of the configuration of activities that make it work, the actors involved, the information required, consumed and produced. Business Process Model and Notation (BPMN) diagramming of the process model (often used interchangeably with process map) is typically used to represent the project workflow, including the stakeholders, actors, phases, and activities.

process model (adapted from process map definition)

A process model identifies the information flows between the different actors and tasks the actors carry out during a project workflow. It is a more general name for a process map.

product

physical or conceptual object that occurs in space

NOTE It is specialization of the general term object.

profile

2D cross-section defined by a closed curve with segments consisting of lines, circular arcs, or B-Spline curves, where such cross-section may be swept along a curve to define the geometry of a 3D solid object.

NOTE In some specifications, the term “profile” may also refer to a vertical alignment curve, and the term “cross-section” may be used to refer to a profile as described within this documentation.

project

encapsulation of related information for a particular purpose providing context for information contained within

NOTE Context information may include default measurement units or representation context and precision.

property

unit of information that is dynamically defined as a particular entity instance

NOTE Similar to "late-bound" or "run-time" in programming terminology.

property occurrence

unit of information providing a value for a property identified by name

property template

metadata for a property including name, description, and data type

NOTE Similar in concept to "extension property" in common programming languages.

property set occurrence

unit of information containing a set of property occurrences, each having a unique name within the property set

property set template

set of property templates serving a common purpose and having applicability to objects of a particular entity

NOTE Similar in concept to "extension class" in common programming languages.

proxy

object that does not hold a specific object type information

NOTE a specialization of object occurrence.

quantity

measurement of a scope-based metric, specifically length, area, volume, weight, count, or time

relationship

unit of information describing an interaction between items

representation

unit of information describing how an object is displayed, such as physical shape or topology

resource

entity with limited availability such as materials, labor, or equipment

NOTE a specialization of the general term object.

NOTE the "resource definition data schemas" section is unrelated to this concept.

schema

the definition of the structure to organize data for storage, exchange and sharing, using a formal language

NOTE The formal languages EXPRESS [ISO 10303-11] and XML Schema [W3C Recommendation] are currently used to define the schemata of this standard

SDK

Software Development Kit refers to a collection of software modules or definitions used to call such software modules from a programming language.

space

area or volume bounded actually or theoretically

NOTE a specialization of the general term product.

tessellation

representation of 3D geometry according to primitives such as triangles that may be directly used by a graphics processing unit (GPU)

NOTE all forms of geometry may be converted to tessellation and is done so for 3D visualization on any device.

type

basic information construct derived from a primitive, an enumeration, or a select of entities

NOTE Similar to the "Type" construct as defined in [ISO 10303-11].

NOTE Similar in concept to "typedef" or "value type" in common programming languages.

select

construct that allows an attribute value to be one of multiple types or entities

NOTE Similar to the "Select" construct as defined in [ISO 10303-11].

NOTE Similar to a "marker interface" in common programming languages.

enumeration

construct that allows an attribute value to be one of multiple predefined values identified by name

NOTE Similar to the "Enumeration" construct as defined in [ISO 10303-11].

NOTE Similar in concept to "enum" in common programming languages.

XSD

XML Schema Definition refers to a file format that describes the structure of data to be included in an XML file.

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