Bridge Data File Protocols for Interoperability and Life Cycle Management

Volume I:

Implementation Roadmap for Bridge Information Modeling (BrIM) Data Exchange Protocols

FHWA Cooperative Agreement DTFH61-11-H-0027

Advancing Steel and Concrete Bridge Technology
to Improve Infrastructure Performance

August 2013

FHWA-HIF-16-003

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Bridge Data File Protocols for Interoperability and Life Cycle Management Volume I: Implementation Roadmap for Bridge Information Modeling (BrIM) Data Exchange Protocols		5. Report Date August 2013 6. Performing Organization Code
7. Author(s) Chen, S. S.; Shirolé, A. M.		8. Performing Organization Report No.
9. Performing Organization Name and Address The Research Foundation for the State University of New York on behalf of Civil, Structural and Environmental Engineering, University at Buffalo, State University of New York Ketter Hall Buffalo, NY 14260		10. Work Unit No. 11. Contract or Grant No. DTFH61-11-H-00027
12. Sponsoring Agency Name and Address Federal Highway Administration Office of Infrastructure – Bridges and Structures 1200 New Jersey Ave., SE Washington, DC 20590		13. Type of Report and Period Covered 14. Sponsoring Agency Code HIBS-10

15. Supplementary Notes
Work funded by Cooperative Agreement "Advancing Steel and Concrete Bridge Technology to Improve Infrastructure Performance" between FHWA and Lehigh University.

16. Abstract
A national level, multi-year implementation roadmap for moving the industry towards bridge information modeling (BrIM) - based project delivery and life cycle management. This roadmap identifies and recommends steps and procedures deemed necessary to facilitate the adoption and use of the developed bridge data exchange protocols. The roadmap is intended to define a strategic plan for establishment and deployment of these protocols as a national standard for data exchange in the bridge industry, both during the execution of the current task and into the future. The objective of this roadmap is to identify specific steps and corresponding timetables for further developing, educating, implementing, and deploying bridge data exchange protocols.

17. Key Words	18. Distribution Statement
roadmap, lifecycle management, BrIM, modeling, bridge, process map	No restrictions. This document is available to the public online and through the National Technical Information Service, Springfield, VA 22161.

9. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No of Pages	22. Price
Unclassified	Unclassified	50	

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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)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

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

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

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1. Executive Summary / Abstract

Without industry standards for BrIM (Bridge Information Modeling) data exchange, there is no common tool to coordinate the various phases of a bridge design and construction project and on into the ongoing maintenance and operation associated with its asset management. What is needed is cradle-to-grave data sharing via such data exchange. OpenBrIM standards for electronic exchange of steel and concrete bridge data are being developed in Task 12 of the Federal Highway Administration's Cooperative Agreement No. DTFH61-11-RA-00010. A Multi-Year Implementation Roadmap is considered necessary in order to facilitate timely acceptance of these data exchange standards among bridge industry stakeholders and overall successful implementation in the bridge practice. Adherence to such a Roadmap will help maximize the probability of the data exchange protocols developed by the Task 12 work to result in more widespread deployment than would otherwise be the case.

A national level, multi-year implementation roadmap for moving the industry towards bridge information modeling (BrIM) - based project delivery and life cycle management is proposed herein. Both top-down (e.g., policy/program-driven) and bottom-up (e.g., authorizing environment / stakeholder influenced) aspects are addressed. The bottom-up aspects are intended to recognize and define inclusion of specific data exchange needs at operational/ practitioner levels. The top-down aspects are intended to recognize and encourage economies of scale resulting from widespread adoption and the policy/standards mechanisms that may be applicable. Organizational capacity constrains both top-down and bottom-up aspects to varying extents; a Task Force is proposed to generate recommendations regarding openBrIM standards deployment. This roadmap identifies and recommends steps and procedures deemed necessary to facilitate the adoption and use of the developed bridge data exchange protocols. The roadmap is intended to define a strategic plan for establishment and deployment of these protocols as a national standard for data exchange in the bridge industry, both during the execution of the current task and into the future.

The objective of this roadmap is to identify specific steps and corresponding timetables for further developing, educating, implementing, and deploying bridge data exchange protocols. Ultimately, what is affected is how an entire industry conducts business. Real - world industry transformation does not simply happen with the flip of a switch, especially when public agencies shielded from competitive pressures are involved. Thus, an evolutionary rather than revolutionary change process is proposed. The planning horizon for such an evolutionary change is presented in three consequent phases: shorter-term (approximately the next 12 months), intermediate- term (approximately 12 months to 5 years), and longer-term (5+ years). The conceptual framework used in the development of this roadmap is based on the proven Roberts Leadership and Management Model (Larson 2004) named after its creator, Professor Marc Roberts of Kennedy School of Government at Harvard University.

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2. Background (Context)

2.1 How We Got Here

In the beginning were master builders. Art, architecture, planning, design, and construction were all under the control and direction of the master builder. Optimal coordination results with appropriate construction technology can produce accelerated construction schedules. Even into the early 20th century after the master builder era, monumental structures such as the Empire State building and Hoover Dam were constructed very quickly (1930's).

The 19th and 20th centuries brought specializations, requiring more documentation and leading to fragmentation (a.k.a. "stovepipes") and a mushrooming body of construction law regulating it all, in a society founded on an increasing abundance of government - enacted laws.

A corollary effect of the complexities of some of the laws has been increased concerns about liability that too often stifle process innovations and integration.

Advances of the past few decades, in automation and information technologies, have brought computerization of previous manual workflows primarily as "stove piped" applications. These stovepipe type applications, using software developer companies' proprietary formats, until perhaps very recently, have been driven by their business models intended to foster their clients' dependence on them and their products.

2.2 Current Status

In many areas of the bridge enterprise, there is increasing recognition of inherent inefficiencies imposed by traditional stovepiped applications. It is also being recognized that better utilization of the galloping advances in information and communication technologies will lead to increased efficiencies even when targeted only to portions of the overall enterprise.

In the post interstate highway construction era we are in, infrastructure managers are experiencing increasing pressures to do more with less. Such pressures impose new demands on public agencies, demands that are similar in some ways to those already familiar to the private sector. A prior study (Chen 2009; Shirolé et al., 2009) demonstrated the feasibility of a comprehensive integration of the entire bridge lifecycle along with the need and opportunity for developing BrIM data exchange standards to facilitate that integration.

An obstacle arising in this environment is the "legacy" – not only legacy data formats associated with legacy stovepiped software and legacy databases but also legacy institutions. Various professional, industry, and trade associations sprung up pre-computerization to protect the interests of their constituents. They are still there, along with IT-oriented ones of more recent vintage such as the buildingSMART alliance (2013). We are arguably stuck with the institutional constraints of a bygone era. An unfortunate result is an all-too-fragmented process of project delivery and asset/operations/life cycle management that "hiccups" at what are often called "pain points."

On the legal front (e.g., Thomas and McDaniel 2013), increasing "audit trail" regulatory requirements create a legal impetus to implement integrative (BIM/BrIM, etc.) technologies since such technologies, properly planned/designed/configured and implemented, could produce such audit trails with the click of a button , as a byproduct of the data already managed by these technologies. This legal impetus, however, is still in flux with the liability concerns that dis- incentivize the sharing of electronic data among different project stakeholders.

2.3 Trends (Where Things Are Going)

The pressure to do more with less is intensifying. This situation should be regarded as providing further incentives to confront, overcome, and eliminate the inefficiencies of the legacy bygone era. Every Day Counts (EDC-2, 2012) initiatives continue, albeit still typically in a piecemeal fashion. The business model of many technology companies, however, is changing to be more supportive of integrative approaches. This is a positive development.

The bridge industry, fortunately, is not alone. Integrated Project Delivery (IPD) in other sectors of the transportation and construction industry, manufacturing integration, ISO15926 (ISO 2013) for capital facilities industry, shipbuilding, aerospace and automotive industries (etc.) come to mind. Thus, although the bridge industry may not have sufficient critical mass (in the overall engine of economic growth), it can leverage its interests via the forging of appropriate strategic partnerships with companion efforts that are concurrently developing or enhancing standards for digital information exchange throughout the supply chain of constructing and operating/maintaining the built environment. These strategic partnerships exploit mutual interests in the construction and operation of civil infrastructure and the (increasingly digital and increasingly sophisticated) data underpinning it all.

Examples of such a strategic partnership are the ones currently operating between AISC and FIATECH on digital exchange standards for fabrication of steel building components and systems, and between the buildingSMART Alliance and Open Geospatial Consortium (OGS) on digital exchange standards for terrain and associated information (e.g., alignments). In the bridge arena, other partnerships one can envision include emerging technology laws, progressive owners, innovative contractors, and current MAP-21 subsidies for the learning curve involved in initial deployment of advanced technology and software. As such, partnerships demonstrate progress, one can envision related partnerships influencing future MAP-21 extensions to continue and adapt and refocus such subsidies as appropriate.

The hope is that the aforementioned "pain points" will be eliminated by this roadmap implementation to the benefit of all involved, including the overall engine of economic growth.

3. Vision

We envision a future where there are widely accepted national BrIM data exchange standards that accomplish for bridge industry stakeholders what .CSV files accomplish for spreadsheet software users and what .PDF and .DXF files accomplish for word processing and CAD software users. To and from these standards, commercial bridge software applications can export and import; the standards are vendor-supported but not vendor-driven. These credible, robust, and adaptable standards have the endorsement of the federal government and other governing bodies. Project receipts and deliverables can and should be digital rather than paper-based. Visualization and 3D/4D/5D based engineering and construction planning and scheduling are easily achieved. Digital files and protocols originating as bridge "birth certificates" support ongoing asset management activities (inspection, load rating, permitting and routing/network analysis, programming rehabilitation), etc. Futuristic developments such as virtual reality, AI, performance monitoring and rapid post-event assessment become supportable.

Time otherwise lost in manual transcription and re-entry of data (along with errors thereby introduced) is eliminated. "Cradle-to-grave" data sharing/re-use is accomplished throughout the entire bridge lifecycle, reducing RFI's (Request for Information) and rework, integrating the supply chain and speeding construction, and improving construction quality and lifecycle management. This vision involves implementing in practical use information technology (IT) interoperability throughout the entire bridge lifecycle. It is hoped that this roadmap will also serve as either an exemplary model or as an integral part of the larger CIM (Civil Integrated Management) umbrella within which bridges are, after all, only a relatively small part.

It may be noted that such full integration will require all databases carefully consistently and accurately geo-referenced and coordinated. Without such coordination, e.g., such BIM/BrIM benefits as clash detection between bridges and non-bridge systems (e.g., utility lines) will not be possible.

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4. Bridge Lifecycle (Enterprise) Process Map

To develop a robust BrIM implementation roadmap, we must first characterize the current process for bridge project development and life cycle management. This includes all of the relevant stakeholders and the exchanges of information that occur in practice. The increasingly popular process-mapping notation (Eastman et al. 2011) is used to depict the bridge design-and-construction and asset management enterprise and constitutes the key point of reference for articulating and "fleshing out" the vision of significantly streamlined and improved IT – enabled means of managing that enterprise. Figure 1 shows a portion of this process map.

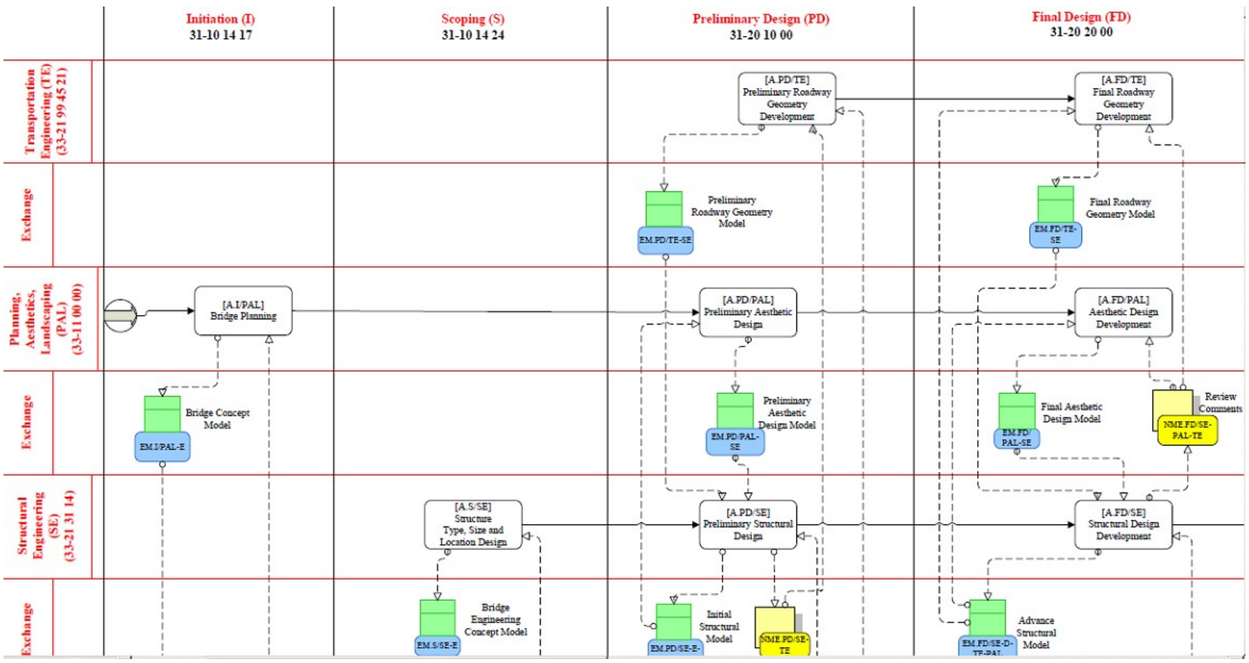

Figure 1. Portion of Bridge Enterprise Process Map (Chen et al. 2013)

In this process map notation:

- The horizontal headings along the top of the figure label bridge life stages, working from left to right. In addition to the stages shown in Figure 1 (Initiation, Scoping, Preliminary Design and Final Design) are the following:
  - Bidding and Letting (BL),
  - Post-Award / Pre-Construction Planning / Detailing (CD),
  - Fabrication (F),
  - Construction (C),
  - Inspection and Evaluation (IE), and
  - Maintenance and Management (MM).
- The vertical headings along the left side of the figure label bridge disciplines, working from upper to lower. In addition to the disciplines shown in Figure 1 (Transportation Engineering, Planning/Aesthetics/Landscaping, Structural Engineering) are the following:
  - Detailing (D),
  - Estimating (E),
  - Construction Management (CM),
  - Fabrication (F),

- Construction Engineering (CE),
- Inspection (I),
- Load Rating (LR),
- Routing and Permitting (RP), and
- Maintenance and Management (MM).

- In between discipline rows are model based data exchanges (a.k.a. "Exchange Models") shown in green and other (non-model based) exchanges shown in yellow.

Each discipline constitutes a stakeholder regarding each Exchange Model (EM) with which that discipline interacts. Thus, e.g., in the Final Design (FD) stage in Figure 1, Highway Designers (Transportation Engineering = TE) and Bridge Designers (Structural Engineering = SE) are stakeholders regarding the roadway geometry Exchange Model (EM.FD/TE-SE). Table 1 shows the horizontal alignment subset of this EM in the right column compared to the horizontal alignment parameters used in LandXML and actual contract plans. "*Derived data*" in the table means the parameter can be derived from other parameters using a mathematical formula. For example, end station is equal to the StartSta(start station) plus Length. From the comparison, it is evident that the OpenBrIM schema using parametric modeling requires less data to achieve unambiguous accurate alignment geometry in support of interoperability.

This process map is a means to identify the needs for successful and timely implementation of interoperability which is defined as the ability to manage and communicate bridge asset related information/ data between bridge industry stakeholders interested in planning, design, construction and bridge life cycle management. Many manufacturing sectors, such as automotive and aerospace industry have been in the process of harnessing information and other emerging technologies to increase the efficiency of their design and manufacturing processes. Development of domain data dictionaries (e.g., ASME, ASHRAE) is an important step in this process. Similar efficiency improvements in bridge industry practices that leverage information and automation technologies and enable interoperability have the potential to accomplish cost- effective life cycle management under ever present funding constraints.

While further enhancements and refinements may be anticipated to the bridge lifecycle process map, it is assumed herein to provide a working point of reference for the discussion of roadmap to implementation.

- What is to be implemented (main and tertiary)
- Where that implementation "fits" in the bridge lifecycle

Table 1. Horizontal Alignment Portion of Roadway Geometry Exchange Model

LandXML (2013)	**Contract Plans**	**openBrIM EM.FD/TE-SE (Chen et al. 2013)**
Horizontal alignment	Horizontal alignment	`HorizontalAlignment`
Line	Straight line	`Line`
Length	Start station, end station	`StartSta, Length`
dir(ection)	Azimuth	`StartAzimuth`
(start and end) easting, northing	N/A	*Derived data*
Spiral (clothoid)	Spiral	`Spiral`
Length	Start station, end station, length (1+049.139, 1+112.140,	`Length`
N/A	Azimuth (241^{o}-52’-58.6”)	*Derived data*
radiusStart, radiusEnd	Infinite, R (230.0 m)	*Derived data*
theta, totalY, totalX, tanLong, tanShort	N/A	*Derived data*
(start, PI, end) easting, northing	N/A	*Derived data*
Curve (arc)	Circular curve	Circular (curve)
Length	Start station, end station, length (1+112.140, 1+480.028, 367.888 m)	Length
Radius	R (230.0 m)	Radius
dirStart, dirEnd	N/A	*Derived data*
chord, delta, external, midOrd, tangent	N/A	*Derived data*
(start, center, end and PI) easting, northing	N/A	*Derived data*

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5. Selected Developments in Related Fields

As mentioned earlier, precedent developments and strategic partnerships should be investigated to derive lessons learned and leverage mutual interests in the development and promulgation and implementation of digital data exchange standards for the built environment. Among such developments and potential strategic partners are the following:

- Infrastructure (e.g., IFC-Infra, buildingSMART)
- Steel structures (e.g., AISC, FIATECH & ISO 15926)
- Concrete structures (e.g., ACI for cast-in-place, PCI for precast/prestressed, PTI for post-tensioned, nuclear for their audit trail requirements)
- Geotech (e.g., gINT, DIGGS (Hoit et al. 2012))
- AASHTO (e.g., TCEED, transXML/NCHRP 20-94, NCHRP 20-83(03), etc.)
- Manufacturing (e.g., NIST initiatives, etc.)
- Electric Power Plants (e.g., EPRI, etc.)
- Emerging Technology Law (e.g., AIA and ConsensusDocs BIM Addenda, 2008; Thomas and McDaniel 2013)
- Application software consortia (existing and/or perhaps yet to be constituted)
- buildingSMART for IFC (Palzar & Turk 2008) based exchange standards
- National Information Exchange Model (NIEM)
- National BIM Standard (NBIMS)
- Other national BIM Standards (and lessons learned therefrom), e.g., HMG's, Korea's, Singapore's (BCA 2012)
- other existing and emerging exchange standards (e.g., COBie, SPie, BIMSie, BPie, ELie, LCie, QTie, WALLie, etc.)
- etc.

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6. Assumptions

Principal assumptions inherent in the writers' thinking as expressed in this paper are in dual areas (technical and organizational), as follows:

- Technological
  - A neutral file format (e.g., IFC, XML) is desirable as a basis for facilitating interoperability. Note that underlying this assumption is that data exchanges are at the client-to-client application level, in contrast to server-based approaches.
  - Software (and related technology) solution providers continue current positive trends away from their traditional business model and in the direction of support for integrative technologies increasingly demanded by their clients.
  - Data quality specs will become an increasingly important category of specifications for appropriate quality standards-shepherding bodies (or consortia of such bodies!?) to oversee and facilitate, perhaps via rigorous testing protocols.
  - Subschema of shareable (needing to be shared) data, residing in what appears to the user as a single data repository for "workhorse" steel and concrete bridges, provides a suitable basis for further extensions.
- Organizational
  - Most existing institutions and organizations continue, thus providing a reasonably understood and defined framework for the organizational capacity and authorizing environment needed to implement the integrated process vision. Such organizations include, e.g., DOTs, AASHTO (including ASIS as well as SCOH and HSCOBS and its technical committees), ACI, AISC, ASTM, NCBC, NSBA, PCI, PTI, etc., as well as technology-oriented ones of more recent vintage such as IHEEP, FIATECH, the buildingSMART alliance, OGS, etc.
  - Return on Investment (ROI) (documentation of quantified benefits and emerging "best practices," including in related fields), is highly desirable. See Appendix B, McGraw-Hill (2012) and Giel and Issa (2013) for further thoughts on quantitative documentation of benefits and ROI.
  - Top-down initiatives and mandates can be expected to continue to increase the pressure on bridge-owning agencies to implement improved efficiencies ("do more with less"), e.g.,
    - Via MAP-21, wherein the US Secretary of Transportation is required to promote and encourage the use of advanced digital models in all federal- aid transportation construction projects,
    - Via the Executive Order Improving Performance of Federal Permitting and Review of Infrastructure Projects (White House 2012, Report 2013),
    - Via the "Open Data" Executive Order (White House 2013), and
  - The data exchange development efforts of openINFRA, PCI, and ACI and perhaps AISC continue to occur sufficiently concurrently with Task 12 work as to provide reasonable collaboration opportunities.

Benefits of improved interoperability throughout the bridge lifecycle can be summarized in the following categories:

- Tangible Benefits:
  - Reduced errors
  - Faster project delivery
  - cost savings

- Intangible Benefits:
    - Process and work-flow re-engineering
    - supply-chain integration
    - risk management and claims mitigation
- Quasi-tangible Benefits:
    - Improved data availability
    - complete audit trail
    - reduced data entry and improved information management
    - reduced rework
    - improved timely design and construction decision making
    - improved quality of construction

Since the current rapidly changing landscape (increasingly digitally connected and even increasingly cloud-dependent) is occurring in an environment with many pre-IT institutions continuing to wield major influence, realignments/refocusing and formation of strategic alliances and the skills needed to facilitate them will be required to occur to perhaps an unprecedented degree.

7. Implementation Roadmap: Overview

7.1 Conceptual Framework: The Roberts Model

What we are talking about is nothing less than a significant transformation of how an entire industry (bridge design, construction and life cycle management) conducts its business.

Fundamentally, the means by which engineers handle information and interact with computer software tools and communicate with each other are changed. This transformation involves a fundamental change through the adoption of state-of-the-art information technologies including the implementation of real-time data and stakeholder service applications, changes in information access and use of policies, and the application of enhanced asset management. A range of recent and emerging state-of-art technologies have the potential to transform the efficiency, effectiveness, reliability, cost-effective life cycle management of bridge network forever. Therefore, accomplishing such a transformation will require strategic planning by owning agencies that delivers on its promises. Such delivery will in turn will require that the strategic planning exercise is followed by strategic leadership and strategic management. The Roberts model is recommended herein as an approach to implement this follow-up and thus bring the strategic planning exercise to fruition.

Larson (2004) summarizes the Roberts Management and Leadership model in terms of Figure 2. In this figure, there are three overlapping circles:

- Vision
- Authorizing Environment, and
- Organizational Capacity

Figure 2. The Roberts Model

The ***Vision*** being cast here can be met starting with the bridge lifecycle Process Map (Figure 1) fully digitized in practice, with data exchanges occurring transparent to users as facilitated by Task 12 data exchange standards (or derivatives therefrom) implemented in the software used by the various stakeholders. Those data exchanges occur via import or export of data from or to upstream or downstream (software applications used by) stakeholders and project stages as the bridge project in question evolves.

Furthermore, the bridge data model evolved thereby provides the basis for ongoing “cradle-to-grave” management of bridge assets and inventories. The Process Map is thus the first step to accomplish the vision.

The ***Authorizing Environment*** permits an enterprise to function and progress**.** It includes the family of stakeholders, not necessarily limited to the project disciplines appearing in the Process Map. (If other disciplines play a significant role, however, it could be appropriate to revise the Process Map to include them!) Techniques to ascertain the desires and requirements of stakeholders include: focus groups, surveys by a variety of means, visits by enterprise leaders, and regular contact with stakeholders including industry associations and software solutions providers. Stakeholder categories appear along both axes of the Process Map as well as in the various institutions and organizations (e.g., AGC, NSBA, NCBC, DBIA, etc.) with which they are involved.

The ***Organizational Capacity*** refers to organization’s ability to do the job, measure up to the vision and satisfy critical stakeholder needs. In our context, we are referring to the “industry” as a whole. This is where leaders enter the picture and their ability, as a group, to meet the demands of a clear and well-articulated vision and the needs of expectant stakeholders who would be impacted by it. It is this organizational capacity that will determine the success or failure of the envisioned objective. The Task Force recommended herein (see Appendix A) is the crucial means of assessing and adjusting the limits of organizational capacity to facilitate openBrIM implementation.

Where the circles depicting the Vision, Authorizing Environment and Organizational capacity coalesce/overlap represents the ***Working Space***. Activities undertaken within this working space satisfy the requirements of the Vision, Authorizing Environment and Organizational Capacity; thereby assuring successful accomplishment of the original objective or the Vision.

The confluence of the three is a relatively small ***working space*** within which “good things can be expected to happen” as shown in Figure 2. All three are needed; none of the three can be ignored. That working space can be enlarged somewhat via adjustments to any of the 3 circles. But such adjustments require changes in people, positions, budgets, opportunities, or (perhaps most threatening of all) culture. As Larson states, when changes have an impact on organizational culture, “the situation becomes a litmus test for success in leadership and management.” It is suggested that sustained leadership better than that applied in the metrication initiative will be needed. Additional suggestions considered relevant from Project Delivery Best Practices (Warne et al. 2009) include the following:

- "Investment in GIS and data management tools for project delivery"
- "The best systems were composed of cohesive, multidisciplinary teams that communicated well among themselves."
- Stakeholders’ "roles and responsibilities must be clearly understood."
- "Successful systems provided for effective hand offs from one division or discipline to another and from one work phase to another," and
- "The silo effect between functional or operational units was completely or nearly completely absent. Leadership’s role in removing these barriers was evident."

Table 2 lists examples of each (Vision, Authorizing Environment, and Organizational Capacity).

Table 2. Examples of Roberts Model Elements

Roberts Model Element	Example
Vision	(see Figure 1): As a result of BrIM-standards based project execution and life cycle management being implemented, owners dealing with construction claims could quickly access the searchable electronic "audit trail" that is a byproduct of BrIM – enabled processes to quickly assess the merits of claims just as easily as a contractor with suitable access to model data can interrogate it instead of issuing RFI's.
Authorizing Environment	Increasing interconnectedness of pieces of the workflow is increasingly realized by software translators, and the integrative Vision embraced by various stakeholders (owners, designers, contractors, etc.) in the bridge lifecycle in a given owner's jurisdiction
Organizational Capacity	In an owning agency organization and the consulting firms serving them, long standing animosities between previously separated highway design and bridge design squads reduce over time; CAD technicians and bridge engineers re- tool to productively use 3D modeling tools, possibly partially subsidized using MAP-21 funds incentivizing deployment of ABC technologies.
Working Space	Progressive leaders clearly understand and champion the vision throughout the organization in an energetic and sustained manner to facilitate the migration from initially non-interoperating software operated by a not-fully- IT-savvy workforce to collaboratively influence that agency's next-gen CAD standards and associated workflows to implement openBrIM data exchange standards (or suitable derivative(s) thereof)

7.2 Stakeholder Analysis

As stated earlier, with reference to the Process Map, each discipline constitutes a stakeholder regarding each Exchange Model (EM) with which that discipline interacts. For convenience herein, the ***discipline*** stakeholder label identifies such stakeholder groups (e.g., detailers, fabricators, etc.). Such stakeholders involved in openBrIM vetting are ideally collaborative and articulate in addition to their discipline competence. Legacy ***subject matter/industry/trade associations*** (e.g., AISC, ACI, TRB/AASHTO) typically group several of these disciplines that are common to a particular industry (e.g., fabricated structural steel, cast-in-place concrete construction, transportation related) along with design and construction standards (and their committees) geared to that particular industry.

TRB/AASHTO is herein considered a special case (of stakeholder category). Although AASHTO's HSCOBS should take the lead promoting openBrIM, as a legacy institution AASHTO poses several nontrivial challenges regarding the promulgation and shepherding of data exchange standards for highway and heavy construction infrastructure of which bridges constitute only one part. AASHTO's cross-cutting Technical Council on Electronic Engineering Data (TCEED) should be involved, as should its subcommittees on Information Systems (ASIS), Materials, and Construction (the latter of which in turn has potentially relevant sections on Contract Administration, Roadways and Structures, Computers and Technology, and Environmental and Human Resources).

Software (or ***Technology***) ***Solution Providers*** provide another distinct category of stakeholder group – but it encompasses each discipline group that uses application software. Toll authorities and local, state, and federal governments (***owners*** and their various agencies relevant to the bridge industry) provide yet another category of stakeholder group; this one has most if not all of the asset management responsibilities.

Complicating a stakeholder analysis is the fact that these groups are not mutually exclusive. Further complicating this analysis is the fact that relevant ***data exchange standards development committees*** (a distinct stakeholder category!) have significantly different dependencies on subject matter loyalties (e.g., the ACI and PCI BIM Committees geared toward concrete construction and the AISC Technology Integration Committee and NSBA TG-15 Data Modeling for Interoperability Task Group toward steel construction, but the buildingSMART alliance quite properly not favoring either).

The openBrIM implementation roadmap must somehow navigate through this multifaceted mosaic. For our purposes, the Subject/Trade Association category is considered subsumed by either the Discipline stakeholder category or the Data Exchange Standards Committee stakeholder category. Thus, for purposes of articulating a targeted strategy, subsequent discussion of the implementation roadmap is in terms of the following five stakeholder categories:

- **Owner,**
- ***Discipline***,
- ***TRB/AASHTO***,
- ***Data Exchange Standards Committee***, and
- Software/***Technology Solutions Provider*** (a.k.a. “vendor”).

8. Implementation Roadmap: Bottom-Up and Top-Down (The Roadmap to the Roadmap)

Table 3 provides a "roadmap to the roadmap" of recommended activities classified in terms of the stakeholder categories outlined above, whether those activities are primarily "bottom-up" or "top-down" or somewhere in-between (and hence Task Force relevant), and into which time frame (short-, intermediate-, or long-term) those activities should occur. The "bottom-up" aspects are considered mainly in the "Authorizing Environment" of the Roberts model, while the "top-down" aspects are considered mainly in the "Vision" portion of the Roberts model. Policy mechanisms are included along in the top-down column. The region in-between "bottom-up" and "top-down" is considered the principal domain of the Task Force (Appendix A) and of the "Organizational Capacity" portion of the Roberts model; the Task Force can be sufficiently influential to shape the culture and not just be constrained by it. The activity identifiers in Table 3 are cross-referenced to the descriptions that follow. Each such activity appears at least once in the table. The description IDs are prefaced with "ST," "IT," and "LT" to denote whether they are Shorter-Term, Intermediate-Term, or Longer-Term, respectively. In the Longer-Term, the Task Force will hopefully have worked itself out of a job and replaced by a suitable consortium.

Table 3. Implementation Roadmap Activities

Stakeholder Category	Roberts Model Element *Authorizing Environment* **Bottom-Up**	Roberts Model Element *Organizational Capacity* **Task Force**	Roberts Model Element V*ision (and Policy Mechanisms)* **Top-Down**
Owner	ST3; IT1d,e; LT1	ST1k; ST2; IT2; IT3d	ST2; IT1e; IT2; IT5; LT6c,d
Discipline	ST1a-j; ST3; ST5; IT3c; IT4a; LT2a,b; LT6d	ST3b; IT1f	none
TRB/AASHTO	ST1e,g; IT1g; LT3	ST3a; IT1c; IT6; LT4; LT6a	ST4a,b; IT3b,c; LT2d; LT7b
Data Exchange Standards Committee	ST1a1-4; ST1h,I; IT4b,c; LT5	ST4a-d; IT1a,f,g	ST4c; IT3a; IT4b,c; LT7a,c
Technology Solution Provider	ST1a3; ST1c; ST5; IT1b1; LT2c, LT6b; LT7	IT1b2	none

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9. Implementation Roadmap: Shorter-Term (next 12 months)

In the shorter-term, each stakeholder category should be engaged in influencing the development of the exchange standards themselves. Commercial technology solution providers are one of these. As one such provider has stated,

"If there were a public-domain non-proprietary industry-wide standard for the electronic exchange of bridge data, we would gladly write a translator for it."

– Development Director for a leading commercial bridge software solution provider (2005). The increasing willingness of such providers to participate in moving away from their traditional business models to embrace integrative solution efforts should be further encouraged and utilized.

At the same time, human nature resists change. "A man convinced against his will is of the same opinion still." - Benjamin Franklin (d. 1790). Training opportunities, documented case study examples of advantages and corresponding quantitative ROI will also be important.

As various sectors of the larger constructed facilities area (CIM) increasingly realize that similar shared issues and challenges are arising in their various (previously stovepiped!) communities, "In a multitude of counselors is victory." (Ancient proverb). Economies of scale may be anticipated as not only entire supply chains are integrated for particular systems (e.g., bridges) but also inter-related electronically to other geo-co-located systems.

ST1: Various educational briefings and targeted stakeholder engagement should continue for further schema vetting and periodic (web)meetings, e.g.,

- ST1a: Further publicize and appropriately link websites for stakeholder engagement
  - ST1a1: FHWA Sharepoint site (serving as the principal portal)
  - ST1a2: TG-15 Google TeamSite (mainly for steel bridge superstructure particulars)
  - ST1a3: openBrIM site (mainly for commercial software solution providers)
  - ST1a4: AISC/GaTech bridge usecase (for coordination/communication with the AISC/FIATECH fabrication exchange model EM.11 development effort)
  - Etc.
- ST1b: Further develop and test the initial, "core" BrIM standards along with Viewer tool.
- ST1c: Further vet 4 – 5 principal EM's (Chen et al. 2013a, b) pursuant to comments received from contacts made at various presentations and meetings in recent months; explore/implement ballot acceptance thereof
- ST1d: Further refine "Final Detailing Model" pursuant to April 2013 AISC EM.11 demo
- @ NASCC
- ST1e: Further presentations and stakeholder engagement at meetings not limited to the bridge community
- ST1f: Further solicit stakeholder vetting of evolving openBrIM exchange standards by wider public review than previous targeted stakeholder engagement efforts
- ST1g: Publicize openBrIM developments at Fall 2013 Visualization symposium (international, including but not limited to bridge community)
- ST1h: Publicize openBrIM developments at Fall 2013 XML transXML workshop (NCHRP 20-94)
- ST1i: As has been done to "seed" other BIM and data exchange standards development committees (e.g., AISC, PCI, ACI, openINFRA), further "seed" other such committees (e.g., PTI, NIEM, NBIMS, transXML, etc) and CIM related committees (e.g., bridge/transportation

committees dealing with design/construction/asset management and information/communication technology) with savvy bridge people

- ST1j: Publicize openBrIM developments at Jan. 2014 TRB workshop/meeting and other spring and summer 2014 meetings (e.g., NSBA, ACI, HSCOBS)
- ST1k: Augment Synthesis / Documentation of quantitative benefits, emphasizing “win – win” scenarios
    - Time savings case studies
    - Cost savings case studies
    - Reasonable extrapolation / inferences for bridge industry

ST2: Identify principal legal issues and add-ons in “BIM Addendums” to standard construction contracts in related fields (e.g., AIA 2008, ConsensusDocs 2008) that are thought to be most relevant to the bridge industry and work with emerging technology law efforts and reviews (e.g., Thomas and McDaniel 2013) to adapt them as appropriate to the bridge enterprise.

ST3: Develop suitable demo projects to test-drive openBrIM standards:

- ST3a: Work with progressive owners to identify/develop suitable projects for MAP-21 subsidies to catalyze BrIM implementation; vet openBrIM standards in terms of workhorse bridge data these owners want shared
- ST3b: Develop model guidelines for training/retooling rank and file staff
- ST3c: Begin synthesizing “best practices”

ST4: Identify options and preferred standards-issuing route(s) (and associated advocacy strategies) (and pros and cons of pursuing each?) from among (e.g.)

- ST4a: HSCOBS via
    - T-19
    - AASHTO/NSBA Steel Bridge Collaboration
    - NCBC/PCI
    - Task Force (to spearhead efforts enhancing development and facilitating national implementation) - see Appendix A for further description.
- ST4b: Other AASHTO subcommittees with partially overlapping interests: on Information Systems (ASIS), Materials, and Construction
- ST4c: buildingSMART Alliance (IFC4 provides a framework (2013) that may eventually support bridges in a future IFC5) and IFC-Infra Technical Working Group (considering various alignment schema proposals as of July 2013)
- ST4d: other data exchange standards developments (e.g., AISC TI Committee, ACI BIM Committee, PCI BIM Committee, etc.) after they have been suitably influenced by new participants doing bridge advocacy; collaborating with the ones doing concurrent development is relevant for the alignment of shared domain vocabularies. Intermediate levels of the IFC schema, e.g., appear to be of interest in this regard.

ST5: Further develop the Viewer/Modeler tool in tandem with Red Equation Corp. in order to:

a) demonstrate tangible outcomes of the openBrIM schema to facilitate stakeholder involvement and
b) serve as a resource for supporting future extensions to openBrIM.

- This graphical visualization tool is available for public download at openbrim.org along with evolving companion openBrIM schema documentation. Related Red Equation Corp. developments intended for public download include brimdata.org (cloud based data management and version control tools intended to promote collaboration based on openBrIM standards) and Smart.BrIM (suite of parametric openBrIM-based software applications for bridge analysis and design etc.).

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10. Implementation Roadmap: Intermediate-Term (12 months – 5 years)

There are many “standards” to deal with, standards that come into existence for many purposes, some of which outlive their usefulness, others of which overlap and could benefit from consolidation. "The nice thing about standards is that there are so many of them to choose from." - Adm. Grace Murray Hopper.

Standards emerging for a bridge structure, for example, will need to be mapped from “plain English” (or “stylized English”) that a bridge engineer would use (e.g., as initially defined in Chen et al. 2013a), to the IFC or XML Model View Definition (MVD) that a software implementer would use (e.g., as initially defined in Chen et al. 2013b).

IT1: Recommended activities in the Intermediate-Term include the following:

- IT1a: Monitor the ongoing Model-View-Definition (MVD) standards shake-out (e.g., among IFC (buildingSMART 2013), (trans)XML (Ziering et al. 2007, SpyPond 2011), ISM (Bentley 2011), etc.) while ensuring that the evolving and increasingly robust Task 12 data exchange protocols continue to be easily migrated or exported to ***any*** of these formats.
- IT1b: Engage software/technology solution providers (TSPs) through.
    - IT1b1: their user communities to incentivize the implementation of translators to increasingly robust and mature data exchange standards, and through.
    - IT1b2: forming or joining a consortium to shepherd ongoing openBrIM standard deployment (modifications, extensions, compliance testing, etc.)
- IT1c: Engage Project-Delivery communities (e.g., Torres & Ruiz 2011).
- IT1d: Adapt owner’s guide documents from related industries (e.g., CURT 2010) to the practices prevalent in major bridge-owning agencies such as state DOTs.
- IT1e: Continue monitoring and adapting legal developments from related industries along with accumulating “lessons learned” and “best practices” from early adopters for wide dissemination.
- IT1f: Develop and advocate for problem statements that explicitly call for development and shepherding of formal data/domain dictionaries and tools to manage ontologies (structured vocabularies) for bridges that dovetail with those being developed in other areas such as NCHRP 20-97 and 20-98.
- IT1g: Monitor and influence the process of augmenting transXML (e.g., via NCHRP 20-
- 94) and/or the recently announced IFC4 (buildingSMART 2013) so that IFC5 (projected for 5 years hence) incorporates suitably robust openBrIM standards.

IT2: Obstacles to address/overcome include the following:

- IT2a: Designer reluctance to share models, which is “for good reasons.”
- IT2b: “reasonable man” legal reasoning (works against early adopters).
- IT2c: Insufficient institutional memory (e.g., re where did that (archaic) spec come from?); NCHRP 20-98 appears to be able to begin to address this concern if a suitable bridge person is on its panel.

IT3: Top-Down processes to consider include the following:

- IT3a: Track UK government BIM mandate ramp-up and deployment experiences in forcing BIM-enabled processes into the mainstream of construction project delivery; catalog best practices, pitfalls to avoid, etc.
- IT3b: Add-on to (or modified!?) NBI reporting requirements along with element-level reporting already required by statute (MAP-21).

- IT3c: Monitor and exploit the trickle-down effects of MAP-21 provisions (Yoders 2013) encouraging the submission of digital data documenting federal-aid construction projects and of broad federal government initiatives such as the “open data” Executive order (White House 2013) and NIEM.
- IT3d: Promulgate Model version control guidelines, guidelines for tweaking Owner-specified exchange standards (think next-gen CAD standards), and guidelines for generating “as built” (or “as constructed”) models.

IT4: Bottom-Up processes to consider include the following:

- IT4a: Refine model guidelines for training/retooling rank and file staff (based, e.g., on lessons learned from early adopters).
- IT4b: Refine and implement procedures for testing data exchanges (conformance testing, coverage analysis, etc.).
- IT4c: Constitute sufficiently comprehensive sets of test suites to serve the interoperability robustness needs of the jurisdictions implementing openBrIM standards.

IT5: Influence the crafting of MAP-21 extensions, e.g., to include explicit openBrIM deliverable requirements in federal-aid bridge construction projects after openBrIM standards reach a suitable degree of maturity.

IT6: Formally rollout the openBrIM standards partway through the Intermediate-Term.

11. Implementation Roadmap: Longer-Term (5+ years)

"And no one pours new wine into old wineskins." Jesus (NIV, Mark 2:22)

"We have modified our environment so radically that we must now modify ourselves in order to exist in this new environment." - Norbert Wiener (d. 1964)

As stated earlier, we have inherited the institutions and organizations of a bygone era. The cacophony of these various organizations that sprang up to address the needs of their constituents is unlikely to go away. Thus, although at a technical level the stovepipes and silos will become more porous (e.g., via API's and data exchange standards), it should not be assumed that still- stovepiped organizational wineskins will easily flex to encourage or even allow flow through those new pores. Such is the nature of the landscape. Thus, e.g., neither FIATECH nor AISC will fade away, even though they have significant overlapping interest in hammering out standards for electronic exchange of data regarding fabricated steel building structures.

Thus, ongoing data exchange standards development activity should continue recognizing and identifying such overlapping interests, beyond those that are already underway in the current Task 12 effort, both nationally and internationally, and forging targeted collaborative efforts without undue bureaucracy to leverage resources and consolidate/refine evolving/maturing process mapping exercises, their EM (Exchange Model) descriptions and associated MVD mappings. The importance of such leveraging efforts is twofold:

- To succeed in such efforts will leverage investments to consolidate gains and increase economies of scale.
- To fail in such efforts will result in no better than isolated piecemeal improvements that likely fail to transform the bridge industry value stream for the better.

LT1: Overhaul / transform transportation infrastructure owning agencies (or otherwise work around their intramural organizational stovepipes) around their integrated stewardship of lifecycle asset ***data*** management down to the "nuts and bolts" details. Guidelines are available (e.g., Henkin et al. 2012) that are consistent with the Roberts model.

LT2: Moving forward to "maintenance mode" for the BrIM data exchange standards once the process of their implementation in practice is deemed sufficiently well underway:

- LT2a: Shift the emphasis of the FHWA Sharepoint site to serve merely as a link site to related subject matter sites (e.g., steel bridge portal, concrete bridge portal) and openBrIM sites, and
- LT2b: Add subject matter website links (e.g., to those for timber bridges and those for FRP bridges etc.) in areas to incorporate in future versions of the openBrIM standards, and
- LT2c: Add links to MVD - maintenance websites (e.g., the buildingSMART alliance and the MVD Solutions Factory, assuming such organizations continue to exist in the planning horizon considered here. Such an assumption may be more reliable than an assumption that AASHTO will succeed in creating its own certification mechanisms for transXML compliance.
- LT2d: Add links to and/or consolidate efforts with related (e.g., CIM and/or NIEM) developments regarding civil infrastructure data exchange standards whose scope would include but not be limited to bridges.

LT3: Assemble and publicize (e.g., 1-PDH webinars) periodic syntheses of successful case studies (including IPD), lessons learned from early adopters, and emerging best practices.

LT4: Proactively influence BIM/BrIM related committees with partially overlapping interests to ensure that bridge data of interest is included in the broader efforts to define and implement data exchange standards for the constructed infrastructure encompassing sectors beyond just bridges.

LT5: Utilize and influence emerging and evolving BIM certification mechanisms (e.g., http://www.agc.org/cs/building_information_modeling_education_program, IFC certification, etc.)

LT6: Implement Deployment/Enforcement Mechanisms

- LT6a: Establish a framework and process for managing domain dictionaries and shepherding / updating mechanism for consensus bridge lifecycle data exchange standards:
  - To extend beyond just "workhorse" bridges,
  - To ensure that IFC5 (that does not yet exist) suitably incorporates essential openBrIM content
- LT6b: Implement Software translators (and testing/certification mechanisms for them)
- LT6c: Implement Specification changes (e.g., re: electronic delivery requirements for such things as a bridge "birth certificate" and or next-gen NBI reporting deliverables)
- LT6d: Implement QA/QC inspection/ certification mechanisms and train service companies involved in their enforcement

LT7: Turn over ownership/management of openBrIM data exchange standards to a suitable industry consortium (i.e., not the Federal Highway Administration). Three options (or paradigms) are suggested for comparative consideration in constituting such a consortium:

- LT7a: Utilize and extend a TSP – originated file format such as ISM (Integrated Structural Model) via publicly available downloads and API documentation. The obvious disadvantage is the vendor-specific origination thereof. Some such formats, however, become accepted as mainstream (e.g., .PDF for documents, .DXF for CAD data) in spite of their vendor-specific origins.
- LT7b: Utilize AASHTO organizational structures and processes if and after such processes and mechanisms are established to shepherd ongoing stewardship of transXML data exchange standards. This option could involve changes to the scope of AASHTOWare and would be plausible after the structures portion of the current transXML standards are expanded to include the aspects of openBrIM that go beyond design and load rating checks.
- LT7c: Utilize buildingSMART organizational structures and processes if and after the just-released (Mar 2013) IFC4 data exchange standards are augmented (e.g., via ifcBridge / openINFRA task group activity) to include suitably robust openBrIM standards in IFC5, which in turn is projected for 5+ years hence. With this option, IFC5- based data exchange deliverables could be incorporated by reference in relevant AASHTO specifications, as ASTM materials specifications currently are.

Regardless of which option is chosen, a consortium scope broader than the bridge industry and openBrIM should be anticipated.

12. Summary and Recommendations

"Do nothing" is not a viable option. This paper presents a "roadmap" for an evolutionary change process for further developing, implementing, and deploying openBrIM bridge data exchange protocols to increase cradle-to-grave data sharing via software interoperabilities in the bridge industry. Deployment of these standards for electronic exchange of steel and concrete bridge data will require a multifaceted approach, both top-down (government/owner – driven) and bottom-up (stakeholder – influenced) over distinct phases of time (shorter-, intermediate-, and longer- term). Development of those standards should involve each bridge industry stakeholder group and be overseen by a high-level Task Force charged with producing recommendations regarding openBrIM deployment mechanisms. Doing so will influence proactively, the larger context of civil infrastructure data exchange standard development to ensure that bridge data of interest is incorporated in that larger effort. Doing so will also catalyze the re-tooling effort needed to facilitate full utilization and demonstration of the improved value stream enabled thereby. Sustain the vision with flexibility and ongoing energy in order to resource the transformation of authorizing environment and institutional capacity to implement interoperable processes throughout the supply chain and lifecycle of bridge design, construction, and asset management. We are talking about nothing less than transforming how an entire industry conducts its business.

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13. Acknowledgements

The authors thank colleagues involved in the AASHTO/NSBA Steel Bridge Collaboration and the buildingSMART Alliance along with the NYSDOT and other DOTs for access to information about their bridge design process, bridge data, and construction sites. Figure 1 and Table 1 originate with Mr. Hanjin Hu, and Mr. Yuanshen Ji assembled the content of Appendix B. In addition, support and assistance of the following are gratefully acknowledged: NWFP University of Engineering and Technology, the University at Buffalo, Bentley Systems, Red Equation Corp. and other software solution providers, the Association for Bridge Construction and Design-Western NY Chapter, and the Federal Highway Administration under Cooperative Agreement No. DTFH61-11-RA-00010 administered by ATLSS (Advanced Technology for Large Structural Systems) at Lehigh University. Any opinions, findings, and conclusions or recommendations expressed in this paper are those of the author(s) and do not necessarily reflect the views of the Federal Highway Administration.

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Appendix A. BrIM Task Force (Proposed)

Introduction. A focused Task Force (TF) is proposed to facilitate the implementation of BrIM data exchange standards to increase cradle-to-grave data sharing via software interoperability in the bridge industry. A set of such standards by its very nature involves many distinct stakeholder groups. AASHTO HSCOBS has previously established an excellent precedent for shepherding the development of crosscutting research product implementation via the formation of a Task Force (e.g., for producing the Specification on Pedestrian Bridges). The present case of implementing data exchange standards for interoperability of BrIM data and mobilizing the multi-stakeholder community impacted by such standards, through the chairs of selected HSCOBS technical committees and liaisons to other affected groups ensures that the concerns and needs of each stakeholder category are addressed. That, in turn, the holistic and wholehearted buy-in and endorsement of HSCOBS is obtained enabling and facilitating wider implementation of the BrIM data exchange standards into bridge industry practices.

Scope. What this TF would do:

- Evaluate and comment on the product (Subtask 12.2 roadmap and openBrIM data exchange standards produced by Task 12) with the aim of easing implementation in bridge enterprise practices.
- Deliberate via email and at HSCOBS meetings
- Utilize FHWA in its role of facilitating the TF (e.g., subsidizing meetings if needed, moderating/threaded discussions on the FHWA Sharepoint site, etc.).

Potential Activities.

- The work of the TF would include such activities as the following:
- Email correspondence, some perhaps on the FHWA Sharepoint site,
- Web-meetings for review/comment for enhancing the product to ease implementation,
- Identify and engage relevant bridge industry stakeholder groups into openBrIM standards development processes
- Identify roadblocks to implementation and ways to overcome them,
- Generate recommendations to get the product accepted by HSCOBS members,
- Generate a position paper to HSCOBS re how to move the product forward,
- Identify need (if any) to write distinct specification(s),
- Oversee/review draft domain dictionaries and/or Guide Specifications as a 1st step (pilot), e.g., incorporating transXML or buildingSMART for Industry Foundation Classes (IFC) based openBrIM specs in the same way as AASHTO incorporates ASTM materials specs by reference

Products. Results of the TF's work are envisioned to include such products as the following:

- Recommendations regarding openBrIM deployment and mechanisms for the maintenance thereof after this Task Force sunsets, e.g., regarding a suitable industry consortium and AASHTOWare's role therein
- Advice regarding (or embodied in) domain dictionaries and/or Guide Specifications

Potential Task Force Members.

Chairperson appointed by HSCOBS Chair

- T-19 Computers (Lead?)
- T-1 Security
- T-2 Joints and Bearings
- T-3 Seismic
- T-4 Construction (e.g., re: ABC)
- T-5 Loads (e.g., re: data exchange needs related to refined analysis)
- T-7 Guard Rail and Bridge Rail
- T-10 Concrete Structures (e.g., re: ABC)
- T-11 Research
- T-14Steel Structures
- T-15 Substructures and Retaining Walls (e.g., re: ABC)
- T-17 Welding (e.g., re: digital inspection records)
- T-18 Bridge Management, Evaluation, and Rehabilitation (e.g., re: LTBP and LCC data and Element-Level inspection domain dictionaries)
- And any others the HSCOBS chair appoints, e.g.,
    - Liaison(s) to related data exchange standards development committees,
    - Liaison(s) to other AASHTO committees (e.g., Subcommittee on Materials, Subcommittee on Information Systems, Subcommittee on Construction, VDC/IPD related committees, AASHTOWare Task Force, etc.)
    - Liaison(s) to other NCHRP projects (e.g., 20-97, 20-98) developing formal data/domain dictionaries

Companion and/or coordinated (Task Force with representation of multiple committees) efforts could also be considered under TRB (akin to the Design/Build Task Force mobilized several years ago) and/or under ASCE (perhaps in conjunction with the Technology Committee under the ASCE Transportation and Development Institute) and/or under larger CIM – oriented and/or NIEM – oriented endeavors.

Appendix B. BIM/BrIM ROI Analysis Considerations

By Y. Ji

Introduction. In 2007, vertical construction industry-wide adoption of BIM was 28%. In 2012, 71% of architects, engineers, contractors and owners report they have become engaged with BIM on their projects. These numbers indicate that BIM, an innovative approach to design and construction for pioneering early adopters just a few years ago, is now taking its place firmly in the mainstream of the North American architecture and construction industry. Engineers, who had seemed the least convinced of BIM's value in 2009, with only 25% involved, still struggle with issues of content and technical analysis. However, they have closed the adoption gap significantly, with 67% reporting participation now (2012), especially among mechanical, electrical, plumbing and structural disciplines.

With the advent of BIM, the building industry is coming to appreciate that technology can radically transform the process by which a building is designed and constructed. But, before committing the funds to purchase that technology, the decision makers in an organization will probably insist that an ROI analysis be conducted. Since both horizontal construction and vertical construction employ many of the same disciplines, BrIM ROI development can be expected to follow and utilize some of that already well underway for BIM.

What are ROI and ROI Analysis. ROI is used to evaluate many types of corporate investments, from R&D projects to training programs to fixed asset purchases. The more complicated the investment, the more complicated the calculation formula becomes. An investment does not have to be in dollars. It can be in materials or assets as well. Calculating the ROI for a design system is a bit more complicated because of the many variables that come into play. The analyst needs to consider not only the cost of the system but also changes in user productivity. Generally, the ROI formula is as below:

$$\frac{\text{Earnings}}{\text{Investment or Cost}} = \text{ROI}$$

ROI of BIM/BrIM Case Studies.

Although there is no industry-standard method to calculate the ROI for BIM/BrIM, most users have a perception of the degree to which they are receiving value for the time, money and efforts they have invested. Therefore, this brief survey will focus on time and money investment saved after the implementation of BIM to evaluate ROI of BIM/BrIM.

1. Online Survey Conducted by Autodesk in Dec. 2003.

Autodesk commissioned an online survey of users of their Revit® Architecture software in December 2003. Approximately 100 users provided responses to the survey. The ROI is calculated at just over 60% in terms of time investment.

As part of the 2003 survey, Revit users responded that on average they spent 35% of their time on design, 46% on documentation, 15% project on project management, and 3% on other tasks. A typical designer works an average of 147 billable hours per month. In total, a typical Revit user spends 82% of his or her time, or 120 hours a month, on design and documentation, the two tasks where Revit is useful and offering a 60% return on investment.

Likewise, another survey respondent (a 300-person architectural firm) reported that several projects done on Revit Architecture were completed with half the budgeted staff and in half the budgeted time.

2. <u>Research Conducted by McGraw-Hill Construction, 2009 to 2012.</u>

Generally speaking, according to McGraw-Hill Construction, research and survey suggests the similarity of perceived ROI for BIM between 2009 and 2012 (table 1). Given the total pool of BIM users has expanded from 49% in 2009 to 71% in 2012, more and more players are benefiting from BIM though the amount of that benefit is remaining flat.

Table 1 BIM ROI (2009 to 2012)
(Source: McGraw-Hill Construction, 2012)

Year	Negative	Break-Even	Less than 10%	10% to 25%	26% to 50%	51% to 100%	Over 100%
2009	17%	20%	16%	21%	11%	7%	8%
2012	18%	20%	14%	22%	12%	9%	5%

During the period from 2007 to 2012, almost two-thirds (62%) of all BIM users perceive positive ROI. 74% of the contractors report a positive ROI compared to only 37% of engineers. ROI correlates strongly with BIM engagement level, rewarding companies with high skill, experience and implementation levels. Specifically, for “very high engaged” firms, 67% reports ROI as “very positive,” which means ROI goes over 25%.

As shown in Table 2, by 2009, 21% of all the BIM users believed that the benefits of BIM adoption are “High/Very High Value” in terms of “increased profits”. When talking about “reducing overall project duration,” this rate rises up to 27%. In 2012, these two numbers increased up to 36% and 37% respectively. For very highly engaged BIM users, the two percentages surged to 52% and 60% respectively.

Table 2. Percentage of BIM Users Who Consider Benefits of High/Very High Value (2009 to 2012)
(Source: McGraw-Hill Construction, 2012)

Return on Investment	2009 Rating by All BIM Users	2012 Rating by All BIM Users	2012 Rating by Very High E-level BIM Users
Increased Profits	21%	36%	52%
Fewer Claims and Litigation	20%	28%	50%
Reducing Overall Project Duration	27%	37%	60%
Maintaining Repeat Business	36%	49%	58%

The BIM implementation level varies by region, player and size of each firm. BIM Expertise Level varies by player and the years of experience using BIM. Both BIM implementation Level and BIM Expertise Level will have significant impact on ROI of BIM. Specifically, the higher level of implementation and expertise, the higher ROI of BIM can be expected in terms of both time and money investment. In addition, long-term BIM benefits and short-term benefits are showing different degrees of impact on different aspects of a project.

3. ROI of BIM Case study by Giel et al., 2009, University of Florida

Constructed by Company X, this case study was intended to determine the cost savings associated with BIM's implementation. The chosen software platform used by Company X has been Autodesk Revit Architecture, Structure, and MEP. In the BIM-assisted projects described in this case study; parametric modeling took place after the design phase was completed when the contract was awarded to Company X. The ROI analysis was then conducted on the project, based on BIM preventable direct and indirect costs and conclusions were made about the potential cost savings to an owner choosing to invest in BIM as an additional service.

Table 3 indicates the cost breakdown used in calculating the projected ROI. From this analysis, the return on investment of implementing BIM was estimated to be roughly 36.7%. It was also discovered that 4% of the total cost of change orders might have been completely eradicated, if BIM had been used.

Table 3 Project Constructed by X, ROI of BIM

Cost category	Amount
Total direct cost of subcontracting out panel shop drawings:	$16,650
Direct costs in preventable change orders:	
Embed fix change order:	$928
Girder and joist seat fix change order:	$8,499
Girder and door opening conflict:	$5,664
Total:	$15,091
Indirect costs of 7-dayBIM-preventable time overrun:	
Daily cost of contractor time overrun (General Conditions) ($855/day):	$5,985
Daily cost of 5% interest on construction loan for time overrun ($976/day):	$6,832
Daily cost of developer administration for time overrun ($446/day):	$3,122
Estimated cost of architect's contract administration for time overrun ($149/day):	$1,043
Total:	$16,982
Total Estimated Savings:	$48,723
Cost of BIM (0.5% of contract value):	$35,640
Net BIM savings:	$13,083
ROI:	36.7%

Note: The cost of investment was approximated at 0.5%, as furnished by the owner for BIM services in the contract. A 5% cap rate was assumed on the Owner's construction load for the purpose of this study.

In conclusion, it can be inferred that the implementation of BIM was perhaps a greater benefit to Company X than the owner. The qualitative benefits of reduced time overruns and lower change order costs were measurable; however, the savings seen on a project of this size were relatively minor. Owners choosing to invest in BIM as an additional service should weigh the scale and size of a project heavily. However, the measurable benefits associated with reduced RFIs, fewer change orders, and reduced project delay uncovered on both BIM-assisted projects are arguably reason enough to invest in the technology.

Summary, Conclusions, and Recommendations.

ROI is a popular metric. Many case studies, online surveys and research have revealed the fact that: BIM implementation can bring significant benefit to ACE/FM industry, in terms of project duration reduction, cost savings, personal safety and so on, even though all the data collected supporting this conclusion is mostly accounting for the direct benefit and savings associated with BIM implementation.

More extensive ROI that is explicitly bridge-oriented should be applied in the future to more fully evaluate the benefit of BrIM implementation for decision making among affected bridge industry stakeholders. Such benefits are likely to be incremental and cumulative. Thus, savings may be anticipated from a single targeted implemented data exchange, and increased savings may be anticipated from carrying an as-constructed model forward for lifecycle bridge-asset management purposes. For example, using a model-based approach for virtual assembly (a.k.a. "laydown") will result in schedule savings in both fabrication time (drill holes once, not twice) and avoidance of physical pre-assembly and teardown. Leveraging such savings beyond a single data exchange can be anticipated as "best practices" from early adopters are assembled and disseminated.