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BrIM for project delivery and the life-cycle: state of the art

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Bridge Information Modelling (BrIM) was introduced to bridge enterprise stakeholders in design, construction, operations and management. These stakeholders are increasingly realizing that a well thought out leveraging of bridge data for multiple purposes through the entire bridge life cycle is important. This paper surveys the genesis and development of BrIM supported by NSBA, NCHRP, AASHTO, and FHWA. This includes aspects that distinguish it from its close cousin, Building Information Modeling (BIM). Principal questions, issues, and challenges that have been raised by various stakeholders about BrIM are summarized in this paper to help clarify the way forward to increased industry acceptance and deployment of BrIM-enabled workflow.

Keywords: BrIM; workflow; life-cycle; IPD; data; XML

1. Introduction

Recently we celebrated the 50 years of Interstate Highway System and President Eisenhower's visionary initiative. Going forward, however, we are confronted with the increasing need for a prudent approach to renew that highway infrastructure. For centuries engineering and construction activities have relied on paper drawings as the primary representation of construction documentation. Other closely related industries have documented and/or projected reduced costs, faster delivery, and improved quality as a result of implementing 3D CAD based integrated design and manufacturing processes along with accompanying interoperability standards. Bridge enterprise is nearing the end of an era and we in the bridge enterprise are overdue to do the same. Failure to do so has been documented as a major cost centre in the closely related capital facilities industry (Gallaher *et al.* 2004). Advances in automation and communication technologies in recent years have been significant (Chen and Shirole' 2006), but they have not yet been fully adapted and integrated with each other and then deployed to accommodate the unique requirements of the bridge construction engineering and management enterprise. At the same time, the recent explosion of interest in integrated project delivery (e.g. Post 2008, Tulacz 2008), Building Information Modelling (BIM) (e.g. Jordani 2008, Rubin 2008) and its closely related cousin Bridge Information Modelling (BrIM) (Chen and Shirole' 2007, Puckett *et al.* 2008) are raising awareness in the industry that there are significant potential efficiencies and competitive advantage to be gained by developing these integrative approaches to greater maturity. Various aspects of BrIM are increasingly being used in bridge infrastructure delivery, albeit in piecemeal fashion. Aspects of BrIM methodology are currently being used in the design and construction of large and complex bridges, such as for visualisation and detailing as well as in bridge operations and management through the use of AASHTOWare.

BIM is changing the product delivery model in the building industry and is certainly leading the bridge community in the area of architecture, structural and mechanical engineering integration. Fabrication and construction processes are being effectively linked as well. BIM technology is paving the way for different delivery models specifically more toward design/build where the design and construction professionals team for the entire project duration. Furthermore, all design professionals are coming on board earlier in the project life-cycle, at a time when critical decisions are made (Young 2007). Also of note, GSA now requires BIM for their major projects (GSA 2009, Hardy 2006).

Although BrIM may be lagging BIM in the area of design and construction, in lifelong operations and management of large inventories of structures the

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bridge community leads with long-time software products associated with management, rating, routing, and economic analysis (AASHTO 2008). This paper conceptually levers what has been done in BIM and is being done in BrIM to advantage. The post-construction activities are paramount for owners of large inventories beginning and ending with bridge management.

Bridge management involves, to an increasing extent, management of bridge data. At the project level, bridge project data management is complicated, unfortunately, by the proliferation of 'stove-piped' software applications (and the variety of accompanying file formats) that have sprung up over the years without due consideration of the advantages to be gained via functional interoperability that would accompany a principled leveraging of bridge data for multiple purposes throughout the bridge life-cycle. In the absence of industry-wide non-proprietary standards for the representation and exchange of life-cycle bridge data, this paper describes and demonstrates some of the potential means and benefits of leveraging bridge data from the design stage for more aspects of the life-cycle than is typical in current practice. The intent is to demonstrate the viability of integrated bridge project delivery and life-cycle management via a prototype integrated system that illustrates representative data exchanges and applications throughout the bridge life-cycle. The paper thus will provide an important update on current FHWA-funded research on Integrated Bridge Project Delivery and Life Cycle Management (Contract DTFH61-06-D-00037) being conducted by the authors.

This project is motivated by the recognition that the current US practice of information transfer during the bridge planning/design/fabrication/construction/operation/maintenance processes involves repeated manual transcription of data that is error-prone, time-consuming approvals (e.g. of shop drawings), and a lack of standardised formats that hinder electronic information transfer. It is also being recognised that without such standards, electronic information exchange is cumbersome at best, and often not possible.

This paper presents current research to address this challenge under FHWA sponsorship to develop a program to explore the promise of parametric 3D BrIM as a technology that will enable not only acceleration of the bridge design and delivery (Chen and Shirole' 2006), but also leveraging that design-and-construction stage bridge data to enhance life-cycle management of the as-built bridge. The authors are developing BrIM for a recently built three-span bridge (Quincy Avenue Bridge over I-25 in Denver, Colorado) and modelling it for its life-cycle. The processes outlined and associated figures were derived from demonstrating BrIM for two alternative bridge designs: steel and prestressed concrete.

Additionally, this paper thus provides a significant update to an earlier paper by one of the authors (Shirole' 1993), which envisioned a confluence of various then-emerging automation and communication technologies to support bridge management functions. Other prior work includes that described in Chen (2002) and Chen *et al.* (2003).

2. The bridge enterprise

Although at the present time there are no non-proprietary standards for electronic exchange of life-cycle bridge data, it is the vision of this project to facilitate the development of an integrated system for the entire bridge life-cycle (i.e. 'from cradle to grave'). This project is primarily the first step toward such a streamlined approach to accomplish its overall program objective. As for the future, a complete modelling of bridge information in standardised format can be anticipated to facilitate integration of computer-aided design (CAD), computer-aided engineering (CAE), computer-integrated manufacturing (CIM), construction engineering and management (CEM) and bridge management (BM) that will enable not only rapid and better quality project delivery but also subsequent cost-effective life-cycle management. All three fundamental objectives of bridge delivery, namely higher quality, faster delivery, and more economical cost over the bridge life-cycle, would then be attained.

Historically, in the development of various computational tools for supporting these various aspects (e.g. planning, design, detailing, estimating, fabrication, construction project management, bridge operations, and bridge management), individual aspects were typically addressed in standalone fashion without sufficient regard for complications arising from multiple data sources. Some of these complications involve the need for tedious, manual, error-prone re-entry of duplicate data into several software 'stove-piped' applications. If a coordinated shepherding of data supporting these individual applications were developed, bridge data integrity would be more easily maintained, and 'handoff' processes from one application to another would be streamlined, if not made altogether seamless.

Just such an attempted coordinated shepherding of bridge data is shown in Figure 1, which shows a conceptual view of the organisation of representative aspects of the 'cradle-to-grave' bridge design and construction enterprise and how they each depend on bridge data represented in the centre of the diagram. A coordinated handling and leveraging of that data could

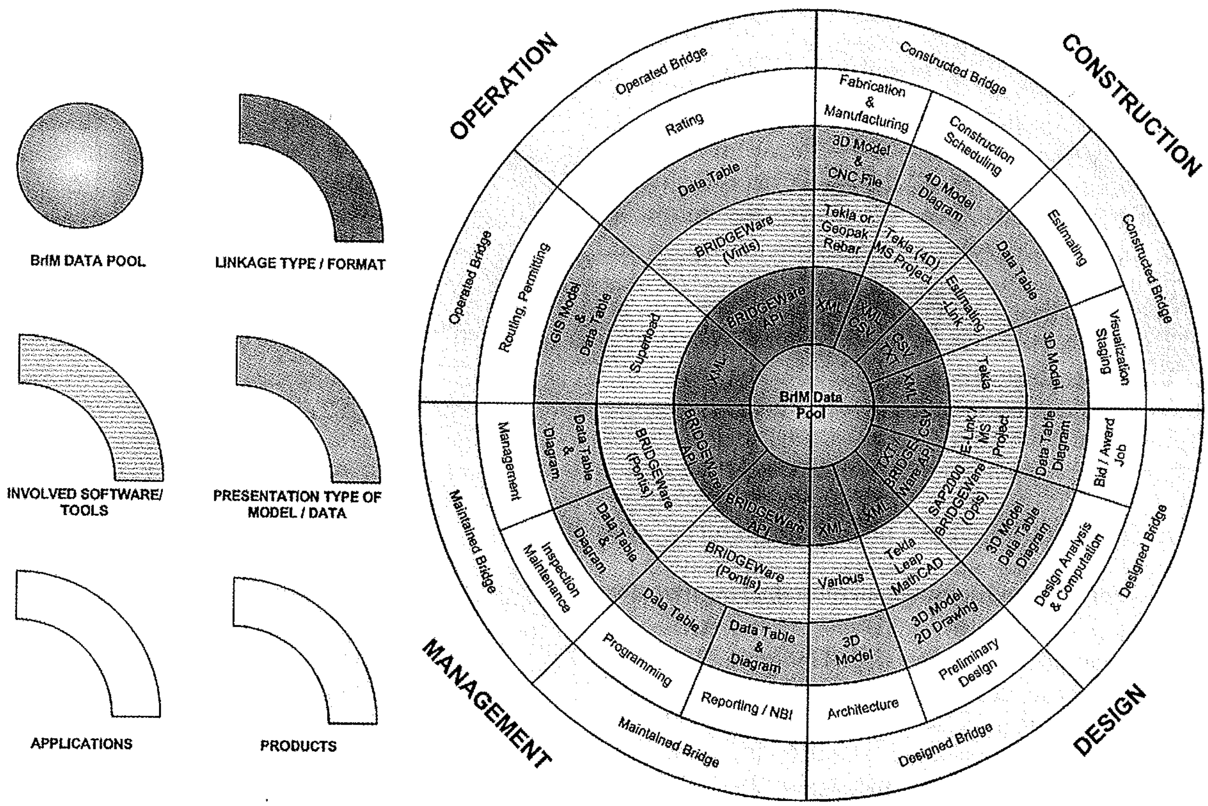

Figure 1. Data model centric view of the bridge enterprise.

prevent the proliferation of problems resulting from multiple (potentially inconsistent) sources of bridge data.

How information flows among particular applications is shown in Figure 2 for a steel bridge superstructure and in Figure 3 for a concrete bridge superstructure. It should be noted that the particular commercial software applications appearing in these figures are just examples based on particular applications investigated by the project team.

3. Design stage

Figure 4 shows a portion of the quantitative data input/verification for the concrete girder alternative of the bridge case study considered in this investigation. As indicated in Figure 3, this data was electronically passed into BridgeWare (Opis) and further 'downstream', e.g. using XML in order to avoid redundant data entry.

Specification checks are performed on the trial section and can be inspected either for the concrete alternate or for the steel alternate. Figure 5 shows a portion of the specification checks performed by Opis on the steel alternate of the Quincy Avenue case study bridge. The software linkage that takes data from MathCad (see Figure 2) into Opis for this check is illustrated in Figure 6, which shows quantitative data in the MathCad worksheet that is passed using XML into Opis, for which the Opis Explorer is shown in Figure 6.

4. Design into construction

Figure 7 shows a 3D view of a portion of the bridge computer model that would have been used to generate design and construction information, including contract plans and shop drawings. That model has its geometry generated such that its geometry is entirely consistent with the roadway stationing, plan, and profile on which the bridge lies. Drawings in turn are (merely) extracted sections from such a model, an example of which is shown in Figure 8.

Detailing for fabrication follows on the heels of the final design. That final design culminated in a set of construction documents for which bids could be prepared, but those documents typically do not contain all information needed for fabrication and construction. Hence the usual detailing phase, in which

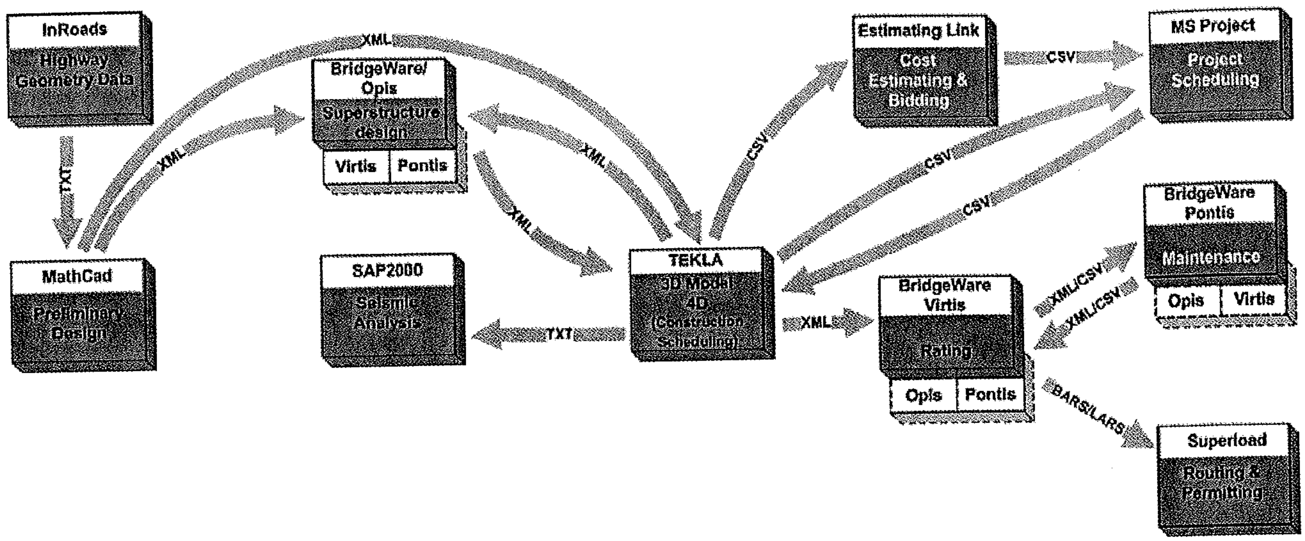

Figure 2. Workflow and software interoperabilities: steel alternate.

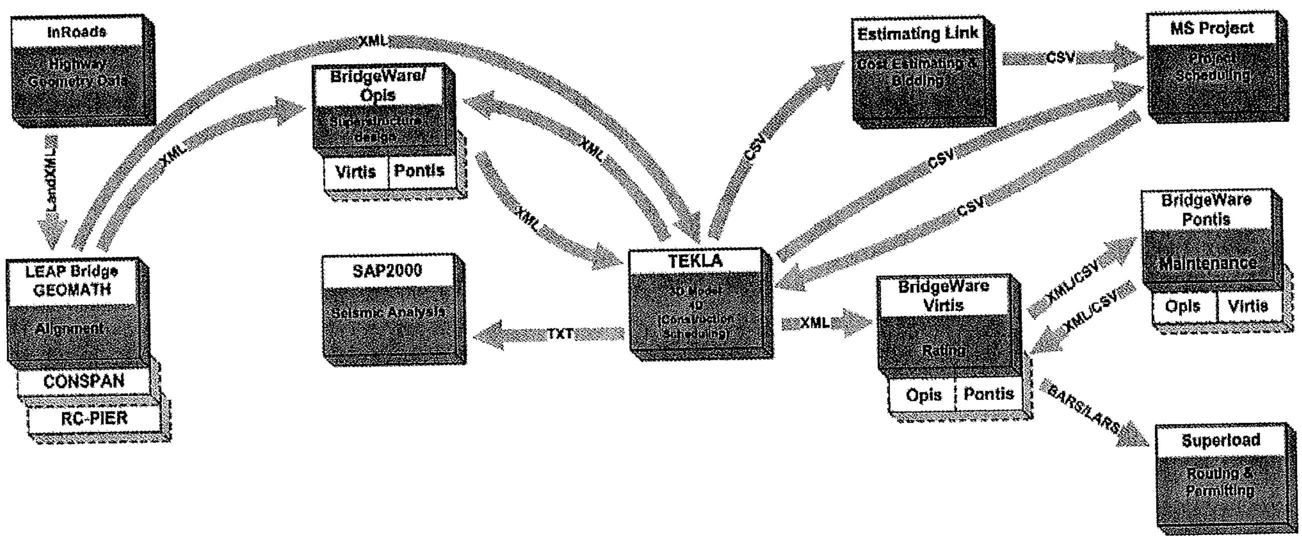

Figure 3. Workflow and software interoperabilities: concrete alternate.

all relevant design data traditionally is manually re-entered by the contractor/fabricator in order to generate shop drawings containing all information needed for fabrication.

In an integrated workflow proposed and envisioned herein, the bridge model data used for final design documentation itself becomes the electronic starting point for the addition of detailing information consistent with both the contractors' means and methods and the design intent (the latter presumably verified as part of the shop drawing review process). Thus, time-consuming error-prone manual re-entry of data is avoided. Having the same model shared with 'downstream' CEM operations is a significant advantage. Multiple versions of bridge data do not proliferate and require disambiguation. Updates to the data have clearly defined access mechanisms to prevent this proliferation.

For electronic data exchange purposes, even in lieu of industry-wide standards there are several approaches that may be taken. Among these, we have test-driven application-specific APIs (Application Programming Interfaces), XML (eXtensible Markup Language), and direct export of CNC (Computer Numerical Control) files when such export is supported by the detailing software. These are used for transferring design model data into the detailing software in order to avoid duplicate data entry and for export to CNC-driven shop equipment. Such equipment exists for such tasks as hole-drilling, automated welding, and rebar bending, for example. Thus, with a suitably equipped fabrication shop and raw material lined up, it is technically possible to start fabricating as soon as the detailing is approved – and the shop itself has no need for 'shop drawings'!

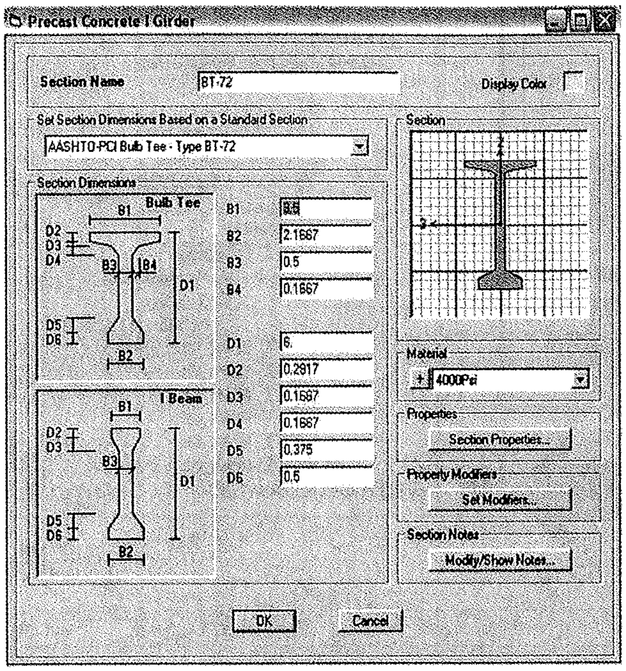

Figure 4. Concrete girder data input/verification.

In detailing software application, Figure 9 shows a portion of a bridge superstructure model, the girders (data) for which were imported using the API or XML.

This detailing model has associated with the bolted connections shown all data needed for material procurement (e.g. bolt diameters, grades, lengths, washers, etc.). Similarly, for welded connections this detailing model has electrode information, total lengths of welds of various sizes, in short all quantity information that would be needed by a fabricator to conduct a detailed estimate of fabrication costs. Figure 10 shows the export of CNC files directly from the detailing software as described above, for direct use by suitable shop equipment.

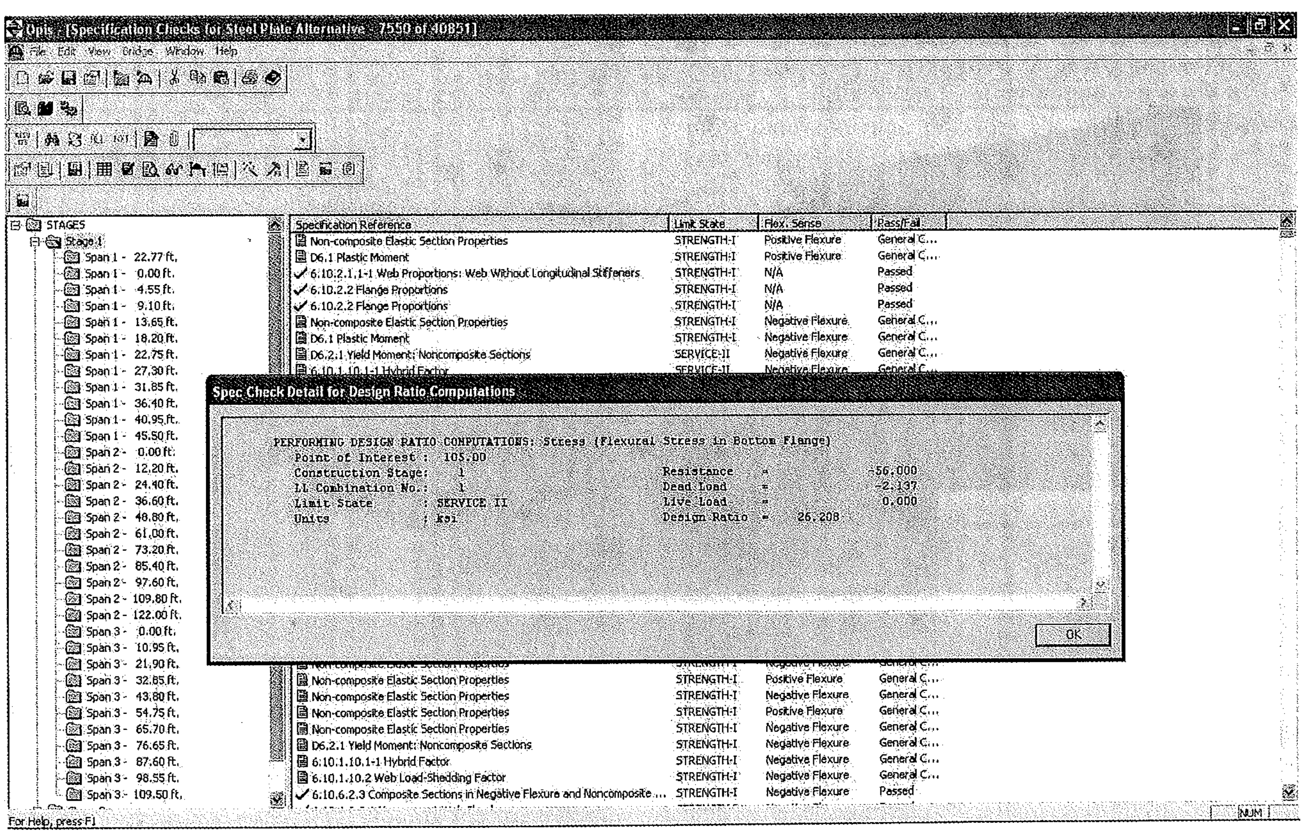

Figure 5. Specification checking in Opis (steel alternate).

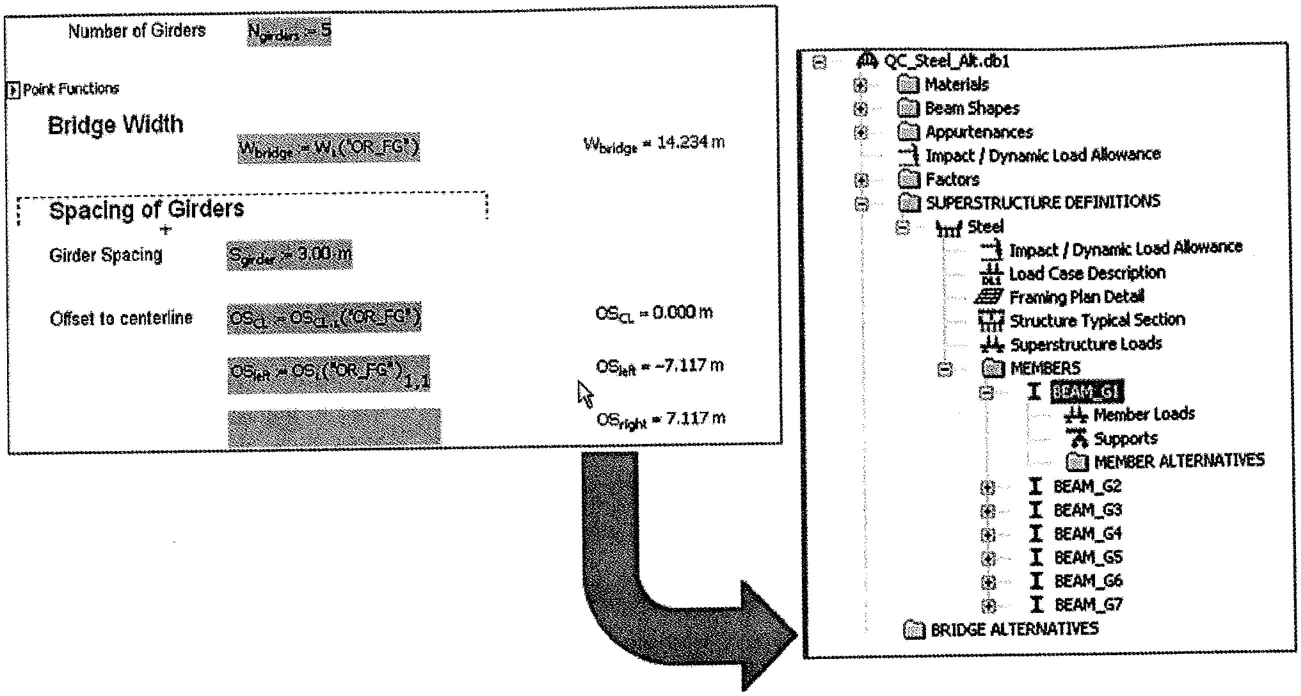

Figure 6. Linking from MathCad to Opis via XML.

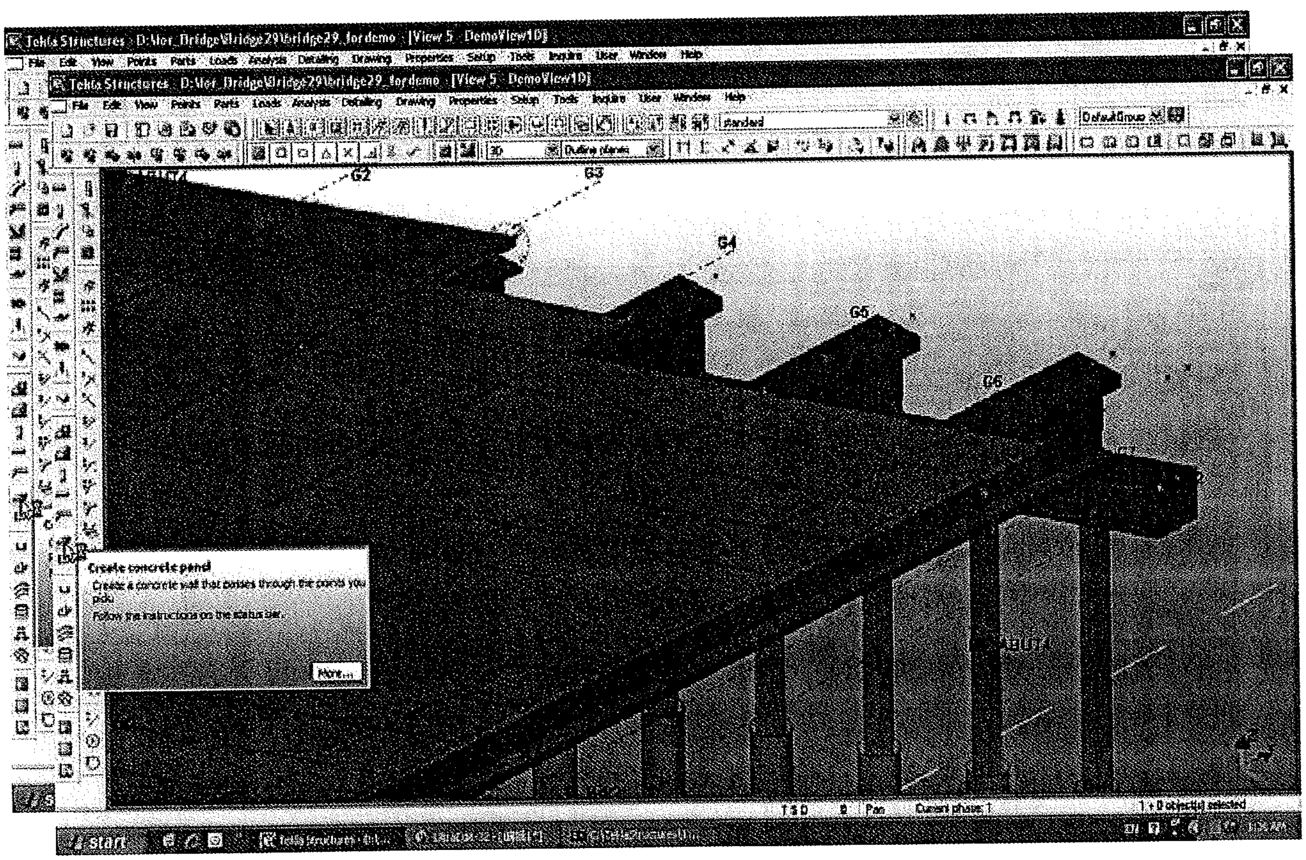

Figure 7. 2D view of a portion of the bridge computer model.

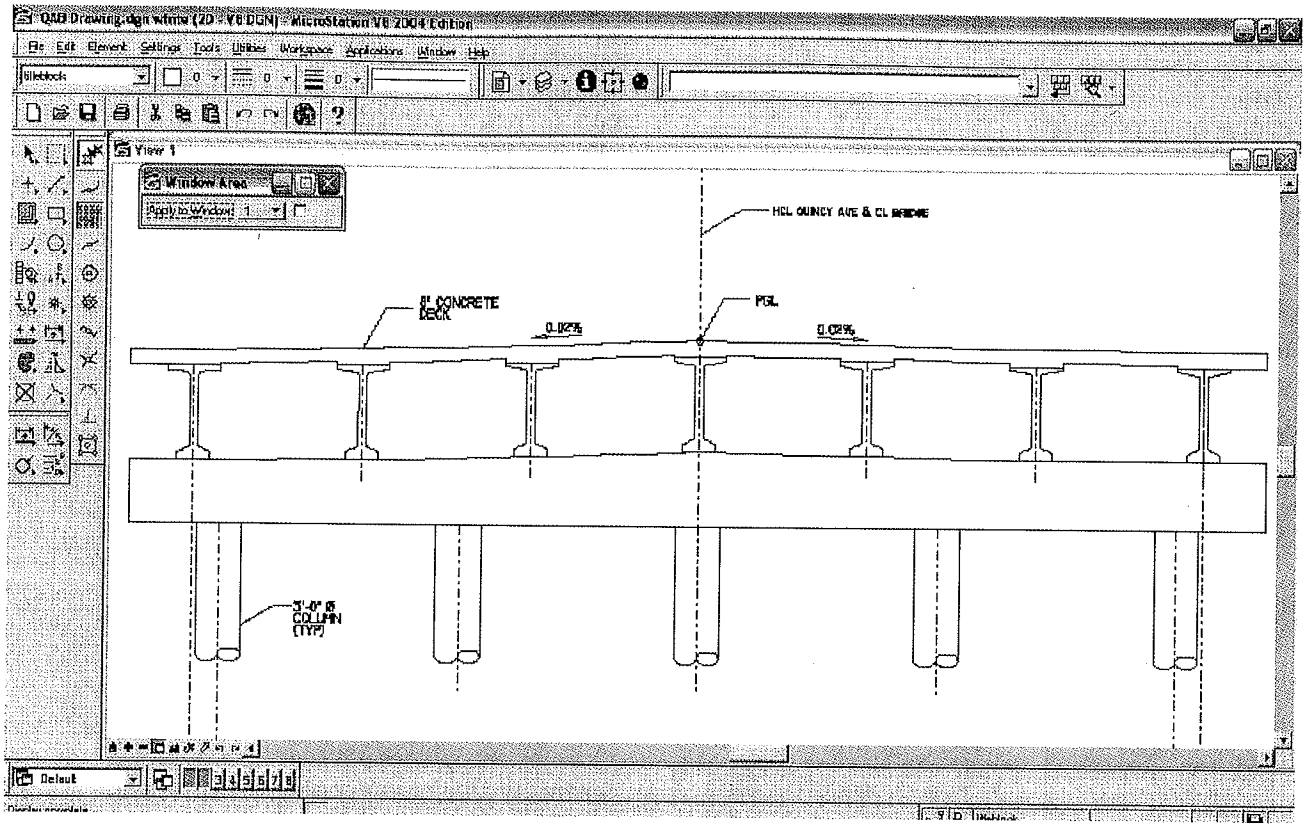

Figure 8. 2D bridge cross-section drawing extracted directly from 3D model.

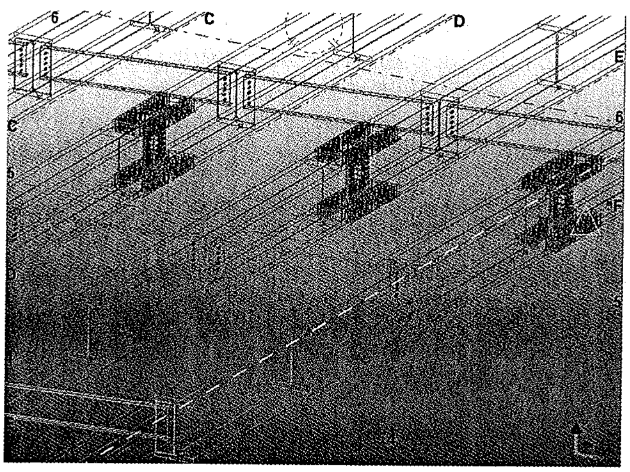

Figure 9. Portion of steel superstructure model in steel detailing application.

As shown in Figures 2 and 3, quantity information from the model can be exported to an estimating application. Just as 2D drawings are merely reports generated from the model, bill of material lists are similarly reports generated from the model. These reports, furthermore, are guaranteed to be consistent with the information contained in the model. These quantity reports can be used for cost estimating or for actual material procurement. Interfacing such a list (e.g. in a spreadsheet software application) to a unit price database then provides the means to carry out cost estimating based on the extracted model quantities. Figure 11 shows a sample screen from the estimating application being used in the present study.

The model detailing software also has capabilities for incorporating '4D' (i.e. time or sequence based) information into the model for use in construction planning. This kind of capability is increasingly being provided in 3D CAD software applications (de Vries and Harink 2007). 'User attribute' data fields associated with the various bridge component objects in the CAD model can be used for such things as erection phasing and material management (both for shipping bills of lading and for on-site material management) as well as for interfacing with Scheduling software applications such as MS Project. Figure 12 shows a glimpse of 4D modelling of a case study bridge for erection sequence planning purposes.

Companion structural analysis software in some cases has the capability to selectively turn 'on' or 'off' not-yet-erected bridge components in order to evaluate structural safety of partially braced partially constructed conditions, or of differing deck concrete pouring sequence scenarios (e.g. in order to evaluate bearing uplift potential).

5. Operation and management aspects

Load rating of bridges constitutes a central recurrent task during the operations phase of the bridge life-cycle. The starting point for the bridge model suitable to drive load rating processes can be the bridge model inherited from the design and construction stages. But it is, of course, critically important that the bridge model data on which a load rating is based be updated based on recent inspection data to reflect current condition changes that may influence the load rating process. Section loss data and removal of questionable strands are examples of such updates.

In an integrated life-cycle environment envisioned herein, having the same model shared between design (checking) and load rating is a significant advantage. Bridge data (e.g. girder section data, material properties, etc.) thus need not be re-entered in order to conduct load-rating, and multiple copies of such data do not proliferate and thereby require disambiguation. Updates (e.g. section loss) to the data have clearly defined access mechanisms and are reflected in the common AASHTOWare, BridgeWare database. For electronic data exchange purposes, that database is, in turn, accessible via either XML or the BridgeWare API which have been defined and designed to facilitate third-party access to the bridge data in order to leverage it for various purposes.

Figure 13 shows a view of one of the screens in Virtis used to verify the data already in the model defining the bridge girder geometry. Associated screens would enable adjustment of any data needed to reflect recently observed *in situ* conditions prior to executing a load rating operation

Figure 14 illustrates one of the screens illustrating an output from the load rating exercise. Having XML-based or BridgeWare API-based linkage

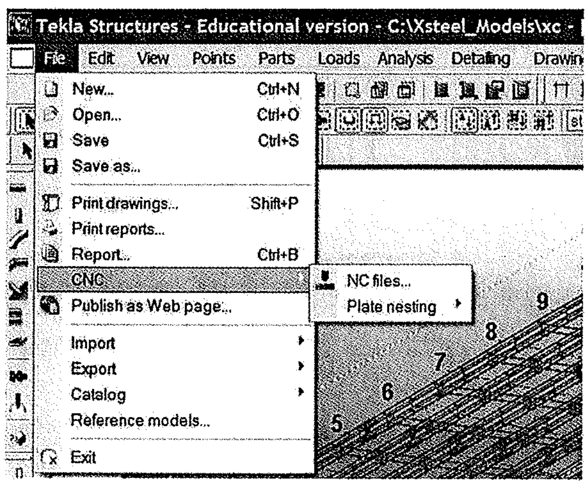

Figure 10. CNC file export.

Item Number		Bid Qty/ Takeoff Qty	Calc. Unit/ Unit Cost	Bid Unit	Total Bid/ Total Cost	Markup %	Item Spread $34,156...	Print Subtotal	Labor Unit	Labor Amt $72,781...	Equi
201.06	LS	1.000	2315.115	2300.000	2300.00	22.6	424.38		911.37	911.37	5
CLEARING AND GRUBBING		1.000	1875.615		1875.62						
203.02	CY	290.000	37.724	38.000	11020.00	24.3	2156.92		15.71	4556.83	
UNCLASSIFIED EXCAVATION AND D		290.000	30.562		8863.08						
203.21	CY	180.000	65.057	65.000	11700.00	23.3	2212.75		24.95	4490.65	
SELECT STRUCTURE FILL		180.000	52.707		9487.25						
206.01	CY	290.000	20.570	20.000	5800.00	20.0	967.13		11.31	3280.91	
STRUCTURE EXCAVATION		290.000	16.665		4832.87						
206.02	CY	70.000	18.938	19.000	1330.00	23.8	256.03		10.42	729.09	
TRENCH AND CULVERT EXCAVATI		70.000	15.342		1073.97						
207.10	SY	270.000	7.107	7.000	1890.00	21.6	335.46		4.01	1081.54	
GEOTEXTILE BEDDING		270.000	5.758		1554.54						
207.16	SY	50.000	12.672	12.000	600.00	16.9	86.69		4.33	216.31	
PREFABRICATED COMPOSITE INTE		50.000	10.266		513.31						
304.15	CY	15.000	73.359	75.000	1125.00	26.2	233.51		36.45	546.82	
SUBBASE COURSE, OPTIONAL TYP		15.000	59.433		891.49						
403.198902	TON	15.000	302.458	300.000	4500.00	22.4	824.40		121.44	1821.53	
HOT MIX ASPHALT, TYPE 7 TOP CO		15.000	245.040		3675.60						
555.0104	CY	27.000	507.476	500.000	13500.00	21.6	2399.29		248.30	6704.15	
FOOTING CONCRETE, CLASS A		27.000	411.137		11100.71						
555.0105	CY	22.000	1917.929	1800.000	39600.00	15.8	5415.72		1056.67	23246.64	3
CONCRETE FOR STRUCTURES, CL		22.000	1553.831		34184.28						
556.0201	POUND	4200.000	1.251	1.250	5250.00	23.3	992.66		0.16	683.72	
UNCOATED BAR REINFORCEMENT		4200.000	1.014		4257.34						
15558.50	SQ. FT.	852.000	4.118	4.000	3408.00	19.9	565.55		2.34	1994.13	
MEMBRANE WATERPROOFING SYS		852.000	3.336		2842.45						

Figure 11. Bridge project cost estimating screen.

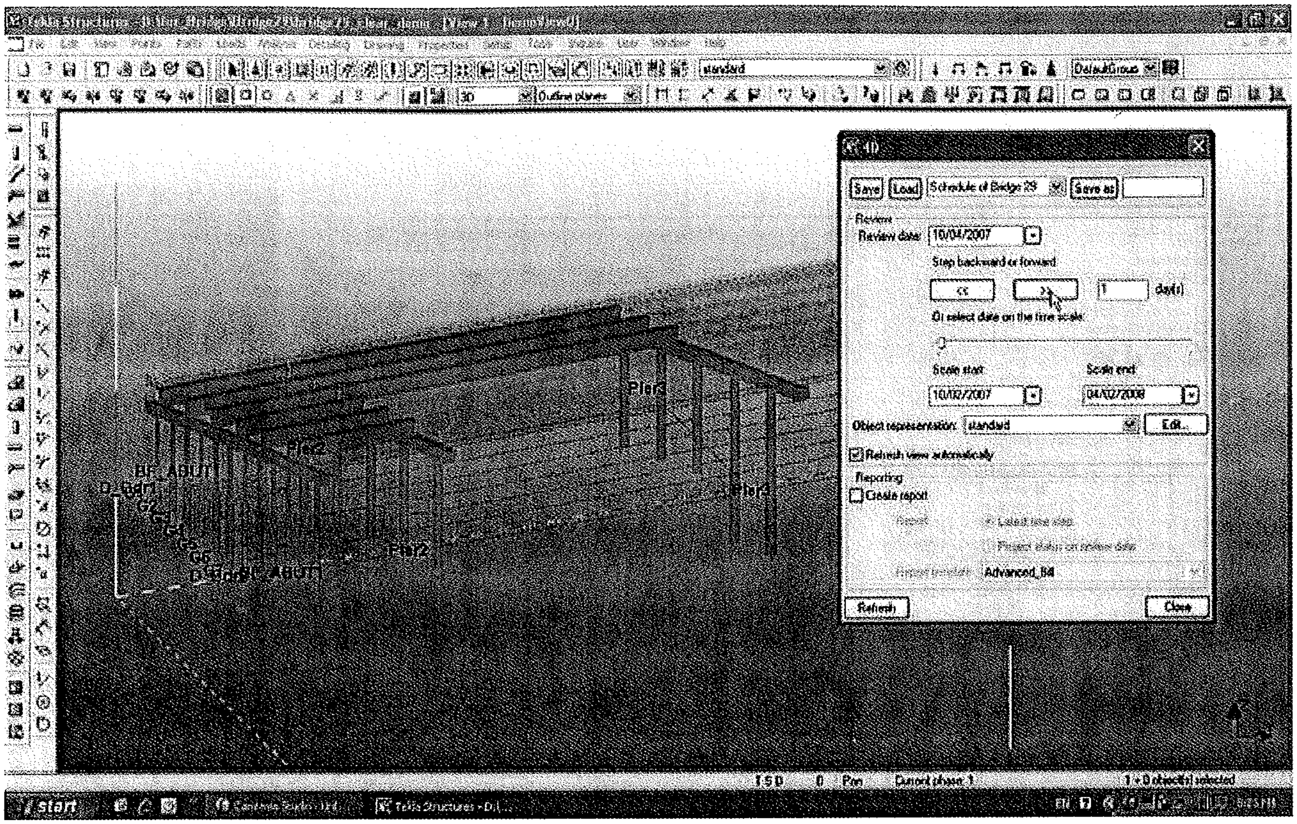

Figure 12. 4D modelling for erection sequence planning.

software facilitates the execution of this load rating exercise by avoiding tedious time-consuming error-prone bridge data re-entry where such is not needed, while in no way excluding the responsible bridge rating engineer from the workflow. Figure 15 shows another useful load rating output in the form of RFs (Rating Factors) for various points along the case study bridge superstructure.

Overweight and special vehicle routing and permitting requests constitute a significant and ongoing burden on surface transportation system owners. The software applications dealing with such requests rely not only upon the very same bridge data used for a bridge rating calculation but also upon the following:

- Software application capabilities to define custom loads (axle spacings, axle loads, etc.), and rate the bridge against such loads instead of the standard HS-20 or HL-93 type notional loads.
- Interfacing to highway routing option data and the bridges located on those candidate routes, all of which will need to be rated in 'batch' fashion for custom loads.

To the extent that BridgeWare-compatible data is defined for such bridges, there is no reason not to include the bridge network data and the applications utilising such data in an integrated environment. Linking such functionalities would enable the following aspects of the routing/permitting workflow: online application for permit vehicle, bridge rating analyses and resulting travel routing, permit issuance, and secure permit payment processing. Figure 16 shows one of the software screens used in the permit application process (Bentley Systems, Inc. 2008), and Figure 17 shows resulting vehicle routing selection (courtesy of AASHTOWare).

The records management burden associated with maintaining biennial bridge inspection data is significant. The Pontis software provides software support at the project level for this data via the BridgeWare database whose ability to share with Opis (for design checks) and Virtis (for rating calculations) provides significant potential advantages to bridge owners. It makes sense for a life-cycle-integrated approach to bridge asset management to make use of this direct data-level support, which eliminates the need for software interoperability architectures in this particular portion of the envisioned integrated environment.

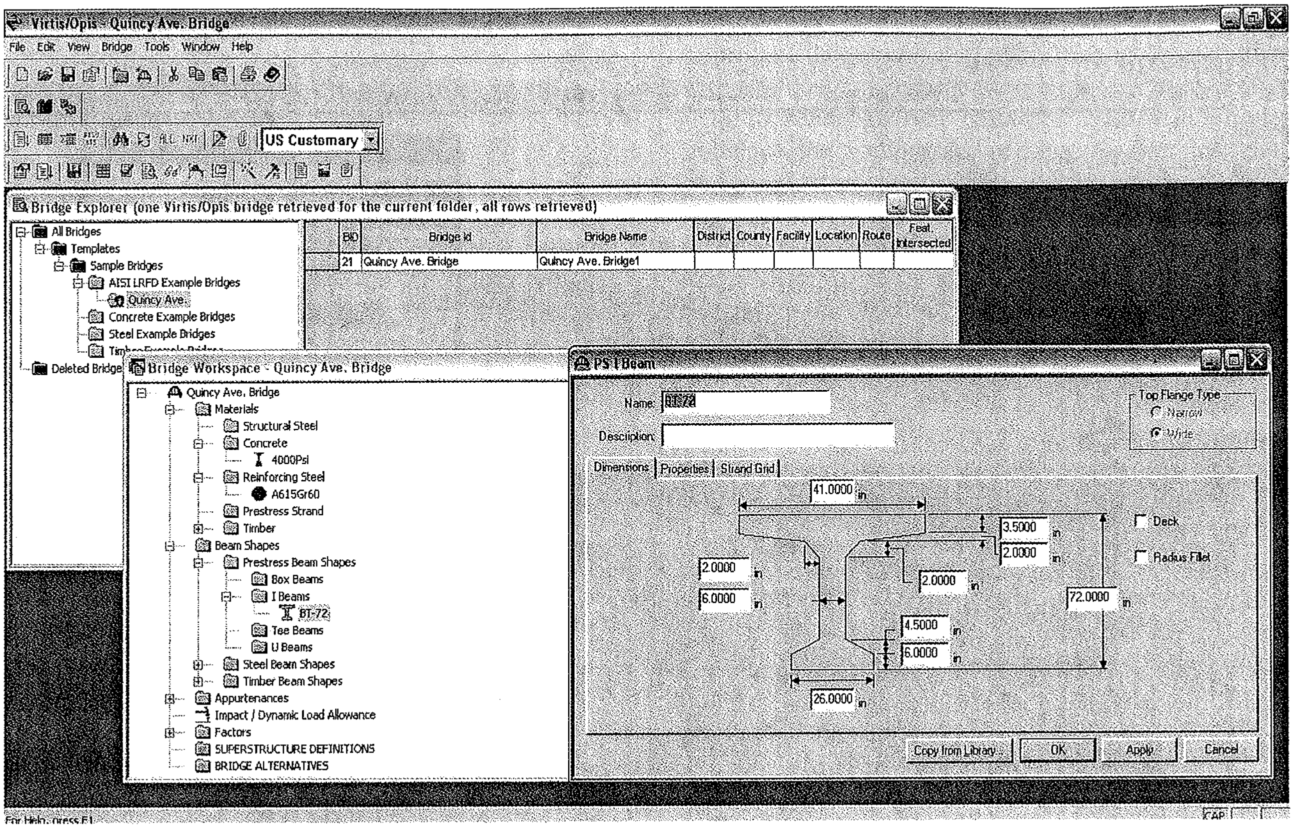

Figure 13. Checking/updating bridge beam definition in Virtis.

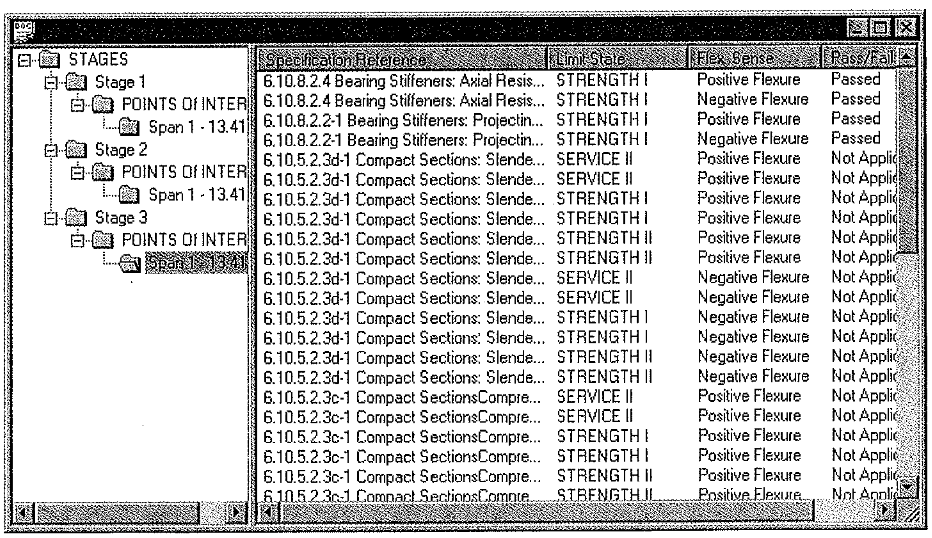

Figure 14. Detailed spec computation for bridge load rating report.

In this segment (project-level bridge inspection data management) would be found support for, for example, NBI condition ratings report generation. As data requirements for such reports evolve over time, the overall bridge life-cycle information management framework envisioned in Figure 1 would need to evolve with it. Figure 18 (courtesy AASHTOWare) shows one of the bridge inspection data screens provided by Pontis.

After inspection data is recorded, a bridge load rating may need to be re-computed (i.e. the

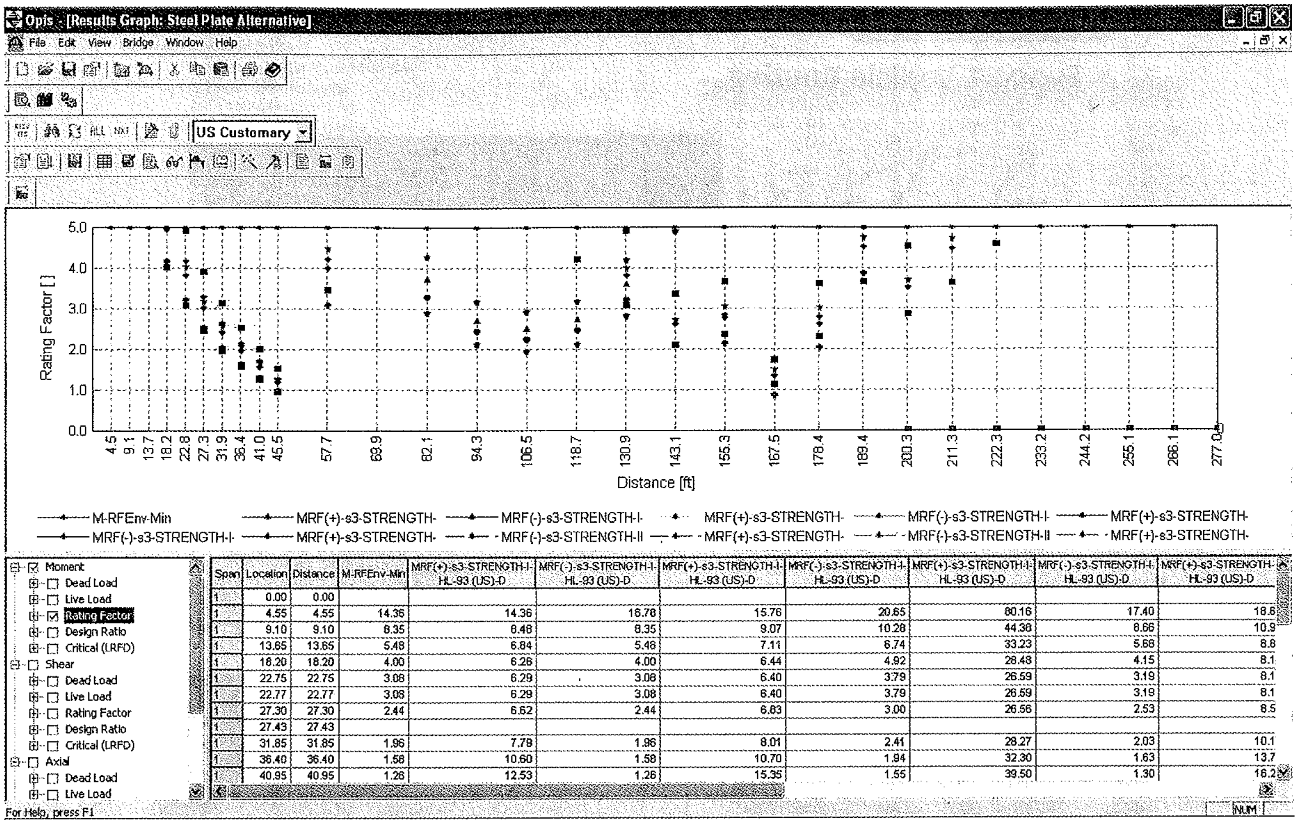

Figure 15. Bridge load rating factors.

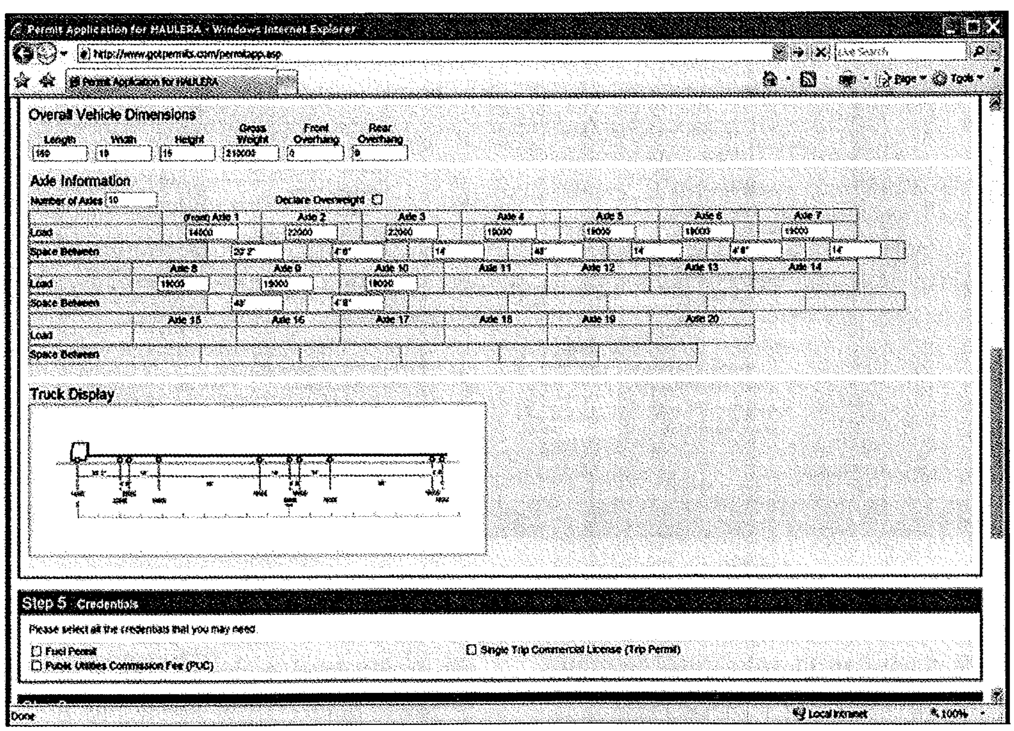

Figure 16. Permit application.

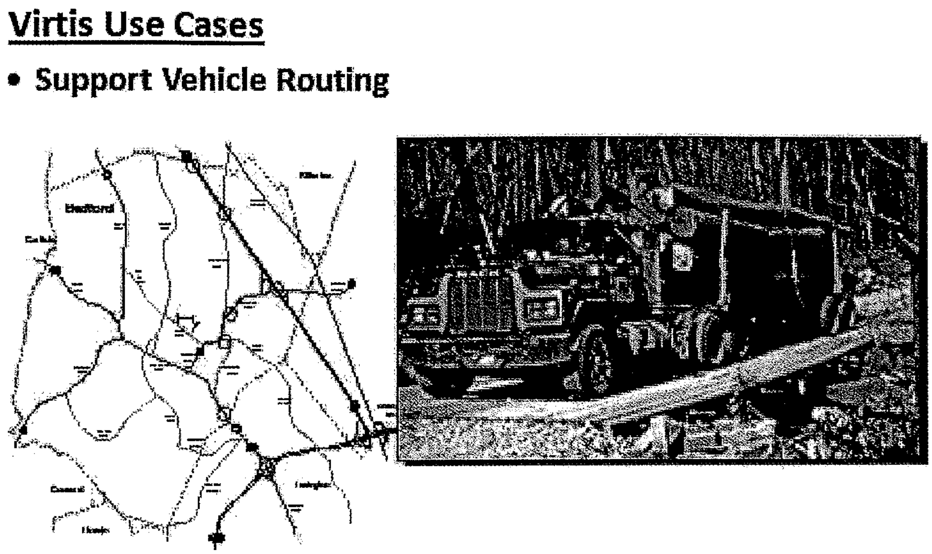

Figure 17. Route selection.

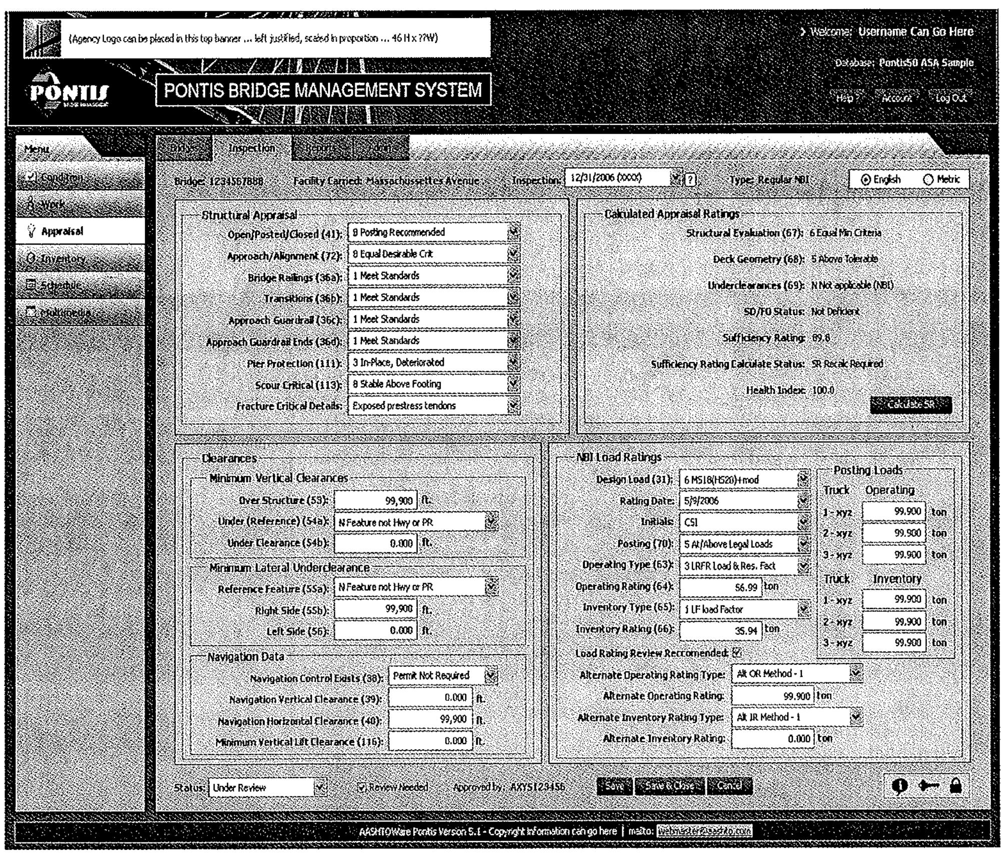

Figure 18. Illustrative bridge inspection data screen in Pontis.

bridge ‘re-rated’). Figure 19 illustrates the interoperabilities associated with this step in the process.

Although network-level bridge management functionality has been typically considered distinct from the project level, access to both is provided by Pontis. Integration performed under this project provides a means to electronically populate the BridgeWare database from the design phase. To the extent that

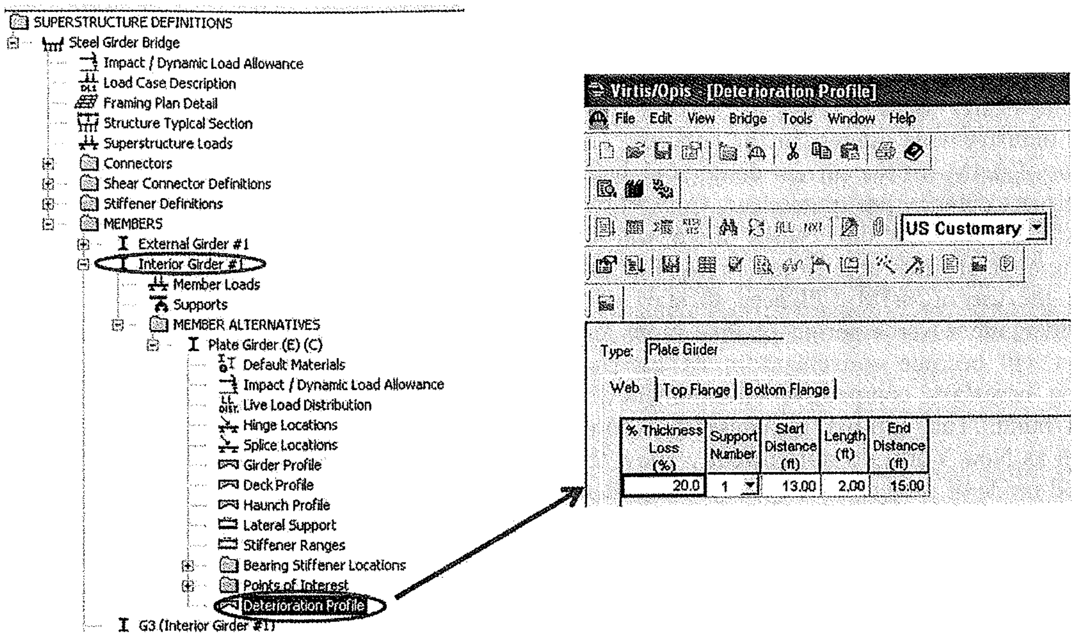

Figure 19. Bridge re-rating example due to observed section loss.

the bridge network is suitably defined in the BridgeWare database, further leveraging of that bridge data is provided by the fact that it is in a common format to support not only design and rating but also both project- and network-level bridge management, such as prioritisation and program decision-making. As with the inspection data described above, this direct data-level support eliminates the need for software interoperability architectures in this particular portion of the envisioned integrated environment.

6. Summary and conclusions

This paper has described an overview of current ongoing work to conceptualise and demonstrate key aspects of BrIM for the life-cycle, a comprehensive shepherding of bridge design, construction, operation, and maintenance data to span the entire life-cycle. Highlights of this approach and accompanying software demonstration include the following:

- Use of a comprehensive 'cradle to grave' view of the data needed to support bridge life-cycle activities.
- Tools and technologies (e.g. XML, APIs) are proliferating that make possible reliable electronic exchange of bridge data in support of life-cycle applications, although resulting solutions are then necessarily *ad hoc*, and demonstrations of implemented software linkages is in the context of two three-span straight grade separation bridges.

Advances in automation and communication technologies in recent years have been significant, but they have not yet been fully adapted and integrated with each other and then deployed to accommodate the unique requirements of the bridge construction engineering and management enterprise. Other industries have experienced significant time and cost savings when an integrated approach was utilised for project delivery (Post 2009a). Examples of other industries that have experienced significant time and cost savings are building (GM plant, Denver Museum) and ship-building (Queen Mary II completely built and on the ocean in 2 years). The *Engineering News-Record* citations in the paper are intended to provide a brief pointer to other industries that have benefited from deployment of related technologies. However, the AE industry is learning and continuing to report successes, shortfalls, suggestions for implementation (Post 2009b) including discussions of adjustments to recently developed model contract language to address liability concerns (Post 2009c).

The lack of industry-wide standards for interoperability and compatibility continue to contribute to the bridge industry's lag behind the building industry in BIM/BrIM related areas. This paper results from a 'Proof of Concept (POC)' project funded by FHWA and supported by AASHTO, NSBA and National

Concrete Bridge Council (NCBC). This project is intended to spark industry-wide interest in BrIM. The liability issues, similar to what BIM is addressing now, will become clearer once FHWA is successful in generating industry-wide interest in the concept. The implications of BrIM for the current design–bid–build mode of project delivery are quite clear. Competitive bidding will be possible only when there will be sufficient number of firms able to use BrIM. For this to happen the use of BrIM will need to start with design–build mode. Over a period of time more and more firms will become conversant in its use and provide the necessary competitive environment for design–bid–build. The authors recognise that some states, such as New York, do not currently allow the design build mode of project delivery. However, there are many other states that do and will benefit from the use of BrIM with design build. The bridge industry can expect to have experience similar to the building industry.

The integrated project delivery approach (BrIM) encourages a more holistic life-cycle cost perspective when considering issues of cost. There currently exists no data upon which to make an informed statement as to the effect of BrIM on design costs. Under BrIM the actual design tasks will be no different than currently required of a bridge designer and as such should not affect the design costs. However, BrIM will enable the designer to explore and evaluate more alternative designs at much less additional cost than currently possible. Additional tasks in the application of BrIM methodology will be model creation and management through the bridge life-cycle, not just the design phase, cost of which, based upon experiences in other industries, will be more than compensated through the time and cost savings during construction phase alone, based on the. Using BIM the General Motors Corporation completed construction of its 200 000 ft^2 plant in 14 months instead of 20 months and at significant cost savings (Sawyer 2005). To date, the seamless flow of design, construction, operations and management information, which has been much needed, has not been possible. There is reason to believe, however, that sooner or later consensus on industry-wide standards for interoperability will emerge. One can expect that this proof of concept (POC) FHWA Project will have paved the way to a truly comprehensive and cost-effective approach to overall bridge life-cycle management.

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