INTEGRATED BRIDGE PROJECT DELIVERY AND LIFE CYCLE MANAGEMENT

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ABSTRACT

Bridge engineers worldwide have used accelerated bridge construction practices successfully for many years. Now with the advent of high performance materials and emerging technologies, even greater emphasis is placed on the development and implementation of accelerated construction technology for renewal of the Nation's roads, bridges, and other structures.

Accelerated bridge construction technology with automated fabrication, construction, and preservation, aligns well with the strategic goals of the United States Department of Transportation's Federal Highway Administration (FHWA), including improved safety, increased mobility and production, enhanced human and natural environments, and continued organizational excellence. The value of this new technology was recognized in June 2005 when the American Association of State Highway and Transportation Officials' Subcommittee on Bridges and Structures passed a resolution on "Comprehensive Integrated Bridge Project Delivery Through Automation to Achieve Rapid Construction."

This paper highlights developments that led the FHWA's Office of Bridge Technology, working with State departments of transportation and the concrete and steel bridge industries, to launch a major initiative to identify available technologies and develop integrated engineering software demonstration packages to promote faster and more efficient automated processes applicable through the entire life cycle (design, fabrication, construction, and preservation) for bridge owners and contractors. The paper includes examples that illustrate how the engineering software package that will be developed will include guidelines and training materials to ease the transition among users from current practices to synergistic integrated automation. Also, the paper explains that integrated automation through 3D modeling is an extension of the conventional 2D methodology in designing, constructing, and maintaining bridges. The use of 3D modeling will generate an architectural blueprint for integrating phases into the automated processes yet it will have the potential to produce significantly improved 2D design drawings, as well as construction drawings, in conjunction with life-cycle management through automation.

Further, the paper will explain how the FHWA will accomplish this major initiative in two contracts. Contract objectives and scope are included. The recently awarded first contract will focus primarily on developing and demonstrating 3D modeling applications for steel and concrete bridges to show potential applications and the benefits of "Integrated Bridge Project Delivery and Life Cycle Management." Similar tasks of a second contract are presented to show the benefits on <u>actual</u> concrete and steel bridges.

KEY WORDS: Automation, Bridges, 3D modeling, Life Cycle Management

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INTRODUCTION

Congestion on our highways is a growing concern in America and around the globe. As Federal Highway Administrator J Richard Capka explained in a June 2006 message to all employees of the Federal Highway Administration:

> Congestion is stifling commerce. Technology and innovation are advancing at breakneck paces and

> we need to be able to take full advantage of what they have to offer…. Transportation will play a huge role in our nation's ability to remain competitive in the global marketplace.

The highway community cannot control the number of vehicles, malfunctions, shifts in workplaces, and other factors that cause congestion, but it can control delays resulting from roadwork that affects existing travel lanes. As a result, interest is growing in finding ways to speed repairs, rehabilitation, and/or replacement of structures and highways. We are increasingly finding that it is possible to reduce the time these projects take and the costs associated with the inevitable disruption during the construction period.

A committee of the National Research Council[Footnote 1] has looked at the competing needs in our infrastructure (such as dams and roads) and has concluded that we need to rethink our approach.[1] The committee's report states:

> There is an urgent need to rebuild America, but the cost is prohibitive if this is not done intelligently…. (T)he nation must strive for intelligent renewal, a process that uses limited resources in a cost effective manner. This calls for…. adapting existing knowledge to the tasks at hand and developing new scientific and engineering knowledge.

Such a process is underway for bridges, as illustrated by recent advances in automation for building bridges. The effort began in the FHWA with identifying automation possibilities for steel bridges. In 1999, the Office of Bridge Technology led a team to review innovations for fabricating and erecting steel bridges in other countries. The goal was to identify efficiencies inherent in automation that might significantly reduce the cost of steel bridges or allow more steel bridges to be constructed for the same money. This team of experts identified areas of automation that seemed appropriate for steel bridge applications in this country. The technology reviews of bridges abroad sponsored by the FHWA and the American Association of State Highway and Transportation Officials (AASHTO) highlighted the benefits of using integrated automation to achieve rapid coordinated design and construction, as well as subsequent cost-effective life-cycle maintenance, repair, and rehabilitation.

To develop a more detailed plan, the FHWA planned a workshop that brought together organizations that wanted to support this effort. The team held the 3-day workshop in 2001 at the Edison Welding Institute (EWI) in Columbus, Ohio. The workshop was sponsored by the FHWA and the National Steel Bridge Alliance (a cooperative effort to improve steel bridge design and construction, and a part of the American Institute of Steel Construction). The EWI, AASHTO, and the National Institute of Standards and Technology were cosponsors. The workshop was attended by 53 experts from England, Germany, Japan, and the United States. They represented bridge fabricators, erectors, consulting engineers, welding engineers, government officials, and academicians.

3D MODELING FOR BRIDGES

One of the deficiencies identified was that U.S. practice of information transfer during the bridge design/fabrication/construction/and maintenance operations is fragmented. These processes involve repeated manual data transcription that is error-prone, approvals (e.g., of shop drawings) that are time-consuming, and formats that beg for standardization to facilitate electronic information transfer. A complete modeling of bridge information in a standardized format will facilitate integration of computer-aided design (CAD), computer-aided engineering, and computer-integrated manufacturing and result in rapid and better quality project delivery and cost-effective life-cycle management. For a typical bridge project to achieve rapid construction, automation is needed from design to detailing, and then manufacturing, construction, and maintenance.

In fact, the bridge industry may be the last major industry to achieve this integration. Civil engineering and construction have relied on drawings on paper as the primary representation for centuries. But the bridge

[1] Civil Infrastructure Systems Research: Strategic Issues, National Research Council Press, January 1993.

industry is essentially the only major industry producing 3D products that does not yet have at its core a digital product model and the attendant electronic data exchange capabilities it will facilitate. Other industries have documented reduced costs, faster delivery, and improved quality as a result of implementing 3D-CAD based integrated design and manufacturing processes along with accompanying inter-operability standards.

Integrated automation through intelligent 3D modeling will be an extension of the conventional 2D methodology in designing, constructing, and maintaining bridges. The vision is that automation will generate an architectural blueprint for integrating phases into the automated processes yet will have the potential to produce significantly improved 2D design drawings, as well as construction drawings, in conjunction with the integrated life-cycle management through automation. This concept will smooth the transition in a synergistic manner, making it possible for users to operate with the conventional 2D process until they are ready to embrace the 3D process. Moreover, as users become aware of the benefits and efficiencies of the 3D process, they will be motivated to modernize.

With this dual 2D/3D capability, integration of islands of automation may be easily achieved, and will be a step in the right direction. However, complete integration from design to preservation will largely depend on available financial resources to provide equipment and support expertise and understanding of the benefits from the integrated process.

ROADMAP FOR 3D MODELING BRIDGE PROJECTS

Because of the complexities of transitioning from current practices, a roadmap is required to develop a computer integrating process for bridge modeling. This roadmap may include a demonstration of the software application since it will be worth the effort to make the application tangible. To illustrate this, an FHWA/industry work group developed a generic plan in February 2004 for steel bridge fabrication using 3D modeling.

The plan has been organized to achieve four outcomes, each of which has an influence on the model. The first outcome is to achieve longer and more reliable performance from bridges through optimal standards and materials. Some objectives to reach this outcome include:

- Use of high performance materials systems and construction practices, developed and implemented through research, specifications, education, and demonstration programs;
- Routine use of state-of-the-art design standards and guidelines, which incorporate better capabilities for inspection and maintenance;
- Routine use of state-of-the-art construction practices (based on the principle of "best practices"); and
- Confirmation that final statements are just as intended, with full documentation of Quality Assurance/Quality Control, inspection, and fabricator training and certification.

The second outcome is to produce bridges that reduce traffic congestion and improve safety during construction. Some objectives to reach this outcome include:

- Better condition assessment information for use in making decisions about bridges;
- Routine use of cost-effective and innovative repair and rehabilitation techniques;
- Use of accelerated construction technologies; and
- Frequent use of modular or prefabricated components for faster completion.

The third outcome is to provide a high level of safety and service under all conditions. Some objectives and strategies include:

- Increasing service life through appropriate system preservation strategies, (e.g., better knowledge of deterioration mechanisms);
- Providing a higher level of service under normal conditions; and
- Providing better reliability when subjected to extreme natural and human-made events.

The final outcome is to improve the match (or fit) of the structures with their environment, through the application of context-sensitive solutions. Some objectives and strategies include:

- Minimizing the environmental impact of highway structures through such measures as development of appropriate standards, noise mitigation, greater consideration of wildlife and runoff, and use of recycled materials;
- Increasing participation by other stakeholders during conceptual design and location selection; and
- Seeking context-sensitive conditions while satisfying all functionality and safety requirements (e.g., esthetic treatments should not preclude the use of accelerated/modular construction technologies).

Another step forward occurred on June 30, 2005, when AASHTO's Subcommittee on Bridges and Structures passed a resolution acknowledging the importance of "Comprehensive Integrated Bridge Project Delivery Through Automation to Achieve Rapid Construction." As reflected in the resolution, reducing the cost while improving the quality of bridges requires the implementation of 3D modeling and for the bridge industry to continue development of the technology as well as maintenance of it and information sharing. Additionally, based on ongoing progress and needs in the bridge industry, the modeling will cover automation for construction of all bridges, independent of material.

BENEFITS

The FHWA and its partners in State departments of transportation and the bridge industry may see many potential benefits in cost and time savings. Demonstrating these benefits will ensure efficient process and quality product due to automation in integrated project delivery. Because most contracts are awarded on the basis of these criteria, the data on benefits will drive customers (bridge owners), vendors (manufacturers), and contractors toward the lowest cost solution.

Other potential benefits include:

- Elevating visibility/image of current capabilities in the bridge industry;
- Improving health and safety of personnel by automating some dirty, dangerous, and often repetitive tasks; and
- Showing how collaborations are possible over great distances with improved communication without travel.

PROTOCOLS AND INTEGRATION OF TASKS

Bridge engineering operations include designing, detailing, fabricating, constructing, and maintenance. Of course, each of these activities may have sub-activities such as surveying, earthmoving, building formwork, drilling holes, and cutting plates during fabrication; and erecting beams and installing reinforcing bars in the field during construction. These activities, when performed manually, can be error prone as well as time consuming, thus making the product costlier.

The vision for integrated automation may involve robotic applications, but is not limited to them. With or without robotic applications, 3D parametric bridge information modeling (BIM) is the key to a seamless integrated effort in designing, manufacturing, constructing, and administering projects to extend bridge life. The 3D parametric BIM contains all information needed to produce drawings, reports, and the interactive feedback to link and operate the automated equipment. The information and data are fully integrated within the model.

Once the components and operations are defined, the process can lead to accelerated delivery of images of bridges as designed, fabricated, built, and maintained. These images can be printed in 2D or 3D and provide appropriate data feedback to, for example, machinery that is capable of receiving and performing the command to drill a hole of a certain size at a particular location on a given plate.

The bridge industry has limited capability to apply 3D parametric BIM in the design process to generate design drawings. It has even less experience in converting design drawings into shop or construction drawings electronically instead by manual transcription. Linking software is often needed to integrate two commercially available software products, including those produced by different vendors, that otherwise would be limited to self-contained operations. In this way, an operation can be carried through succeeding operations as part of the integration process. The linking software could simplify modeling for any type of bridge, however complex, to generate configurable and versatile solutions as the project moves from conceptual design through structural engineering to construction, and life-cycle management.

The linking software can enable the process to work more efficiently for seamless operations without the need for manual manipulation. However, compatibility is of the essence. For example, the linking software (or the electronic file) must be capable not only of capturing (receiving) information generated in the design process from software A, but converting it into suitable data that are compatible with software B for producing shop drawings of the components, unit(s), or the entire structure in an easy-to-visualize 3D format (or 2D format if necessary).

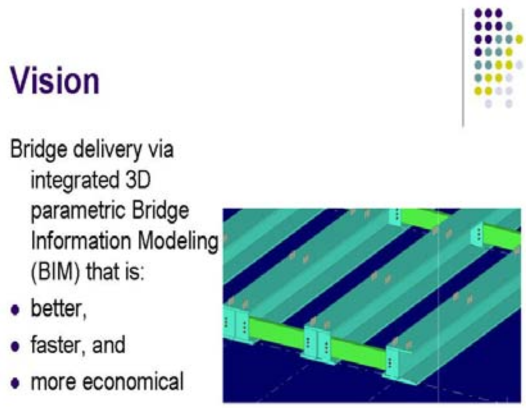
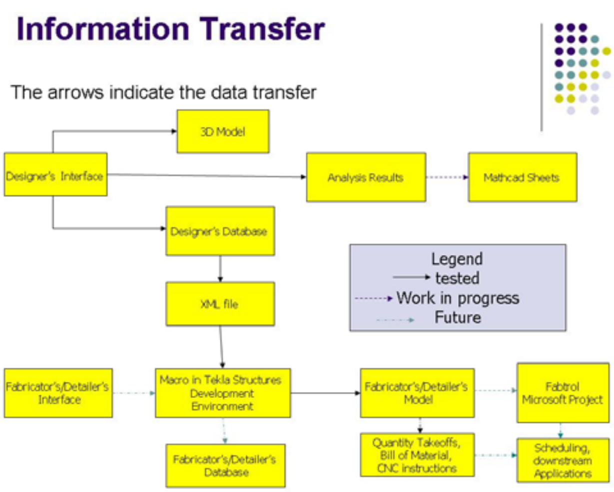


Figure 1

Windows-based interfaces and 3D modeling make it possible to build a virtual project in advance of the actual operation. They increase the likelihood of successful activities by mitigating if not eliminating interferences and possible errors and thereby enhancing productivity. For this reason, 3D modeling can be a powerful tool for potential collaborative effort, at a much faster pace, among engineers engaged in design, detailers in producing construction drawings, and contractors and owners in administering the project.

In the bridge industry, this technology transfer can be driven by bridge engineers working with software engineers. Software knowledge resources are available for efficient and economical application of commercial software.

The above discussion demonstrates that challenges to bridge owners and bridge managers are real and immediate. The 2001 Columbus workshop suggested addressing the challenges by following the steps documented for steel bridges in "Computer Integrated Steel Bridge Design and Construction: Expanding Automation[13] (the Final Report on the workshop issued in April 2002 and available online at:



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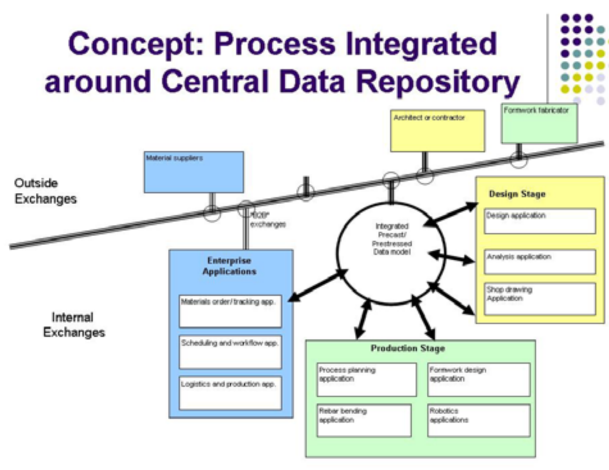

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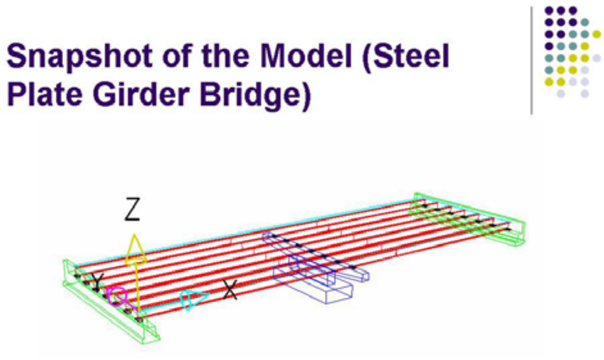

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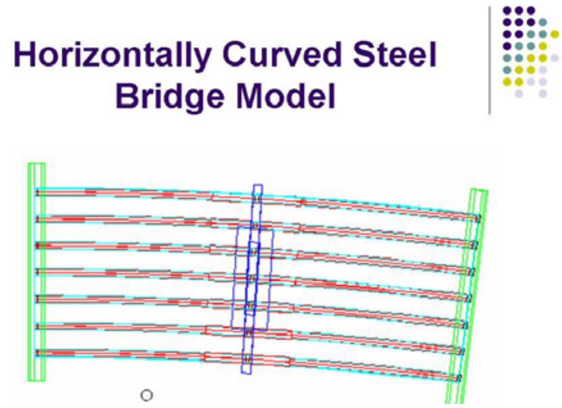
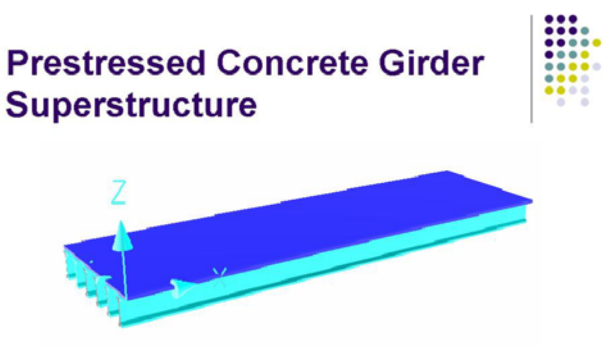


Figure 5

http://www.fhwa.dot.gov/bridge/automate.htm). These suggestions have been modified by the authors to include concrete bridges and are listed below:

- Solid modeling (based on a simple 3D model);
- Standardized specifications and detailing (very amenable to automation);
- Automated inspection;
- Higher productivity fabrication processes, e.g., narrow-gap electroslag welding for steel bridges;
- Systems approach for design through the life-cycle maintenance process (not just robotic operation in a fabricating plant);
- Possibly a design-build and maintenance approach where design teams join with fabricators of steel and concrete components during the manufacturing process, so each team can search for efficiencies and make efficient future maintenance operation by others possible; and
- Showcase the benefits of automation and 3D parametric BIM to encourage their adoption in organizational operations so their benefits will be achieved throughout the bridge life-cycle.

Automated modernization will come in the bridge industry through activities such as electronic designing, fabricating with electronic copies of shop drawings (no hard copies necessary), virtual assembly, tracking records of materials and partially or completely fabricated components, and personnel records.



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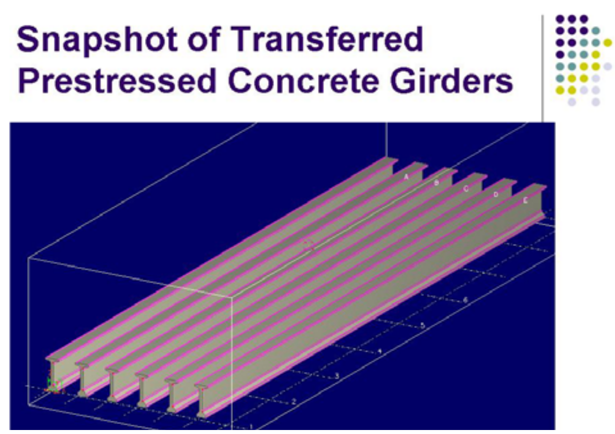
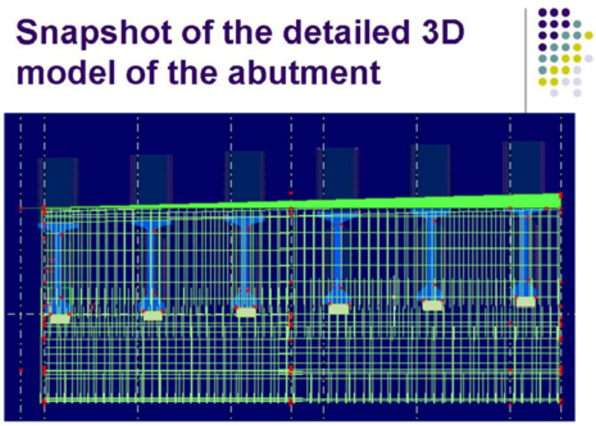


Figure 7

Expectations from this advancing technology will continue to grow as benefits are achieved. Field and office personnel and managers will require real-time information while minimizing administrative tasks to achieve it. Synergistic and general upgrades will drive efficiency and the “best-run” organizations will increasingly want and adopt more and more automation where 3D will obviously have an important role. When integrating bridge geometry further with the "time" component, as is the case in such areas as the planning phase and life-cycle analysis, one will have to consider 3D model with "time" as another essential element.



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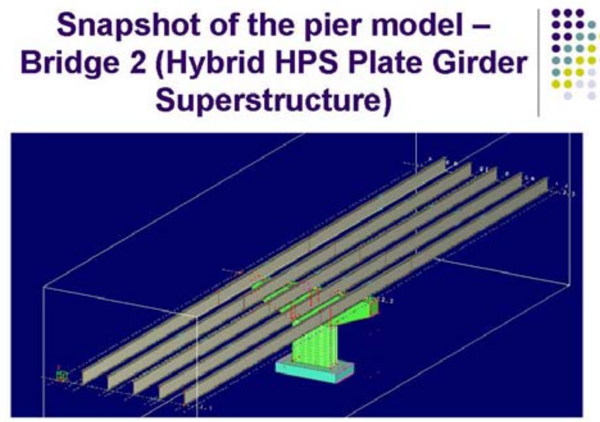

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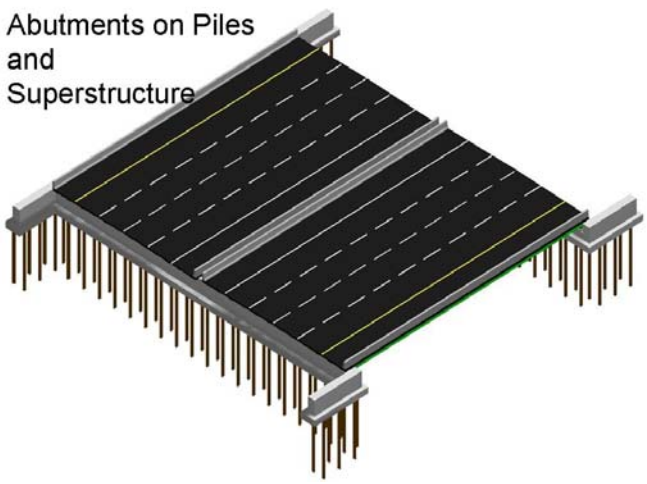

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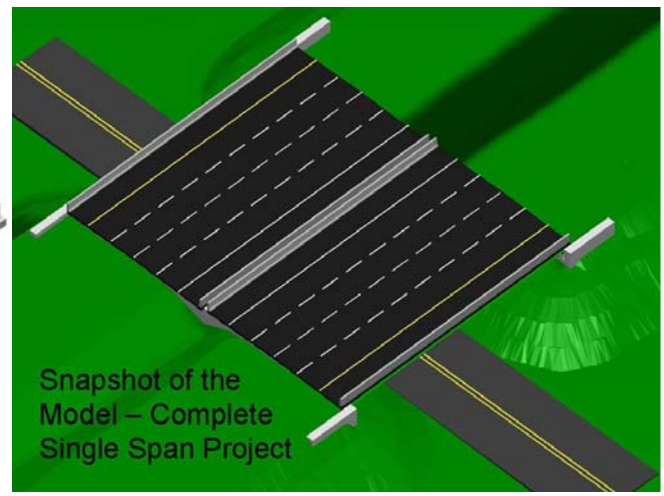

Figure 11

SELECTION OF THE DATA MODELING PROCESS

The selection of the data model is critical to the successful development of an integrated project delivery and management system. NIST has been involved in data preservation and exchange for many years. Compatibility with different systems and software, across a spectrum of users, and the stages of the project life cycle is crucial to the acceptance of integrated project delivery and management systems in the bridge community. Based on a Work Plan of FHWA contract (DTFH-61-06-D-00037, discussed below) the following existing models may be considered:

- **AASHTOWare Centric Data Modeling:** The AASHTOWare system would require major improvements so it can contain the data fields needed to hold the target data, for example, for transfer of design and construction, data for use in life-cycle management.
- **AASHTOWare Hybrid Data Modeling:** With AASHTOWare Hybrid Data Modeling, all data after the bridge is constructed is held within AASHTOWare (Virtis, Pontis). During design, fabrication, and construction the BrIM model is used. BrIM is able to export its data to AASHTOWare for long-term operations and management.

- **BrlMData Modeling:** BrIM is used for all activities that are modeled. Presently it does not adequately address the operations and maintenance but is leading in design and construction.

The interaction and data transfer among these existing processes will have to be robust if they are to be used while development is underway on more comprehensive technology that is capable of all the necessary steps.

To develop this new technology, the FHWA has initiated a contract to advance and promote the 3D modeling concept and its application for integrated bridge project delivery, for concrete and steel bridges, through life-cycle management. The contract objectives, its scope, and tasks are briefly discussed below.

CONTRACT OBJECTIVES

The objective of this program is to develop integrated design, fabrication, construction and preservation technologies using 3D modeling for concrete and steel bridges (super and sub-structures). The objective is to demonstrate the use of integrated processes to owners, designers, contractors, fabricators, and erectors while promoting the efficiencies of enhanced technology. Efforts accomplished under this contract may include:

- Development of half-day and 2-day presentations that promote the objectives of this program, and
- Development of integrated engineering software that demonstrates applications and the benefits of the program. Presentation of half-day and 2-day seminars at selected locations. This may include presentation of technical papers and participation in national conferences.

Successful development and demonstration of Integrated Bridge Project Delivery and Life Cycle Management may lead to a second phase that is not included in this contract. The possible second phase would include validation of the benefits of this technology by comparing the design, fabrication, construction and load ratings of two steel bridges, one by conventional and one by advanced technology; as well as two concrete bridges, one by conventional and one by advanced technology.

CONTRACT WORK SCOPE

The scope of this work includes developing and presenting a demonstration project for steel and concrete bridges to achieve “Integrated Project Delivery and Project Management” and identify available technologies; research and develop an integrated engineering software demonstration package that will promote faster and more efficient automated processes applicable through the entire life cycle (design, fabrication, construction, and preservation) for bridge owners and contractors. For this purpose, the contractor will develop an Integrated Software Package (CD or DVD) that will use video clips so attendees can see equipment and software in such actions as:

- 3D modeling and designing the bridge structure (moderate size, at least three spans);
- Shifting of computer-generated paperless drawings among formats and directly to production equipment;
- Use of computer–generated designs for 3D cutting;
- Tracking repairs, maintenance, life-cycle management (including load rating); and
- Analyzing virtual designs to determine permit loads.

The package will also provide guidance or recommendations on:

- Selecting equipment and software, including integration of products into an entire system;
- Standards for data transfer and methods for integration and inter-operability for steel and/or concrete bridges; and
- Standardizing agency practices to allow more automation.

In addition, the contractor will quantify the costs and benefits of integrated automation for the major steps in the conventional processes (i.e., projected savings – reduction in cost and time) including development and delivery of a complete functional software package. Development and delivery of "linking" software will facilitate integration with existing commercial/modified commercial software.

SUMMARY

Over the last several years, much effort has been expended to advance bridge construction technology in the United States. Reviews of technology in other countries, government/industry/academia workshops, design-build projects, and other worldwide activities have demonstrated the potential and practicality of using advanced computer-controlled technologies to reduce total construction time frames considerably, reduce fabrication/construction/maintenance costs, and improve communication dialogue in every aspect of a project through its life cycle.

To deliver quality products efficiently and economically, those who are involved in designing, constructing (fabricating, erecting, surveying, earthmoving, contracting, etc.), and maintaining bridges must be able to access advanced technologies that allow direct application of market-ready software. Additionally, the use of modified software, including those that may require linking software, specifically designed and developed to work with commercially available software, should make it possible to achieve integrated project delivery through the life cycle of each bridge.

ACKNOWLEDGMENT

The 3D modeling concepts for "Integrated Bridge Project Delivery Through Life Cycle Management" noted in this paper are based on:

- FHWA scanning report, "Steel Bridge Fabrication Technologies in Europe and Japan, Report No. FHWA-PL-01-018, http://www.international.fhwa.dot.gov/Pdfs/SteelBridge1.pdf (March 2001) [(12)];
- Workshop Report to the Federal Highway Administration and National Steel Bridge Alliance, "Computer Integrated Steel Bridge Design and Construction: Expanding Automation,"

  http://www.fhwa.dot.gov/bridge/automate.htm (April 2002) [(13)] ; and
- Paper "Integration of Information and Automation Technologies in Bridge Engineering and Management: Extending State of the Art," Transportation Research Board Annual Meetings, Washington, DC, January 2006 by Chen, S.S (Dept. of Civil Engrg., Univ. at Buffalo), Shirole, A.M. [(18)] (Arora and Associates, P.C.).

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Note: This paper was presented for the first time at the International Institute of Welding Congress in Bangkok, Thailand in December 2006. The FHWA is engaged in promoting the concept of the 3D modeling for integrated activities through automation for bridges in the United States, also by sharing the technology abroad, and thus encouraging professionals to adopt the technology. The FHWA has established a Web site (http://www.fhwa.dot.gov/bridge/integrated/) where further details will be posted as they evolve.