A Vision for Bridges for the Future

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This paper was originally authored in 2001 to contribute to a strategic vision for bridge research. While some of the initiatives presented have had follow up action, most issues remain. This paper has been updated for the corrosion workshop.

Background

The number of substandard bridges in the United States has been reduced from more than 250,000 in 1982 to 151,000 in 2012. On an annual basis, about 10,000 bridges are being constructed, replaced, or rehabilitated at a cost, to all levels of government and the public, of over $8 billion, while total annual bridge costs, including maintenance and routine operation, are significantly higher. Although it may appear that we are keeping ahead of the current bridge deterioration rate of about 3,000 newly deficient bridges per year, most of the bridges being built today are using the same technologies, materials, and methods that were used to construct bridges 20 or more years ago.

Unless there is a fundamental change in the methods and materials used to construct highway structures, the number of substandard or deficient bridges and other highway structures is likely to increase in the future. This is due, in large part, to (a) current projections for increasing traffic growth, (b) the fact that most of the bridges built today will deteriorate at about the same rate as the bridges built 20 years ago, and (c) a median age of greater than 50 years for all bridges nationally. Additionally, the projected need for continuing renewal of the nation’s bridges will take place in an environment of unprecedented demands to not only keep traffic moving, but to also increase capacity and reduce delays. There will also be ever-increasing demands to keep costs, both initial and long term, as low as possible.

Although there is clearly a need to develop and deliver a new generation of high performance bridges, we must recognize and emphasize the need to effectively and efficiently manage the existing inventory of bridges and other highway structures. Even if we were to develop and implement new technologies today, it will literally take decades to reengineer the nation’s highway system. New challenges have also been presented in the area of homeland security and global climate change. These needs and others have been clearly identified by the National Highway R&T Partnership (2002). Our initiative, known as the Bridge of the Future, specifically meets the need for enhanced materials, structural systems, and technologies, as well as enhanced specifications for improved structural performance. The initiative on Stewardship and Management specifically addresses the needs for reliable and timely data and information, improved decision support tools, and the development of quantitative, relevant, and useful measures of performance. Finally, the need to integrate probabilistic life-cycle analysis into infrastructure management is addressed in our third focus area that will help assure the Safety, Reliability, and Security of highway structures subject to both normal and extreme events. Each of these initiatives is further discussed below.
**Vision**

Our vision is to get out in front of the bridge deterioration curve and stay there. We will work—in partnership with the States, industry, and academia—to develop and widely implement more durable bridges and highway structures. The outcome of this program should be bridges and other highway structures that last longer, have far lower maintenance demands, and can be maintained and modified to accommodate changes in traffic or function much more quickly and far less intrusively than current technology allows. It is therefore envisioned that highway structure replacement will become the option of last resort when deciding upon an optimal strategy for maintaining and enhancing the capacity of the Nation’s highway system.

**Approach**

The approach proposed suggests a new way of doing business, recognizing and emphasizing the elements needed for success. The strategic goals of the program are to enhance mobility and productivity, extend the life of bridges and other highway structures, and improve safety and performance. The path to achieving these goals requires the pursuit of four critical elements:

- **Information** – reliable data for better decision-making
- **People** – training and professional development for an effective workforce
- **Technology** – next-generation breakthroughs for better tools and techniques
- **Deployment** – putting innovations into practice for achieving real-world benefits

The purpose, scope, and specific strategies planned for each of these four elements is presented below; it is, however, important to note that these elements are not independent functions, but are interrelated and synergistic. Better-performing, more cost-effective, safer highway structures cannot be attained without considering and adequately investing in information, people, technology, and deployment as part of an overall strategic program.

To reach our goals and have this vision come to fruition, we must develop and deploy more effective, powerful, and comprehensive decision support systems. The bridge management systems of the future must be based upon better information, better knowledge, better technology, and better decision support tools. These systems will provide decision-makers with the ability to select the optimal course of action for a bridge or population of bridges at any point in their life and for any planning horizon.

The research and technology program proposed will build previous research and is expected to result in the development and delivery of totally new and innovative bridge systems that will help eliminate the bottlenecks of the future. This research program includes initiatives and programs addressing each of the above four critical strategic elements for success. Within this framework, the proposed research program has three interrelated and concurrent themes or focus areas: developing and delivering the Bridge of the Future; stewardship and management of our existing inventory of bridges as we reengineer for the future; and ensuring the safety, reliability,
and security of the Nation’s bridges. Our current thinking on how to address each critical element is offered below.

Information

FHWA’s National Bridge Inspection Program and National Bridge Inventory database (NBI) is the most comprehensive source of long-term bridge information in the world. We are mining this data to benefit from the information contained in it through the Virginia Bridge Information Systems Laboratory. We also are mining the element level data. Both the NBI and element level data are typically collected using visual inspection techniques; hidden or otherwise invisible deterioration damage is therefore not usually collected. The non-quantitative, subjective, highly variable, and nonspecific nature of this data makes it inadequate for comprehensive long-term life-cycle decision support. An essential element of the research necessary to support the information needs for bridge management for the future is therefore a long-term bridge performance program.

Long-Term Bridge Performance Program

As noted above, current bridge inspection programs do not provide the detailed, quantitative performance information necessary to reliably predict long-term bridge performance. A long-term bridge performance program, modeled after the Long Term Pavement Performance Program, was proposed and has been implemented. This includes a program of detailed inspections and periodic evaluations conducted on a representative sample of bridges to monitor and measure their performance over an extended period of time (at least 20 years). It is anticipated that the resulting database will provide high quality, quantitative, performance data for highway bridges to support improved designs, improved predictive models, and better bridge management systems. A second component of this long-term bridge performance program will be a subset of instrumented bridges that can provide continuous long-term structural bridge performance data. A third component of the program proposed, detailed forensic autopsies of decommissioned bridges was not implemented. This is the subject of a new proposal to the National Science Foundation and is currently under review. The intent is to collect valuable performance data on corrosion, overloads, alkali-silicate reaction, and other essential deterioration processes from these decommissioned bridges.

Technology for Better Information

We also proposed to support the improvement or development of technologies which can address a few of the most immediate, high-priority needs for better quantitative condition data in a rapid, nondestructive (or less intrusive) manner. Some of these needs include: rapid inspection of asphalt-covered bridge decks, rapid load testing and load capacity rating of bridges, inspection and safety assurance of bridge cables and tendons, and detection and assessment of cracks in structural steel. We proposed to emphasize the development of nondestructive evaluation
technologies and methods to meet these needs as an integral part of our comprehensive strategy to improve the data and information that are used to make decisions about the optimal management of highway structures.

A new robotic bridge deck evaluation system has been developed and is being evaluated. Projects directed at rapid load rating and evaluation and nondestructive evaluation of fatigue prone details are being pursued by the author under VDOT and FHWA sponsorship.

People

As noted earlier, this research program will only succeed if current and future workforces are up to the challenge. Transportation systems managers, engineers, technicians, and workers must have adequate education, training, information, tools, technology, guidelines, procedures, and best practices to meet the challenges of the 21st century. The proposed structures research and technology program therefore suggested a multi-thrust approach for augmenting the capability of the transportation workforce through educating and training.

Demonstration Projects

In the past, an important element of the FHWA education and outreach program was its Demonstration Projects program. Although the Demonstration Projects program was considered as an effective mechanism for introducing new ideas and technologies to transportation professionals, it has not been as active in recent years. We proposed to revitalize and modernize the use of demonstrations projects as a key tactic for reaching out to our State DOT and industry partners to introduce new technologies. New knowledge delivery mechanisms now exist, like computer-based training and Internet- or teleconference-based distance learning, and these will also be used to the fullest extent, where appropriate.

Centers of Excellence

We also proposed the establishment of several Centers of Excellence focused on issues related to bridges and highway structures at a limited number of institutions would greatly benefit the highway engineering industry. These Centers serve as a source for educating the next generation of bridge engineering teachers and researchers, assist in the development of the next generation breakthroughs and technologies, and would act as a conduit to transfer knowledge resulting from research and development programs. These Centers of Excellence would work in concert with the already established University Transportation Centers, Local Technical Assistance Program centers, and other transportation engineering organizations and centers.

Training

We also proposed to develop a suite of new NHI courses in the structures area. Many structures courses in NHI’s current course catalog are out-of-date and in need of significant updating or augmentation. They do not provide the comprehensive treatment necessary to fully serve the highway structural engineering community.
Partnering and Cooperation with Industry

Another key element of our plan to expand the workforce was to work more energetically and proactively with industry to help improve the knowledge, qualifications, and productivity of the highway structure construction, fabrication, and manufacturing workforce. We envisioned greater emphasis on and support for expanded industry certification programs, as an example.

Fully Exploit Technology for Training

We were well aware of how expensive and time-consuming training can be. We therefore proposed to explore and exploit new technologies where they are most effective, such as the use of distance- and computer-based learning, to help raise the level of technical knowledge and expertise across the industry.

Technology

Another major emphasis in our proposed research and development programs were to develop new and improved technologies to meet the needs for both the short term and the future. In the short term, our intent is to assist in “filling the gaps” that may exist from existing and planned R&T activities (e.g., NCHRP, State Planning & Research, F-SHRP); in the longer term, the emphasis will be on breakthrough technologies and systems.

The Bridge of the Future

A major initiative in our proposed focus on new technology was to develop the Bridge of the Future. The products of this initiative were to be new generations of bridge systems that provided unprecedented long-term performance. These systems will effectively use and combine high-performance materials into the most structurally efficient and cost-effective systems. The objective of this research initiative, focused on new construction, was to develop innovative bridge systems that efficiently employ high performance materials and prefabricated structural systems in their most efficient manner. To develop the Bridge of the Future, the following performance objectives would need to be met:

- Material degradation is no longer a factor in limiting service life
- Total construction time (with a focus on “in the field” activities) significantly shortened
- Easily widened or adapted to new demands in days or weeks, rather than months or years
- Total life-cycle cost far less than that of current bridges
- Virtually immune to hazards and the resulting distress imposed by floods, earthquakes, fire, wind, overloads and collisions.
- Entire bridge (foundations to parapet) designed, analyzed, and constructed as a system
- Lateral clearance greatly increased with longer spans
- Elimination of vertical clearance problems with shallower structures
- Constructability, inspectability, maintainability, and durability all of equal importance

**Stewardship and Management for the Future**

We recognize that these goals would seriously stretch our creative, technological, and financial capabilities. Meanwhile, we would need to continue to effectively support the management of the huge existing investment in the as-built transportation infrastructure. This was the focus of our initiative in Stewardship and Management.

Stewardship is defined as the conduct, supervision, or responsible management of something entrusted to one’s care. In this regard, highway system stewardship is more than the absence of waste or the presence of fiscal controls. Stewardship includes employing a business process that ensures that the best and most appropriate technologies and practices are used on every project and at every phase of a bridge’s life cycle. The products of this research focus area were to be comprehensive life-cycle decision support systems and the technologies to effectively and efficiently manage the Nation’s tremendous in-service infrastructure investments.

Comprehensive life-cycle decision support provides the knowledge, understanding, information, and technology to support good stewardship. Delivering these products would require little research if we already knew and understood everything and had all of the technology and information we needed. Unfortunately, the current state of knowledge and understanding of long-term bridge performance was and still is inadequate to support needed comprehensive decision support systems. The Long Term Bridge Performance Program, as discussed above, is one important element of this initiative; others are discussed below.

We proposed to continue to conduct research to fill gaps in existing bridge and highway structure knowledge and technology. Examples of this type of research included continued emphasis on fatigue and fracture mechanics, corrosion engineering and control, and cement and concrete performance and durability. The recent failure of a bridge in Wisconsin, problems with tendon corrosion in Florida, and continuing problems with alkali silicate reactivity, demonstrate that these needs exist. We also proposed to sponsor research in strengthening, rapid repair, maintenance, and preservation. Our continuing research and development of new nondestructive evaluation technologies was also a critical part of our stewardship initiative.

Good stewardship requires good decision-making. We planned to pursue the research necessary to develop the underlying knowledge, understanding, and technology necessary to support comprehensive life-cycle decision support systems. Some examples included the development of more realistic and accurate models to predict the long-term performance of bridges and other highway structures, long-term performance of bridge construction materials, development and testing of new performance measures, and research to measure and predict the effectiveness of typical maintenance and preservation actions. We also planned to maintain and enhance our world-class knowledge and capabilities in the application of information technologies to support this research.
Ensuring the Safety, Reliability, and Security of the Nation’s Bridges

While the stewardship and management initiative addressed the long-term and routine factors limiting bridge performance, such as corrosion and fatigue. The most common cause of bridge failure, historically the result of a catastrophic event, such as a flood, earthquake, or vehicle or ship collision were not included. Also, new needs were identified as a result of threats from terrorism. Dealing with rare and unusual events was one focus of our initiative to ensure the safety, reliability, and security of our Nation’s bridges.

This part of the proposed research and technology program would produce the knowledge and technology required to ensure that the Nation’s highway bridges are safe and that they will continue to function reliably in the event of these extreme or infrequent catastrophic events, including threats to national security. These events and threats were to be addressed within a logical and comprehensive modern risk-analysis framework.

We proposed research to fill gaps in knowledge and to develop improved technology to ensure the safety and reliable performance of highway bridges exposed to extreme and infrequent events. We proposed to continue the hydraulics research program to address the most frequent cause of bridge failure, scour. Wind-induced problems were still of significant concern and importance, as evidenced by recent problems with large-amplitude oscillation of cable stays under conditions of light rain and wind – our aerodynamics research program would therefore work to better understand this and similar problems on new bridges and develop workable countermeasures for existing bridges that exhibit the problem. Unlike terrorism or vehicle impact, earthquakes and floods affect large land areas and many highway structures, significantly disrupting regional mobility, emergency response, and regional economies. Each major earthquake and flood teaches us new lessons in bridge response and performance, and new standards and technologies often result. The seismic research program has developed, and would continue to provide, guidance for retrofitting existing bridges to make them less likely to fail during earthquakes, and new design concepts that provide enhanced performance.

Emerging Issues and Technologies

In addition to the research programs described above, there is still a continuing need to respond to emerging problems and issues, and to facilitate ways to fully exploit emerging technologies. It is essential to be knowledgeable about and prepared to advise policy-makers, government officials, and others on important technical issues. As an example, we should be prepared to address highway structure impacts potentially resulting from global warming. The implications of significant changes in weather patterns are important and far-reaching. One credible scenario of global warming is a redistribution of water on a global scale, resulting in a lowering of the water level in the Great Lakes by several feet. The potential impacts on sedimentation processes and the consequent effect upon scour and stream stability at thousands of highway bridges should therefore be understood. The FHWA continues to be uniquely positioned to explore and exploit emerging technologies which States and other industry partners such as so called “micro-electro-mechanical” systems, that have the potential to revolutionize construction processes and quality control, and which could redefine what is possible for long-term measurement of
structural performance and deterioration. The pace of technological change in the global transportation industry and the scale and scope of the challenges facing the Nation all demand that FHWA assume this role.

We outlined an ambitious and far-reaching program of outreach, research, and development to obtain new knowledge and technology. All of this was needed and important, but the benefits of this work would not be fully realized unless and until this new knowledge and technology is put into practice. The final element required for success was to facilitate the deployment of research and development program results.

**Deployment**

As mentioned previously, we proposed to reemphasize the use of Demonstration Projects as one method to introduce and help move new technology into practice. We also proposed to build upon a decade of research in high performance materials and to broaden and redirect the Innovative Bridge Research and Construction (IBRC) Program as our primary mechanism for facilitating new technology application. The IBRC was beneficial, but it was characterized by research that is focused on small, incremental steps such as replacing steel reinforcement with polymers or replacing standard concrete with higher-performing concrete. The emphasis of the new program, proposed to be called the Innovative Bridge Research and Deployment (IBRD) Program, was to move beyond incrementalism. The goal of the new IBRD program was to demonstrate and spur the development of totally new and innovative bridge systems. We broadened the scope of the program beyond its previous focus on new materials to include new structural systems, and innovative approaches for strengthening, rehabilitation, repair, maintenance, and preservation technologies for existing bridges.

Although the IBRD program was intended to facilitate major “leaps” in technology and practice, it is recognized that many of the nearly 600,000 bridges in the existing National Bridge Inventory could benefit from incremental advances in technology and practice. The proposed bridge and highway structures deployment program therefore required a careful balance of research and technology products in order to ensure that national practices in bridge design, analysis, construction, maintenance, and management efficiently and effectively addressed national needs and be deployed and used to their fullest extent by the range of State and industry partners.

**Closing**

We described our prior thinking on a program of research, development, and technology delivery which addressed many of the priority needs identified for bridges and other highway structures. The program was strategic in nature, but had both specific short-term and long-range goals. The strategic landscape has not changed greatly in the last decade and many of needs, issues and desired outcomes remain to be met. This paper is offered to help frame and spur discussion for the corrosion workshop.