



Highways of the Future—A Strategic Plan for Highway Infrastructure Research and Development

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Prologue

This *Highways of the Future—A Strategic Plan for Highway Infrastructure Research and Development* was developed in response to a need expressed by the staff of the Federal Highway Administration (FHWA) Office of Infrastructure Research and Development (R&D) for a coordinated plan that provides direction for future infrastructure research and a framework to support the reauthorization efforts in advance of the expiration of authority under Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU). This plan supports not only the mission of FHWA, but also serves as a reminder of the value added by addressing the Agency's strategic plan. This plan also demonstrates how the focus on highway infrastructure research, development, and technology deployment benefits the economy of the Nation.

Introduction

Highways are the backbone of the American transportation system, moving the vast majority of the Nation's products and goods, and providing the vital link between all modes of transportation. As the foundation of the Nation's economy, highways have made it possible for the American people to enjoy, benefit from, and essentially take for granted, the ability to safely and efficiently travel wherever and whenever they wish.

As the Nation moves into the heart of the 21st century, the highway system is largely a victim of its own success. The economic growth made possible by the highway system has fueled tremendous increases in the demands placed on it. At the same time, the Nation's investment in highway infrastructure has not kept pace with these growing demands. These circumstances present highway agencies with many critical challenges, including:

- The need to extend the service life of existing highway infrastructure.
- The need to build, rehabilitate, and rebuild infrastructure in ways that:
 - Minimizes the impact of construction activities on already congested highways.
 - Optimizes the overall cost/benefit for the improved infrastructure.
 - Facilitates future adaptation to accommodate changing demands.
- The need to effectively address the mobility challenges posed by natural or man-made extreme events and hazards—including earthquakes, hurricanes, floods, collisions, and acts of terrorism—by designing and constructing less vulnerable infrastructure to minimize loss, and employing rapid restoration techniques to restore functionality after a disaster occurs.

Effectively addressing these challenges will require a multifaceted, multidisciplinary, and collaborative approach. Success will require active involvement on the part of highway stakeholders from all levels of government; the highway design, materials, and construction

communities; and academia. Success also will require work spanning the full technology continuum—from fundamental sciences and advanced research to create new knowledge, materials, and systems; through applied R&D; to effective technology transfer and deployment—as well as policy and program management initiatives.

This strategic plan addresses one facet of the required approach—the work that needs to be pursued by the FHWA Office of Infrastructure R&D. In addition to guiding FHWA’s infrastructure R&D, it will serve as a foundation for collaboration with other FHWA units and offices, and stakeholders throughout the highway community.

The approach articulated in this plan is founded on the ideal that FHWA’s emphasis should be on a collaborative, interdisciplinary, and crosscutting approach to highway infrastructure research. This approach recognizes the following principles.

- Pavements and bridges function as an integrated system, instead of independent elements within a highway.
- Although the fundamental structure and components of pavements and bridges are quite distinct, some R&D needs are common to both.
- Only by using all facilities and assets available within FHWA’s Office of Infrastructure R&D, and working collaboratively with counterparts in other FHWA offices and stakeholders throughout the highway community, will we be able to leverage our resources with the other resources required to address the wide range of needs and issues in the near and long terms.

Goals

Listed below are FHWA’s Office of Infrastructure R&D goals.

- Conduct research to develop knowledge, guidelines, analytical and physical tools, and test methods and procedures that:
 - Enable the delivery of safe, environmentally-friendly, long-lasting, disaster-resilient, and cost-effective highway infrastructure, and provide a high level of service.
 - Support end-user efforts to more effectively maintain and manage the Nation’s infrastructure based on the realities of funding needs versus funding constraints.
- Provide specialized technical assistance to address infrastructure issues of national importance requiring research capabilities and technical expertise uniquely available at the FHWA’s Turner-Fairbank Highway Research Center.

To achieve these goals, the FHWA Office of Infrastructure R&D will deliver research products, which are ready for adoption and implementation by highway agencies responsible for infrastructure design, construction, and management. As we do so, we will effectively promote these research products and provide support to facilitate the implementation of new technology products and services.

Research Outcomes

The ultimate outcomes of this proposed program of strategic initiatives and research will be:

- Nationally applicable, integrated, infrastructure performance monitoring systems and asset management models and approaches.
- New materials that provide more durability and reliability.
- New systems that can be constructed faster, yet are more reliable and significantly more durable.
- Advanced infrastructure performance prediction and design models.
- Tools and technologies that address effective inspection, preservation, and rehabilitation.
- Infrastructure planning, design, contracting, construction, and maintenance practices that address highway infrastructure as an integrated system.

In the near term (within 5 years), the FHWA Office of Infrastructure R&D will deliver research products that move current technological knowledge and the state of the art into practice. This research will be accomplished by improving existing engineering tools for analysis and design; developing more durable materials; and providing construction, maintenance, and rehabilitation guidelines that enable infrastructure reliability and durability. At the same time, the research needed to lay the foundation for products to be delivered in the longer term will be aggressively pursued to enable delivery of fully integrated approaches to infrastructure asset management, such as consideration of a full corridor, including pavements, bridges, and appurtenances. To achieve this long-term outcome will require the results of FHWA's near- and mid-term R&D products, and other yet-to-be-developed technologies.

R&D Strategies

In order for the FHWA to be “innovators for a better future,” as expressed by Agency leadership, the FHWA Office of Infrastructure R&D will focus on the needed R&D in which there is an appropriate Federal Role by virtue of national needs, scope, duration, or risk. This role will require pursuit of the following overarching strategies, with key initiatives within these strategies. Details concerning individual projects and programs that comprise these initiatives will be provided in a separate document.

I. Long-Term Infrastructure Performance

Facilitate the development of a long-term highway infrastructure performance program, and databases and other tools and technologies (that is, combining bridge and pavement information, using both current FHWA systems and newly created programs) to collect meaningful data to support development of integrated asset management systems and processes that consider the full life cycle of highway infrastructure from planning through design, construction, and preservation. This strategy will build on and integrate the current Long-Term Pavement Performance and Long-Term Bridge Performance Programs, and provide the foundation for other strategies. The strategy includes development of the following activities:

- A publicly available data set documenting the performance of a well-characterized set of pavement test sections and bridges, including their design, materials, construction, preservation, and maintenance, that is representative of the majority of the Nation's highways.

- Improved bridge and pavement monitoring sensors and systems (e.g., smart sensors, embedded sensors and systems) that permit both periodic and continuous performance evaluation and accurate condition assessment.
- High-speed and high-resolution, nondestructive evaluation (NDE) technologies for inspection, evaluation, and performance monitoring.
- Analysis and data-mining tools that can be applied across a range of infrastructure databases and data sets.

II. Durable Infrastructure Systems

Develop durable and resilient infrastructure systems and elements to improve in-service performance, reduce maintenance needs and costs, reduce life-cycle costs, and significantly improve safety during normal service and during extreme hazard events. This strategy will require that infrastructure durability and deterioration-prevention be addressed in a more systematic manner by developing:

- High-performance, long-life, advanced materials that increase resiliency and reduce maintenance and reconstruction needs such as self-monitoring or self-healing materials.
- Improved systems, preservation techniques, analysis methods, and technologies to prevent material degradation, corrosion, cracking, fatigue, and other serviceability problems in existing highway infrastructure.
- Advanced infrastructure performance prediction and design models for both service-level and extreme events.
- Tools to identify and manage critical lifeline routes.
- Designs and details that provide resiliency during extreme hazard events, systems that facilitate evacuation as well as support response and recovery operations, and highways that can be repaired and returned rapidly to service.
- Intelligent disaster-resilient infrastructure such as smart bridge systems and countermeasures.
- Infrastructure designs and details that facilitate effective inspection, maintenance, and repair.
- Quality assurance and control standards and procedures that can be applied effectively during the fabrication process and in the field.

III. Accelerated Highway Construction

Develop accelerated construction, rehabilitation, and reconstruction methodologies for highway systems and structures. This strategy directly addresses the Nation's congestion and safety needs, and the impending crisis due to aging infrastructure.¹ The R&D to be pursued as a part of this strategy include:

- Prefabricated structures and systems, including bridge substructures and superstructures, and geotechnical constructions.
- Advanced fabrication, construction, and erection techniques and equipment.
- Structures (bridges and pavements) that are adaptable to changing conditions and system demands.

¹ On average, the Nation's bridges are approximately 42 years old, and the majority of pavements on the national highway system have surpassed their original design life.

- Technologies to enable real-time quality control and assurance in accelerated construction settings.

IV. Environmentally Sensitive Highway Infrastructure

Develop technologies to enable environmentally sensitive highway infrastructure. This strategy will to reduce detrimental environmental impacts arising from construction and maintenance of highway infrastructure, as well as the physical, chemical, and aesthetic attributes of highway transportation. Elements of this strategy include:

- Quantification and characterization of the impacts of highway infrastructure on the environment.
- Technologies and knowledge to support context-sensitive solutions (CSS) and initiatives.
- Technologies to enable expanded use of recycled or waste materials in highway construction.
- Pursuit of less damaging (more “green”) and renewable materials and construction technologies.

V. Performance-Based Specifications

Develop comprehensive performance-based specifications. Such specifications are needed to: (a) balance risk between agencies and industry (contractors), (b) encourage innovation, (c) provide greater consistency between design expectations and actual performance, and (d) support innovative contracting procedures and construction practices. This strategy is dependent on the ability to predict future performance accurately. The strategy also will build on outcomes from the Long-Term Infrastructure Performance Strategy and Durable Infrastructure Systems Strategy research. Specific examples of performance-based specifications include:

- Extreme-event infrastructure design standards that provide specified levels of operation and service based on identified post-event needs, but which prevent catastrophic failure.
- Service-level infrastructure design and material standards that allow more innovation than current prescriptive infrastructure design and material standards.
- Materials and construction standards that link design and construction, and compel contractors to minimize constructed project life-cycle costs.
- Bridge and pavement construction standards that hold contractors responsible for meeting structural and functional thresholds over the long term (more than 15 years).

VI. Comprehensive and Integrated Infrastructure Asset Management

Build on and integrate the outcomes from the Long-Term Infrastructure Performance Strategy, Accelerated Highway Construction Technologies, Durable Infrastructure Systems, Environmentally Sensitive Infrastructure and Performance-Based Specification strategies to deliver the tools and technologies needed to achieve fully integrated processes and systems for asset management, including infrastructure planning, design, contracting, construction, preservation, and maintenance. Activities included in this capstone strategy include development of:

- Improved performance and life cycle cost models that consider the full life cycle of the infrastructure from planning through design, construction, maintenance/preservation,

rehabilitation, and reconstruction in an integrated and comprehensive fashion, and are applicable to any combination of materials.

- Analysis of data collected under the Long-Term Infrastructure Performance Strategy to derive information needed to support sound decisionmaking in the asset management process.

VII. Core Infrastructure R&D Facilities, Capabilities, and Functions

Maintain and improve the infrastructure that supports FHWA's ability to meet our goals effectively for both R&D and specialized technical assistance, including:

- Routine and nonroutine maintenance of equipment used in conducting research and providing specialized technical assistance.
- Facility upgrades required to enhance and maintain the FHWA Office of Infrastructure R&D's ability to conduct safely and effectively the state-of-the-art research, testing, and evaluation needed to achieve the goals articulated in this plan. Needs in this area include: (a) facility safety enhancements, (b) capital equipment, and (c) enhanced experimental and high-performance analytical computing capabilities.
- Development of a *Research Data Management System* (RDMS) for all highway infrastructure research. The RDMS is seen as a foundation for successful pursuit of our research objectives and is needed to: (a) achieve full compliance with the Federal Data Quality Act, (b) ensure that future research builds on past work and knowledge, (c) ensure data integrity, (d) make data and metadata more readily available to future researchers and end users inside and outside of FHWA (such as for future specification calibration and validation), and (e) support enhanced collaboration between researchers.

The following steps will be needed to achieve an effective RDMS:

1. Definition of research data and metadata standards.
 2. Development of specific research metrics and expected outcomes.
 3. Definition of standard test and evaluation protocols.
 4. Enhancement of data management and mining/interrogation tools.
 5. Development of secure data capabilities, including disaster recovery tools and protocols.
 6. Population of the RDMS through an aggressive program of data collection from many organizations and agencies, both within the traditional highway industry and those communities that have tools and technologies, which can have an impact on highway engineering practice in the future.
- Continued operation of the Materials Reference Library to store and disseminate samples of materials for use in key infrastructure research projects, making it possible for future research to build upon and extend the findings of past research where appropriate.

Resources

Achieving the outcomes described in this plan will require significant investment. The required resources may be classified in three broad categories: (1) human, (2) program funding, and (3) facilities and systems.

I. Human Resource Requirements

The staff of the Office of Infrastructure R&D is the foundation on which this plan was developed and is critical to successful pursuit of the goals that it defines. As a minimum, a well- and appropriately trained cadre of 40 to 50 Federal staff and a similar number of onsite support staff will be required.² This research staff must be supported by strong contracting, financial management, and publications/communications capabilities in other offices. Staff development and training resources must be available to provide the advanced technical, leadership, and administrative training required to develop and maintain the skills required to support program activities. Equally as important, adequate funding and physical resources must be available to support active and ongoing stakeholder involvement during the life cycle of the R&D programs to ensure that the research products are responsive to stakeholder requirements and delivered in forms that can be implemented.

II. Program Funding

The strategies and activities articulated in this plan rely on a combination of research conducted “in-house” by the Federal and onsite contractor staff working at the Turner-Fairbank Highway Research Center, and research conducted by other institutions under contracts, grants, and cooperative agreements managed by the FHWA Office of Infrastructure R&D staff. Timely pursuit of these strategies is dependent on: (a) the availability of adequate financial resources for Federal and contract staff to conduct the annual R&D program, and (b) adequate funding and staffing to support dissemination of products and new knowledge, and to provide end users with technical support.

III. Facilities and Systems

Effective and efficient pursuit of the goals defined in this plan will require continued investment in systems and facilities for the conduct and management of the research. The cost of meeting these facility and system requirements is included in the overall program-funding requirement. This strategic plan articulates the requirements here to emphasize their vital importance.

² Although program funding traditionally provides contractor staff, the need for such staff is articulated under human resource needs in recognition of their role as an extension of the Federal research staff.

Benefits

The outcomes envisioned and described in this plan will benefit the American public by enabling improvements in the safety, performance, and cost effectiveness of the Nation's highway infrastructure, while minimizing the environmental impacts of highway construction, maintenance, and rehabilitation. The results of this strategic plan will make reductions in highway congestion possible, and enhance safety characteristics and improvements of the overall driving experience for the American public.

The FHWA is charged with ensuring minimum standards of safety for the public as it travels on the Nation's roads and highways. While many other organizations and agencies conduct highway infrastructure research, the FHWA is positioned uniquely to address the continuum of highway research from high-risk, exploratory, and advanced research, through the highly applied, problem-specific research that is necessary to address current issues and immediate problems. This broad range of research capability provides a high likelihood of success that is critical for sustaining the Nation's economy in the near and long terms.

Collaboration

In pursuing the R&D program described in this plan, the FHWA Office of Infrastructure R&D will work closely and collaboratively with other FHWA offices and with the broader community of highway stakeholders to ensure that the program:

- Addresses agency goals, missions, and requirements.
- Is appropriate for the FWHA and relevant to the mission of the Agency.
- Is well coordinated with related work by others to avoid duplication of effort and to maximize the overall value of the R&D investments.
- Delivers outcomes in the form of readily implementable products at the earliest appropriate time.
- Moves products into practice as quickly as possible to achieve maximum possible benefits.