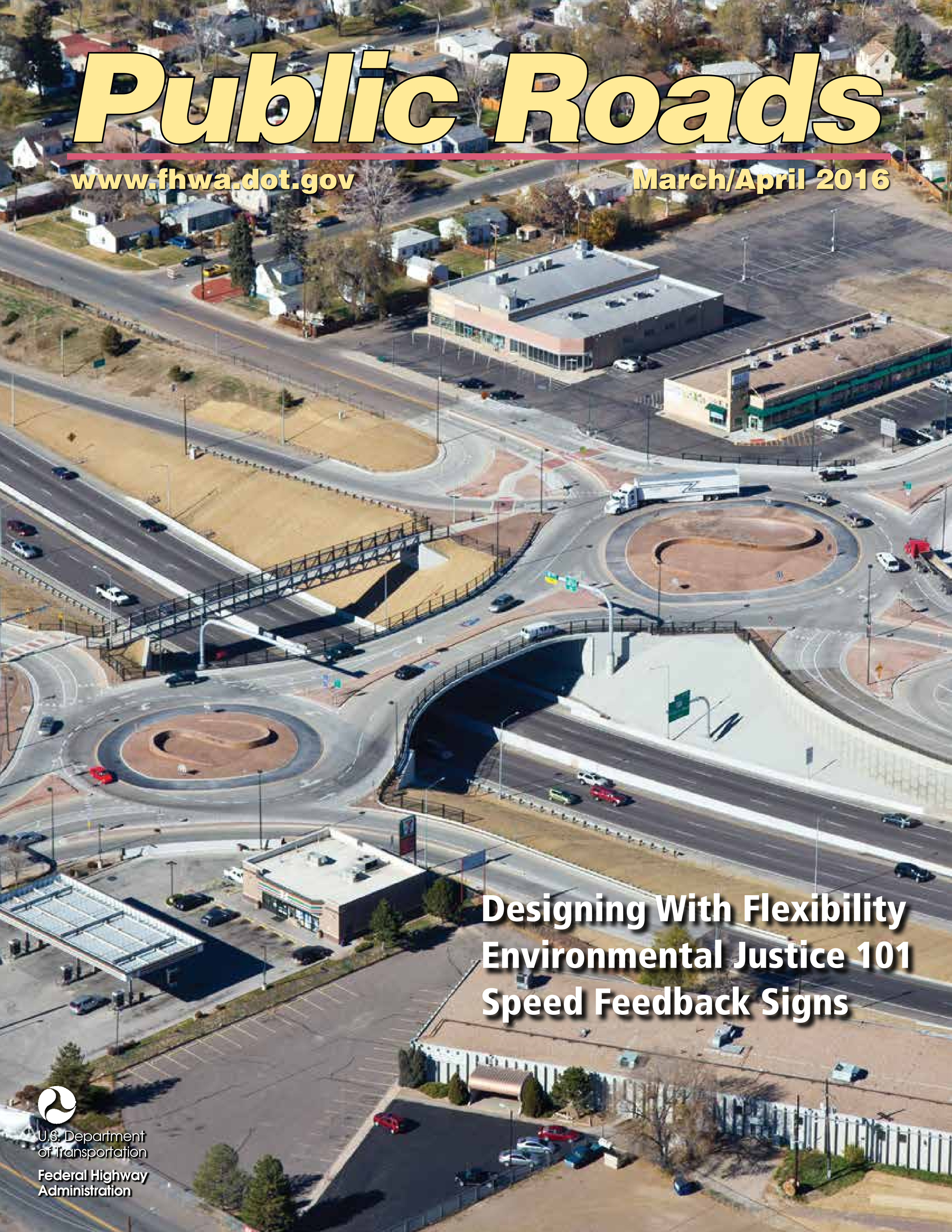

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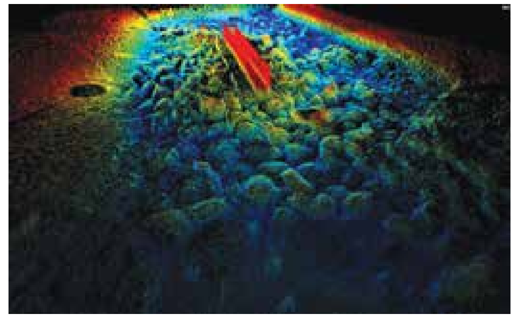
March/April 2016 **www.fhwa.dot.gov** **Vol. 79, No. 5**

Articles



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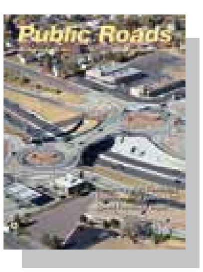

Front cover—Innovative and emerging tools are changing the way transportation agencies approach geometric design. Designers for this project at the I-70 interchange at Pecos Road in Denver, CO, had to balance a multitude of competing factors to meet the transportation goals of the community. For more information, see "The Evolution of Geometric Design" on page 28 in this issue of PUBLIC ROADS. *Photo: Kiewit Infrastructure Co.*

Back cover—The Massachusetts Department of Conservation and Recreation employed flexible designs to add bike lanes to this section of the Lynn Fells Parkway in Saugus, MA. Recent revisions to the Federal Highway Administration's highway design policy aim to increase flexibility in design to meet the needs of all transportation users. For more information, see "Toward More Flexible Design" on page 2 in this issue of PUBLIC ROADS. *Photo: Michelle Danila, Toole Design Group, LLC.*

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Guest Editorial

Flexible Design Is Key to Improving System Performance

From construction of the interstate system during the Eisenhower era through establishment of the National Highway System in 1991, the Nation has become more dependent on the performance of highways than anyone could have predicted. Geometric design criteria help highway engineers design roads efficiently and consistently, but simply meeting standards does not guarantee reaching performance goals. Information gathering and analysis help engineers better understand how flexible design choices affect performance. Applying this knowledge has the potential to make infrastructure more sustainable, strengthen the economy, and improve safety, mobility, and livability for all U.S. residents.

Of particular interest to the Federal Highway Administration's Office of Program Administration in recent years is the progress being made in understanding the safety effects of design choices. More than ever before, practitioners with the American Association of State Highway and Transportation Officials; the Transportation Research Board; and Federal, State, and local officials use this information to develop flexible design solutions that deliver improved performance.

More agencies now use practical design to inform decisions and balance what, how, and how big to build within their tightened budgets. This concept is not new. But, by increasing the use of data-driven predictive analysis of performance, FHWA officials believe that all transportation departments—from the smallest towns to the largest States—will be able to unlock more flexible designs. This flexibility will result in delivery of context-sensitive solutions at a lower project cost while improving the overall performance of the transportation system. Performance-based practical design, as this process is called, represents the next step in the evolution of highway design.

To accelerate improvements in system performance, the industry needs to improve professional skills in applying performance-based practical design. Implementing new tools and approaches will facilitate rewriting the fundamentals of highway design so that they are more flexible and better meet the Nation's critical transportation needs.

A new report, *Evolving Geometric Design Decision-Making in the United States*, discussed on page 28 in this issue of Public Roads, was developed through an AASHTO and FHWA partnership. Representatives of both organizations presented the report in June 2015 at the 5th International Symposium on Highway Geometric Design in Vancouver, Canada. The report describes many of the efforts undertaken in the last 5 years to accelerate improvements in system performance.

Recognizing the need to adapt, FHWA leadership recently proposed streamlining the required 13 controlling criteria for design and their application on the National Highway System. The proposed changes, published in the *Federal Register*, represent one of the latest examples of how performance-based knowledge is shaping the future of flexibility in highway design. State and local agencies too should consider how to incorporate performance-based design flexibility into their decisionmaking.

As the industry's understanding of the relationship between design and performance grows and more tools become available, practitioners' confidence in applying design flexibility also will grow. The profession is taking steps to embrace new design approaches and apply them more consistently. Doing so will further improve system performance and return on taxpayer investment—not to mention the benefits to mobility, safety, and livability for all.

Thomas D. Everett
Director
FHWA Office of Program Administration

The controlling criteria for highways are undergoing a makeover to provide engineers with greater flexibility to create best-fit solutions.

Toward More Flexible Design

by Elizabeth Hilton and Dan Goodman

(Above) The city of Austin, TX, encouraged pedestrian travel in this corridor by providing a wide, clear, and accessible sidewalk on this downtown street. Roadway design is increasingly focused on flexible solutions that incorporate multimodal transportation options.

July 11, 2016, marks the 100th anniversary of the creation of the Federal-aid highway program. As this major milestone approaches, it is interesting to look back at how the program has evolved over the years, especially in the design arena. From the first standards issued more than 80 years ago to a recent push for greater flexibility in design, geometric design of highways and streets has come a long way. And it is still evolving.

Today's transportation engineers need to strike a balance between standards and addressing the specific circumstances and context of each project. In addition to considering standard roadway characteristics, their designs have to account for economic, environmental, and social impacts, as well as support larger community and regional goals, including meeting the needs of all users.

But how do they succeed with so many challenges and expectations? Flexibility is key. In response to the call for greater flexibility in the design process, the Federal Highway Administration recently proposed to revise a key aspect of its highway design policy—the controlling criteria—making it easier for engineers to develop designs that meet community needs.

Here's a look at how the industry realized the need for more flexible design and what the revised controlling criteria would mean for road designers.

The Early Days of Design

The initial focus of the highway program was on linking parts of the country, upgrading wagon trails for use by the automobile, and providing better access for farmers to connect with markets. In the early days, most projects involved upgrading existing roads built initially for wagon traffic. By and large, States were more concerned about road surface and drainage than geometric design.

By the 1920s, the number of more powerful motor vehicles was growing, and State and Federal highway officials recognized the need to design roads to accommodate higher speeds. State highway agencies also realized the need for more consistent designs, including improved sight distance, curvature, and superelevation. In 1928, the American Association of State Highway Officials (AASHO) (now the American Association of State Highway and Transportation Officials) published the first "standards of practice" to promote uniformity in design.

AASHO policy guidance continued to evolve and focus on the design of rural highways, and later urban arterial highways and freeways. AASHO worked cooperatively with the U.S. Bureau of Public Roads and its successor, FHWA, which adopted AASHO guidelines for use on Federal-aid highway projects. Design guidance focused on provisions only for motor vehicle travel.

A Coming of Age for Design

During the 1960s, the context in which State highway agencies operated began to change. Community awareness of the impacts of freeway construction through established neighborhoods resulted in public opposition that many engineers had not previously encountered. The public also began to express concerns about the environmental impacts of projects, such as the movement of large amounts of earth to provide flatter, wider roadways. Increasingly, public pressure mounted for State departments of transportation to adopt practices that the industry knows today as context sensitive solutions, which are collaborative, interdisciplinary approaches that involve all stakeholders in providing a transportation facility that fits its setting. Solutions also emerged that increased opportunities for nonmotorized transportation and use of transit.

Beginning in the late 1960s, as highway agencies became part of departments of transportation, the focus shifted to a broader concept of transportation to include the movement of people and goods by a variety of modes of travel—aviation, rail, highways, city streets, transit, bicycling, and walking. AASHO became AASHTO with the addition of "Transportation" to its name in 1973, reflecting the growing emphasis on intermodal transportation.

Today, engineers find themselves challenged more than ever to deliver multimodal projects that take into account environmental and social impacts. They also must consider the economic aspects of their designs in the face of constrained transportation funding. Rather than simply following standards from a book, engineers are developing unique solutions to address the specific circumstances of each project and achieve the best overall solution, while also maximizing the return on investment.

To this end, FHWA and many DOTs are embracing performance-based practical design. This approach focuses on including features necessary to achieve performance goals for the project, rather than designing based solely on the standards. For a more detailed look at how geometric design of highways is changing, see "The Evolution of Geometric Design" on page 28 in this issue of PUBLIC ROADS.

Flexibility, such as that afforded by performance-based practical design, is crucial for engineers to develop solutions that balance the needs of all roadway users and meet the goals of the greater community. It facilitates a connected network of both motorized and nonmotorized transportation infrastructure that enhances access to jobs, schools, and essential services in a cost-effective manner.

The First Geometric Design Standards

In 1928, AASHO members approved the following four standards of practice to achieve some uniformity in highway design:

- Wherever practicable, shoulders along the edges of pavements shall have a standard width of no less than 8 feet (2.4 meters).
- On pavements, 10 feet (3 meters) shall be considered the standard width for each traffic lane.
- The crown of a two-lane concrete pavement shall be 1 inch (2.5 centimeters).
- No part of a concrete pavement shall have a thickness of less than 6 inches (15 centimeters), and all unsupported edges shall be strengthened.

Source: America's Highways 1776–1976.

These illustrations show before-and-after cross sections of an urban street where narrowed lanes provide space for bike lanes without increasing the overall width of the road. Revisions to the controlling criteria will allow engineers to make such decisions without requiring approval for the design exception from FHWA. *Source: Toole Design Group.*

The city of Overland Park, KS, added bicycle lanes to Switzer Road by narrowing the travel lanes when workers restriped the road after placing an ultrathin bonded asphalt surface. The proposed updates to the controlling criteria will make it easier for transportation agencies to make these kinds of decisions without requiring Federal approval for exceptions. *Photos: John Keating, City of Overland Park.*

13 Controlling Criteria

(Adopted in 1985)

1. Design speed
2. Lane width
3. Shoulder width
4. Bridge width
5. Horizontal alignment
6. Superelevation
7. Vertical alignment
8. Grade
9. Stopping sight distance
10. Cross slope
11. Vertical clearance
12. Horizontal clearance/lateral offset
13. Structural capacity

Updating the Controlling Criteria

FHWA regulations incorporate the geometric design standards for projects on the National Highway System (NHS) by reference. The standards are comprehensive, covering a broad range of design characteristics, while allowing for flexibility in their application.

Since 1985, FHWA has emphasized a subset of the design criteria contained in adopted standards by designating them as the 13 controlling criteria: design speed, lane width, shoulder width, bridge width, horizontal alignment, superelevation, vertical alignment, grade, stopping sight distance, cross slope, vertical clearance, horizontal clearance, and structural capacity.

The controlling criteria are the same for all projects on the NHS regardless of roadway type, surrounding land use, or other context. Design exceptions are required when any of these controlling criteria are not met. In addition, the Moving Ahead for Progress in the 21st Century Act (MAP-21) in 2012 expanded the NHS to include many urban roadways, which made them subject to the controlling criteria.

Through research conducted since 1985, however, engineers and planners have gained a better understanding of the traffic operational and safety effects of the controlling criteria. In 2014, the National Cooperative Highway Research Program Report 783 *Evaluation of the 13 Controlling Criteria for Geometric Design* examined the safety and operational effects of the controlling criteria. Consistent with the research findings and FHWA's efforts regarding performance-based practical design, FHWA recently proposed changes to the 13 controlling criteria.

On October 7, 2015, the following proposed changes were published in a notice in the *Federal Register*:

- Three criteria were proposed for elimination from the list of controlling criteria: bridge width, vertical alignment, and horizontal clearance (lateral offset to obstruction).
- Three criteria were proposed to be renamed to improve clarity and understanding: horizontal alignment to horizontal curve radius; grade to maximum grade (to eliminate minimum grade as a controlling criterion); and structural capacity to design loading structural capacity.
- Design speed and design loading structural capacity were proposed to be retained as controlling criteria for all NHS roadways.
- The following criteria were proposed as controlling only on high-speed (design speed greater than or equal to 50 miles per hour, mi/h [80 kilometers per hour, km/h]) NHS roads: lane width, shoulder width, horizontal curve radius, superelevation, stopping sight distance, maximum grade, cross slope, and vertical clearance.

These proposed changes would result in only two controlling criteria remaining for NHS roadways with a design speed of less than 50 mi/h (80 km/h): design speed and design loading structural capacity. The significant reduction in the number of controlling criteria applicable to roadways with lower speeds will give engineers the flexibility they need to design solutions that address the project goals in a way that is more compatible with the community. For example, engineers will have more flexibility to narrow vehicular lanes without needing Federal approval to do so.

FHWA received more than 2,300 comments on the proposal. After carefully considering these comments, FHWA will issue a final rule on the proposed policy change in the *Federal Register*. Once finalized, the updated policy will be available at www.fhwa.dot.gov/programadmin/standards.cfm.

By ensuring that design exceptions are required only for criteria with the greatest safety or operational impacts, FHWA will effectively remove barriers to applying greater flexibility in design. Where the remaining controlling criteria cannot be met, design exceptions are still available as tools that transportation engineers can use to help them provide the best overall design.

Seleta Reynolds, general manager for the Los Angeles Department of Transportation (LADOT) in California, says, "LADOT supports this streamlining effort and appreciates FHWA's objective of providing local agencies with more flexibility in project design. Beyond flexibility, these changes encourage local agencies to be innovative and design projects that enhance community safety and mobility for everyone."

Achieving Better Design

The changes to the controlling criteria are a significant step in supporting FHWA's partners and stakeholders as they work to implement projects that result in better and more sustainable outcomes, such as improved connectivity and mobility for people of all ages and abilities, enhanced safety, and increased equity. The changes to the controlling criteria also demonstrate how much the focus of the Federal-aid highway program has evolved since its creation. Today, FHWA focuses on the safety of all users of the transportation system and on connecting people to work, schools, and other important destinations in ways that meet the needs of all modes and are sensitive to community character, livability, and quality of life.

To further assist State transportation departments and partners in achieving these goals, FHWA has several additional efforts underway to improve guidance on a multitude of issues. Several products will be available soon, including a workbook called *Incorporating On-Road Bicycle Networks Into Resurfacing Projects* and a resource titled *Achieving Multimodal Networks: Applying Design Flexibility and Reducing Conflicts*. The latter will include explanatory graphics and highlight key concepts for a broad range of design topics, such as crossing treatments, school access, transitions from State highways to main streets, and intersection geometry. The intent of these design topics is to help communities build connected pedestrian and bicycle networks, apply design flexibility, and enhance safety for all roadway users.

FHWA proposed only two controlling criteria for NHS roadways with a design speed of less than 50 miles (80 kilometers) per hour:

1. Design speed
2. Design loading structural capacity

The addition of this bike lane improved conditions for bicyclists on South Congress Avenue in Austin, TX, a key urban corridor. *Photo: Nathan Wilkes, City of Austin.*

Elizabeth Hilton is a geometric design engineer in FHWA's Office of Infrastructure where she focuses on geometric, bicycle, pedestrian, and accessible design. She is a former chair of the Transportation Research Board's Design Section and Geometric Design Committee and serves as FHWA's representative to the AASHTO Technical Committee on Geometric Design. She is a licensed professional engineer in Texas. She holds a B.S. in civil engineering from the University of Texas at Austin and an M.B.A. in public administration from St. Edward's University.

Dan Goodman is a transportation specialist on the Livability Team in the Office of Human Environment at FHWA. He is a member of the TRB Pedestrian Committee and former chair of its Pedestrian Research Subcommittee. He serves as FHWA's representative to the AASHTO Joint Technical Committee on Non-Motorized Transportation. He has a B.S. in political science from Kalamazoo College and a master of community planning degree from the University of Rhode Island.

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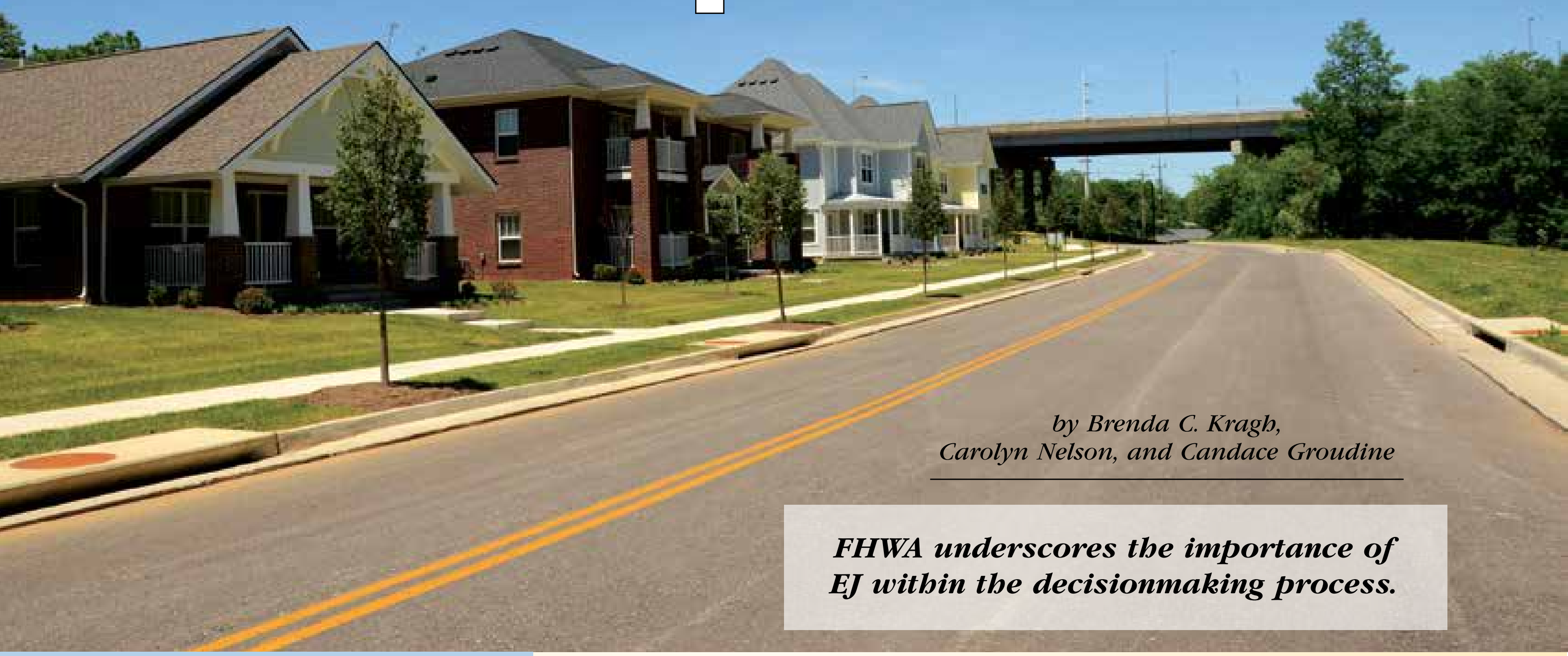
Editor's Note: As of press time, the final rule listing specific criteria has not been published. Visit www.fhwa.dot.gov/programadmin/standards.cfm to read the final provisions of FHWA's policy regarding controlling criteria for design.

Environmental Justice: The *New Normal* for Transportation



by Brenda C. Kragh, Carolyn Nelson, and Candace Groudine

FHWA underscores the importance of EJ within the decisionmaking process.

(Above) These homes were built as part of the Newtown Pike Extension in Lexington, KY, to help mitigate the project's disproportionately high and adverse impacts on the Davis Bottom neighborhood. *Photo: Stantec.*

Historically, Federal agencies and funding recipients did not always consider impacts to all affected communities for transportation projects. As a result, sometimes these activities may have caused disproportionately high and adverse impacts on minority populations and low-income populations that were not addressed.

Environmental Justice (EJ) at the Federal Highway Administration means identifying and addressing disproportionately high and adverse effects of the agency's programs, policies, and activities on minority populations and low-income populations to achieve an equitable distribution of benefits and burdens. This includes the full, fair, and meaningful participation by all potentially affected communities through all phases of transportation decisionmaking.

FHWA considers EJ in all phases of project development including planning, environmental review, design, right-of-way, construction, and maintenance and operations. FHWA also considers EJ in all other programs and activities, such as public involvement, freight planning, safety measures, tribal consultation, and the Title VI Civil Rights Program.

In 1983, at the request of Congress, the U.S. General Accounting Office (now the Government Accountability Office) investigated and published a report titled *Siting of Hazardous Landfills and Their Correlation with Racial and Economic Status of Surrounding Communities*. The report found that three out of the four offsite hazardous waste landfills investigated in Alabama, North Carolina, and South Carolina were located in majority black communities, and all four site areas contained at least 26 percent of the population with income below the poverty level. The report also indicates the siting of such hazardous waste landfills was a State responsibility at that time.

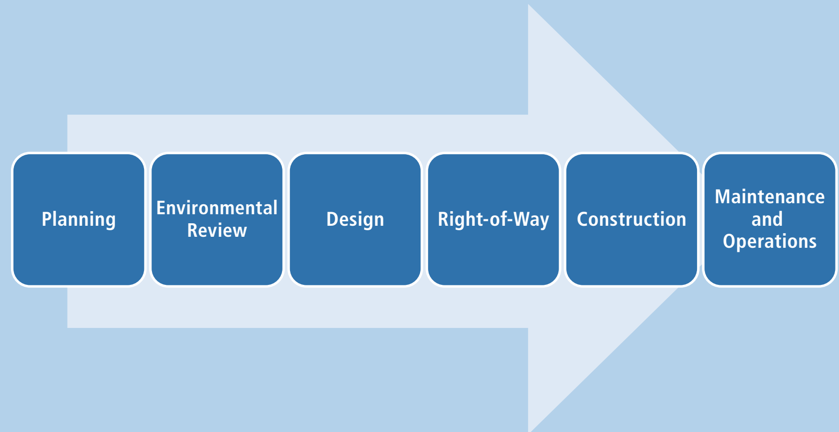
In 1994, President Bill Clinton signed Executive Order 12898, requiring Federal agencies to identify and address adverse human health or environmental effects resulting from their programs, policies, or activities on affected populations. Following the issuance of E.O. 12898, the U.S. Department of Transportation and the Federal Highway Administration issued EJ orders establishing policies and procedures related to their activities.

The agencies' EJ orders involve identifying and addressing the potential effects of transportation projects on minority populations and low-income populations. Doing so requires the full, fair, and meaningful participation by all communities throughout all phases of transportation decisionmaking.

Since issuance of the EJ orders, recipients of Federal funds, such as State and local transportation agencies, have continually requested specific guidance on implementation. Understanding the uniqueness of contexts, varying data needs and quality, changing demographics, and other complex unknowns at different stages of project development make providing specific guidance problematic. That is why FHWA has chosen an oversight approach that offers flexibility to States and local transportation agencies, because they know their communities best.

To assist recipients of Federal funding in complying with EJ requirements, FHWA offers training, technical assistance, case studies, and webinars on EJ, and guidance on specific definitions and parameters in its EJ order. FHWA also has developed a number of programs, partnerships, and documents, including the new *Environmental Justice Reference Guide* (FHWA-HEP-15-035). Together, these resources help ensure that all who accept Federal funds meet EJ requirements, as well as a host of other Federal requirements, such as those in Title VI of the Civil Rights Act of 1964.

FHWA Considers EJ in All Stages of Project Development



Source: FHWA.

EJ Orders: The Specifics

E.O. 12898 signifies the acknowledgement of the Executive branch of the Federal Government that environmental issues must be considered when Federal agencies engage in decisionmaking that is likely to have an impact on minority populations or low-income populations. E.O. 12898 requires that all Federal agencies develop policies to achieve EJ "to the greatest extent practicable and permitted by law." Although Executive orders are not laws, they do require Federal agencies—and, by extension, the recipients of Federal funding—to abide by them.

E.O. 12898 mandates that each Federal agency develop an agency-wide EJ strategy. The strategy must list programs, policies, planning, and participation processes that, at a minimum, promote enforcement of all health and environmental authorities in areas with minority populations or low-income populations; ensure greater public participation; improve research and data collection relating to the health and environment of these populations; and identify differential patterns of consumption of natural resources.

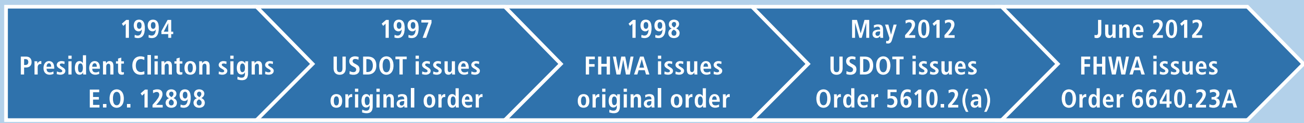
USDOT issued its EJ Strategy in 1995 and updated it in 2012, which identifies three fundamental principles of EJ that guide the Department's actions:

- To avoid, minimize, or mitigate disproportionately high and adverse human health and environmental effects, including social and economic effects, on minority populations and low-income populations.
- To ensure the full and fair participation by all potentially affected communities in the transportation decisionmaking process.
- To prevent the denial of, reduction in, or significant delay in the receipt of benefits by minority populations and low-income populations.

USDOT further responded to E.O. 12898 by issuing the DOT EJ Order in April 1997. In May 2012, USDOT issued Departmental Order 5610.2(a), an update to the earlier order. The revised order provides more detail on how the objectives of EJ must be integrated into planning and project development,

President Clinton signed E.O. 12898 on February 11, 1994.

Timeline of Executive, USDOT, and FHWA EJ Orders



rulemaking, and policy formulation. It also affirms the importance of considering EJ principles as part of early planning activities.

In June 2012, FHWA issued FHWA Order 6640.23A, a directive that replaced a previous FHWA EJ order from 1998. This order explains the agency's EJ policy and describes how EJ should relate to a broad range of FHWA activities.

"FHWA EJ Order 6640.23A reflects FHWA's longstanding policy to actively ensure nondiscrimination in federally funded activities," says Gloria Shepherd, associate administrator of the FHWA Office of Planning, Environment, and Realty. "The order provides a framework to identify and prevent discriminatory effects when administering FHWA's programs, policies, and activities. We want to ensure that impacts to communities and people are recognized early and continually throughout the transportation decisionmaking process."

In 2013, FHWA also established an EJ Implementation Workgroup, which meets monthly to discuss relevant EJ issues. The group includes staff from headquarters and division offices within a variety of disciplines. The group also hosts outside speakers, such as staff from the U.S. Environmental Protection Agency (EPA) who have demonstrated and discussed their EJSCREEN program with the workgroup.

The FHWA Implementation Workgroup developed the *EJ Reference Guide* in 2015 to increase EJ capacity among transportation practitioners at FHWA division offices, State departments of transportation, and metropolitan planning organizations (MPOs). The guide is available at www.fhwa.dot.gov/environment/environmental_justice/resources/reference_guide_2015.

EJ and Title VI

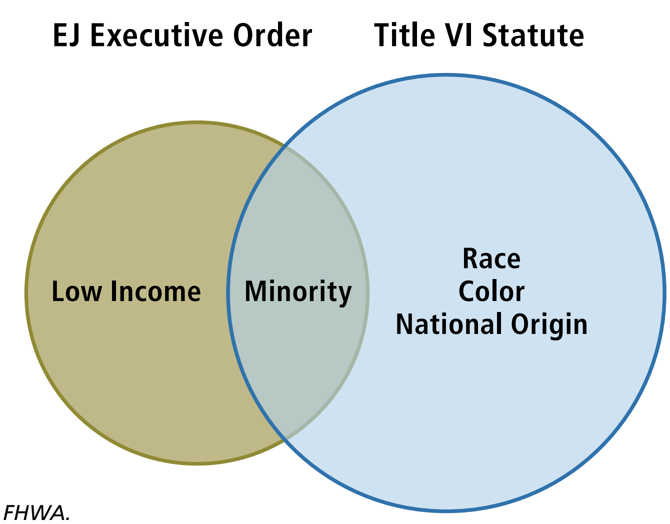
The transmittal memorandum that accompanied E.O. 12898 explained how agencies can use specific provisions of existing law to achieve the order's EJ goals. In the memorandum, President Clinton encouraged agencies to account for EJ in the implementation of Title VI, which prohibits discrimination on the basis of race, color, or national origin in programs receiving Federal assistance.

"The memorandum is significant because it helps to provide the broader civil rights context upon which the E.O. is based," says Warren Whitlock, associate administrator for the Office of Civil Rights at FHWA. "In addition to being about agencies' aspirations to avoid actions that are discriminatory, the E.O. is also about the obligation to take practical steps to achieve greater social equity."

Although the nondiscrimination principles of E.O. 12898 and the Title VI statute intersect, they are two separate mandates, each with its own requirements. For example, the term "minority," which is a category under EJ, overlaps with "race, color, and national origin [including individuals with limited English proficiency]," which the Title VI statute protects. EJ principles, however, also apply to low-income populations, which the Title VI statute does not cover.

Under USDOT's and FHWA's Title VI regulations, a recipient of Federal financial assistance is prohibited from administering its programs in a way that discriminates against individuals based on their race, color, or national origin. For example, an agency's policy or practice that results in discriminatory effects or disparate impacts violates Title VI regulations, even if the results are unintended. For example, a State may grant a permit for an industrial plant to operate in a predominantly minority community because the owner of the proposed plant met all the applicable legal standards. However, if the plant begins emitting toxic pollutants when it is operational, the State could be found in violation of EPA's Title VI regulations because

Populations Protected Under EJ and Title VI



Source: FHWA.

it failed to protect the residents of this community from adverse disparate impacts from the cumulative effects of pollution coming from the plant. The Title VI regulations also prohibit intentional discrimination.

One central objective of E.O. 12898 and the transmittal memorandum is to ensure that Federal agencies enforce and promote nondiscrimination. On the other hand, Title VI applies to all activities of Federal recipients, not only those which may have human health or environmental effects.

Although the Title VI statute protects persons from discrimination solely on the basis of race, color, and national origin, the FHWA Title VI Program includes other nondiscrimination statutes and authorities under its umbrella, including E.O. 12898, ensuring that FHWA's recipients do not discriminate based on income, sex, age, disability, or limited English proficiency as well.

Supporting Implementation

The FHWA Title VI Program uses several tools to ensure nondiscrimination. For example, every State department of transportation must submit an implementation plan that describes how, as a recipient of Federal financial assistance, it reviews program areas to identify disparate impacts on the public that may constitute discrimination.

In addition, FHWA's Office of Civil Rights, which oversees the FHWA Title VI Program, conducts reviews of State DOT programs to ensure compliance with those requirements and to strengthen programs containing deficiencies. If a State DOT determines that a project causes disproportionately high and adverse impacts on a given population group relative to other population groups, then it must analyze the disparate impact. The Federal program areas subject to such review and analysis may include planning, environment, design, right-of-way, construction, maintenance and operations, safety, research, and training.

Further, a core element of the FHWA Title VI Program is a regulatory requirement that the State DOT collect demographic and economic data about its populations. These data enable State DOTs to identify trends and impacts associated with their program areas and to determine whether one or more of the population groups has borne disproportionately high and adverse impacts.

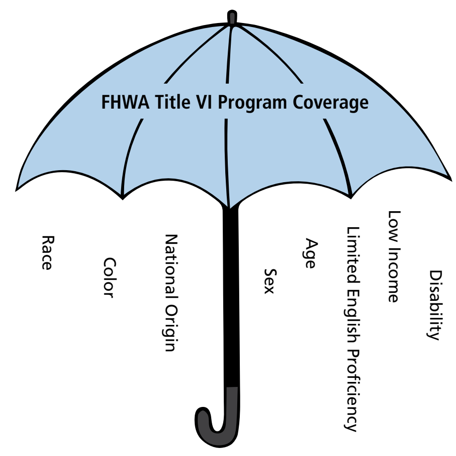
FHWA also requires every State DOT to sign a document subjecting it to the Standard Title VI/Nondiscrimination Assurances. Among these is E.O. 12898, which is one of the numerous statutory, regulatory, and executive authorities to which the assurance binds its signatories. The Title VI Program also requires that FHWA conduct reviews of all recipients, helping them strengthen their programs by maintaining compliance with Title VI and other nondiscrimination requirements.

"Title VI requires all recipients of Federal funding to ensure that their programs operate in a nondiscriminatory manner," says Deeana Jang, chief of the Federal Coordination and Compliance Section in the Civil Rights Division of the U.S. Department of Justice. "The nexus of Title VI and Environmental Justice is exemplified by Title VI's requirement that recipients' and subrecipients' activities that affect the environment or human health must not intentionally discriminate or have the effect of discriminating against any person on the basis of race, color, or national origin."

Transportation Decisionmaking

Properly implemented, EJ principles and procedures improve all levels of transportation decisionmaking by enabling practitioners to make transportation decisions that meet the needs of all people. These principles ensure the design of transportation facilities that fit more harmoniously into communities. They also enhance public involvement, strengthen community-based partnerships, and provide minority populations and low-income populations with opportunities to learn about and improve the quality and usefulness of transportation in their lives.

Principles of EJ also help to improve data collection, monitoring, and analysis tools that assess the needs of and analyze the potential impacts on minority populations and low-income populations. These tools help to minimize and mitigate unavoidable impacts by identifying concerns early in the



Source: FHWA.

The FHWA Title VI Program is broader than the Title VI statute and encompasses other nondiscrimination statutes and authorities under its umbrella, including Executive Order 12898 on EJ.

planning phase and providing offsetting initiatives and enhancement measures to benefit affected communities and neighborhoods.

Environmental Review

Environmental Justice should be an integral part of the environmental review process including the implementation of the provisions of the National Environmental Policy Act of 1969 (NEPA). NEPA requires Federal agencies to consider the social, economic, and environmental effects of each project proposed for Federal funding. Regardless of the NEPA class of action, recipients of FHWA funds must address whether the proposed project will impact EJ populations. Where there is an impact to the EJ population, part of the analysis will include determining if there will be a disproportionately high and adverse effect on minority populations or low-income populations.

NEPA requires, and FHWA is committed to, examining and avoiding potential impacts on the social and natural environment when considering proposed transportation projects. The agency's NEPA process is an approach to balanced transportation decisionmaking that takes into account the potential impacts on the human and natural

Comparison of EJ, the Title VI Statute, and the FHWA Title VI Program

Area of Comparison	EJ	Title VI Statute	FHWA Title VI Program
Authorizing Source	Executive Order 12898	Civil Rights Act of 1964	Title VI Program and Related Authorities: 23 Code of Federal Regulations 200
Goal	Identify and address disproportionately high and adverse human health or environmental effects on minority populations and low-income populations.	Prohibit discrimination on the basis of race, color, or national origin in programs receiving Federal assistance.	Ensure that funding recipients comply with Title VI and related civil rights authorities.
Protected Classes	Minority populations and low-income populations	Race, color, and national origin	Race, color, national origin, sex, age, disability, low-income, and limited English proficiency
Covered Actions	Federal programs, policies, and activities	All activities of recipients of Federal assistance	All activities of recipients of FHWA assistance
FHWA Lead Office	Office of Civil Rights and Office of Planning, Environment, and Realty	Office of Civil Rights	Office of Civil Rights
Entities Responsible for Implementation	FHWA offices and recipients of Federal assistance	FHWA offices and recipients of Federal assistance	FHWA offices and recipients of FHWA assistance
Provides Authority for Private Parties to Initiate a Lawsuit	No. However, where an agency opts to examine EJ as part of its NEPA analysis, courts may review the EJ analysis under the Administrative Procedure Act.	Yes. However, there is only a private right of action in a lawsuit for claims of intentional discrimination and not disparate impact discrimination. Only the funding agency issuing the disparate impact regulation has the authority to challenge a recipient's actions under a disparate impact claim.	No.

environment and the public's need for safe and efficient transportation.

On December 16, 2011, FHWA issued a memorandum titled "Guidance on Environmental Justice and NEPA." The memorandum describes the process involved in addressing Environmental Justice during NEPA review, including documentation requirements. The 2011 memo also supplements the FHWA Technical Advisory T6640.8A, which provides guidance for documenting the potential social, economic, and environmental impacts considered in the development and implementation of highway projects. The memorandum provides that "explicit consideration of potential effects on minority populations and low-income populations is required in NEPA documents, and normally will be found under the social and economic discussion sections. This guidance applies to all NEPA classes of action, as appropriate."

In the transportation decisionmaking process, EJ sets forth a practice by which the impacts on low-income populations and minority populations are addressed in NEPA to provide more comprehensive and balanced outcomes. NEPA's critical elements (addressing impacts, developing alternatives, public involvement, documentation, interagency coordination, and mitigation) can all be completed under the purview of EJ, leading to better transportation decisionmaking.

Learning From Successes

Federal agencies, State DOTs, and MPOs all play a part in advancing EJ by involving the public in transportation decisions. Effective public involvement enables transportation professionals to develop systems, services, and solutions that meet the needs of the public, including minority populations and low-income populations. There are many examples of transportation initiatives that successfully integrate EJ principles. Partners and stakeholders can use these successes to champion the opportunities and responsibilities of EJ.

The Newtown Pike Extension project in Lexington, KY, for example, illustrates the effective consideration of EJ principles; implementation of the process of assessing community impacts; collaboration among Federal, State, and local agencies working with affected communities to understand their needs; and integration of quality of life considerations into transportation projects. The project is an example of how transportation planning, project development, and design can enhance quality of life in a community.

The purpose of the project was to extend and upgrade the Newtown Pike to improve the flow of traffic, draw traffic away from downtown, and improve access to the University of Kentucky central campus. The extension project was first conceived in 1931 and saw some movement in the 1970s. However, potential impacts to low-income communities and minority communities, publicly owned properties, and historic resources presented challenges to project implementation. By the 1990s, traffic congestion in the downtown area was severe, prompting a renewed effort to find a solution.

Through the NEPA process, FHWA and the Lexington-Fayette Urban County Government, with a strong presence of and partnership with the Kentucky Transportation Cabinet, moved the project forward in a manner that considered and protected surrounding communities. The build alternatives for the Newtown Pike Extension project would result in relocations in the low-income community of Davis Bottom. The community impact assessment noted the absence of affordable replacement housing and projected that a no-action alternative would also result in a decline of Davis Bottom, continuing the trend begun by years of uncertainty around the project.

Through a survey and public engagement opportunities, the community expressed interest in remaining in the area. The community impact assessment documented that the build alternatives and the no-action alternative would disrupt family and community ties, that residents would lose the opportunity to walk to major job providers in the downtown area, and that many families would be forced to move from a location where they had resided for generations. The assessment concluded that because none of the residential relocation or community disruption impacts would affect the other neighborhoods along the proposed corridor to the same degree, impacts to Davis Bottom met the disproportionately high and adverse impact requirements of Executive Order 12898.

To avoid disruption to community cohesion and mitigate EJ impacts, the project partners incorporated a variety of mitigation strategies. Most notably, development of the Southend Park Urban Village Plan provided the framework for mitigation of EJ impacts. The plan called for housing that would enable residents of the Davis Bottom community to remain in the area. It proposed a new neighborhood, later named Davis Park, on 25 acres (10 hectares) of the Davis Bottom neighborhood to provide homes, rental units, and new or renovated community facilities. A Community Land Trust (CLT) was created as part of the project to implement the plan.

"Homeowners who may have been more enticed to take their relocation benefits and move away were provided an enhanced resale formula if the home they chose to relocate to was in the upcoming Community Land Trust," says Thomas Nelson, Jr., division administrator for the FHWA Kentucky Division. "This formula allowed for the purchase of a higher quality, more energy-efficient home that would also let them build equity and remain a part of the community. Renters deciding to stay in the area and move into the CLT would receive 10 years of rent subsidy instead of the usual benefit of 42 months."

Those affected by relocation had an opportunity to stay in subsidized temporary homes established directly in the redeveloped area. The plan also called for strategies such as erecting a noise barrier to protect

The Newtown Pike Extension involved construction of affordable housing and noise barriers, as shown here, to reduce the project's impacts on surrounding residential areas.

Stantec

the residential areas from increased sound from the adjacent railroad.

"There was great concern over temporarily relocating the residents away from their existing homes during the redevelopment of the area," says David Whitworth, project delivery team leader at the FHWA Kentucky Division. "We felt that if members of the community were scattered into available temporary housing throughout the city, the community could be lost forever. The project team made the decision to provide various incentives for the community cohesion. These incentives were well-received and helped retain residents as a core community to build onto."

State DOT Leadership

State DOTs are at the heart of planning, design, construction, operations, and maintenance of projects across all travel modes. They allocate resources from various Federal-aid programs. To successfully integrate Title VI and EJ into their activities, State DOTs need the technical capability to assess the benefits and adverse effects of transportation activities among different population groups and use that capability to develop appropriate procedures, goals, and performance measures in all aspects of their mission. They also need to ensure that Statewide Transportation Improvement Programs satisfy the letter and intent of Title VI requirements and EJ principles.

Further, State DOTs need to ensure meaningful public involvement is afforded to minority populations and low-income populations. In addition to involving the public, they need to work with Federal, State, local, and transit planning partners to create and enhance intermodal systems, and support projects that can improve the natural and human environments for EJ communities.

The Massachusetts Department of Transportation (MassDOT) worked to enhance public involvement with weMove Massachusetts, a strategic planning process for multimodal transportation. The strategic process is the State's first comprehensive, data-driven effort to prioritize transportation investments. MassDOT engaged in extensive public outreach to EJ and Title VI communities, and used email and media releases, social media, and discussions with legislative stakeholders to reach a geographically diverse set of stakeholders for weMove Massachusetts. In addition, MassDOT released a questionnaire that was available in five languages to learn about travel choices, key issues, and attitudes toward various modes of travel. This effort enabled MassDOT to identify core themes relevant to stakeholders and ensure that EJ populations were taken into consideration.

"MassDOT's outreach to minority [communities] and low-income communities was critical to understanding the transportation needs of all of our customers," says Trey Joseph Wadsworth, manager of MPO activities with MassDOT. "Recognizing that many of these customers are left out of the conversation, the most valuable lesson learned was to utilize the established relationships that other governmental organizations have with EJ and Title VI communities. For weMove Massachusetts, we found connecting with local public health departments to be the most fruitful."

The Role of MPOs

MPOs serve as the primary forum where State DOTs, transit providers, local agencies, and the public develop plans and programs for local transportation that address the needs of a metropolitan area. MPOs can help local public officials understand how Title VI and EJ requirements improve planning and decisionmaking.

For example, the Denver Regional Council of Governments (DRCOG) used geographic information systems (GIS) to identify low-income and minority areas and transposed those areas onto maps in the *2035 Metro Vision Regional Transportation Plan*, its long-range transportation plan. Through this exercise, DRCOG confirmed that more than half of the anticipated fiscally constrained regional transportation system expenditures are for public transit and other nonroadway projects and services with a greater propensity to benefit minority and low-income residents.

The council also has resolved to ensure that future road projects funded by DRCOG include multimodal elements that benefit nondrivers. In the early 2000s, DRCOG conducted an analysis to identify employment areas that are underserved by transit. DRCOG's plan is to improve accessibility to employment centers in the region.

Similarly, the Baltimore Metropolitan Council in Maryland developed a long-range plan, *Plan It 2035*, in which the staff conducted a GIS analysis to estimate the accessibility of minority populations and low-income populations with respect to home-based work and nonwork trips. The council's goal was to ensure that the plan would have no disproportionately high and adverse impacts on these communities. The MPO identified and compared impacts for both existing and committed projects and under a preferred alternative scenario.

DRCOG
DENVER REGIONAL COUNCIL OF GOVERNMENTS
We make life better!

weMOVE
MASSACHUSETTS
planning for performance

CREATE Program

CREATE Program

Shown here are before and after images of the Union Pacific Third Mainline-Proviso Yard in Chicago, which received a multimodal facility makeover as part of the Chicago Region Environmental and Transportation Efficiency Program. Before the improvements, there were two Union Pacific main lines to the south (right) of the Metra station on which both freight and Metra commuter trains operated. Pedestrians had to cross the two tracks at grade to get from the parking lot (far right) to the station shelter. In addition, a double Union Pacific main track had only a single track connection to the north-south Indiana Harbor Belt tracks. During 6 hours of "rush hour" per day, Metra commuter trains occupied both tracks, restricting freight operations.

After the facility makeover, pedestrians can access the Metra station via an underground tunnel, eliminating the need to cross the train tracks at grade. The covered ramp and stairwells leading to the tunnel are visible in the foreground before the station platforms. The improvements also include a new 3.5-mile (5.6-kilometer) third main line, built to the north of the station platform to enable freight trains to travel east and west via Union Pacific's primary route at the same time passenger trains are operating during rush hour. In addition, a second connection between the Indiana Harbor Belt tracks and the new Union Pacific third main line provides access to Proviso Yard via overhead bridge (visible here to the north of the tracks).

Transportation agencies cannot fully meet community needs without the active participation of well-informed, empowered individuals, community groups, and other nongovernmental organizations such as businesses and academic institutions. These individuals and groups advance the letter, spirit, and intent of Title VI and EJ in transportation.

Publications and Other Resources

Because each EJ context is unique to a specific place, history, and custom, developing rules that are appropriate for every situation is difficult. However, practitioners have access to many resources that can help them identify and address EJ issues.

The FHWA *EJ Reference Guide*, published in April 2015, brings together existing resources and examples that FHWA and partners can adapt to specific scenarios. The purpose of the guide is to provide FHWA practitioners with a single reference document to help them ensure compliance with EJ requirements when reviewing transportation plans; evaluating FHWA projects; developing or revising FHWA policies, guidance, and rulemakings; and creating and implementing FHWA programs.

The *EJ Reference Guide* does not create new requirements or replace existing guidance. Its primary audience is FHWA practitioners; however, the guide is also available and useful to State and local practitioners, and the public.

In addition to publishing the guide, USDOT and FHWA have approached EJ guidance through training and case studies. Since 2001, FHWA has offered an instructor-led, 2-day training through the National Highway Institute, course 142042 Fundamentals of Environmental Justice. NHI has conducted 44 sessions since updating it in 2007. More recently, FHWA is pursuing a Web-based, self-paced version and a new EJ analysis course.

The agency also has an Environmental Justice Web site at www.fhwa.dot.gov/environment/environmental_justice and an Environmental Review Toolkit Web site at www.environment.fhwa.dot.gov. The sites include case studies that illustrate EJ considerations. In addition, the FHWA Livability Initiative Web site at www.fhwa.dot.gov/livability includes a brochure on the Newtown Pike Extension Project.

The signing of E.O. 12898 created the National Environmental Justice Advisory Council and named the U.S. EPA the lead Federal agency on EJ. The order directed EPA to create a Federal Interagency Working Group on EJ, composed of representatives from 17 agencies of the Federal Government. High-level representatives from each agency signed a memorandum of understanding in 2011 that commits each agency to an annual progress report on EJ activities. USDOT and its fellow Federal agency partners also committed to advancing EJ through policies, programs, and activities.

As a member of the working group, USDOT creates an annual summary report on the Department's EJ activities, which are available at www.fhwa.dot.gov/environment/environmental_justice/ej_at_dot.

Implementation Activities

In preparation for USDOT's 2014 EJ annual progress report, FHWA sent a request for EJ activities to FHWA's 52 division offices. All of the divisions responded with activities to report. What follows is a summary of several key activities and accomplishments reported in 2014.

The FHWA Florida Division reported assisting the Florida DOT with the development, review, and distribution of a three-part series of EJ training videos. The first covers the foundations of EJ. The second specifies key definitions for EJ analysis, and the third provides a detailed methodology. The videos are available at www.dot.state.fl.us/emo/pubs/sce/sceVideos.shtm.

In another example, staff at the FHWA Illinois Division worked with MPOs in the State to improve identification of low-income and limited English proficiency groups, conduct meetings in locations convenient to EJ populations, provide multilingual information, and use visualization techniques such as maps.

The Chicago Region Environmental and Transportation Efficiency Program (CREATE) is a first-of-its-kind partnership of USDOT, the State of Illinois, city of Chicago, Metra, Amtrak, and the Nation's freight railroads. The FHWA Illinois Division aided in development of CREATE and the partnership's EJ mitigation methodology to apply to all 70 Chicago-area projects, as appropriate. Because of the development of a consistent approach to EJ, evaluations and reasonable mitigation measures will save time on project development and ensure consistent application across all projects.

Other EJ Resources

EPA has produced many resources on EJ that are available to the public. The agency recently released EJSCREEN, an EJ mapping and screening tool that provides a nationally consistent dataset and approach for combining environmental and demographic indicators. The agency also recently released its *Draft EJ 2020 Action Agenda Framework*. The framework will help EPA advance EJ through its programs, policies, and activities. In addition, EPA hosts the EJ Interagency Working Group Web site at www3.epa.gov/environmentaljustice/interagency/index.html, which contains useful EJ resources (such as the 2011 *Environmental Justice Federal Interagency Directory* and the *Community-Based Federal Environmental Justice Resource Guide*, which are currently being updated).

Several other Federal resources related to EJ also exist. One example is the Federal Transit Administration's Circular 4703.1, *Environmental Justice Policy Guidance for Federal Transit Administration Recipients*. FHWA and FTA have joint planning regulations and project development/NEPA regulations, but much of FTA funding is in the form of grants. The FTA circular serves as a guidance document on EJ activities for grant recipients. Most of the FTA definitions are identical to USDOT's and FHWA's EJ orders, but a few procedures differ.

Next Steps

FHWA continues to support EJ through participation in the EJ Interagency Working Group and by providing annual EJ reports. FHWA is working with the Office of the Secretary of Transportation to update USDOT's EJ Strategy. In addition, FHWA is working to advance the EJ state of the practice through the development of EJ resources such as fact sheets and webinars. FHWA strives to build capacity on EJ and explore topics on the impacts of climate change and EJ, EJ and tolling, and EJ and automated vehicles.

When EJ considerations are addressed throughout the transportation decisionmaking process, FHWA and USDOT can meet the transportation needs of communities while also enhancing quality of life for all individuals in those communities. As agencies work diligently to identify and address disproportionately high and adverse effects, EJ becomes the new normal.

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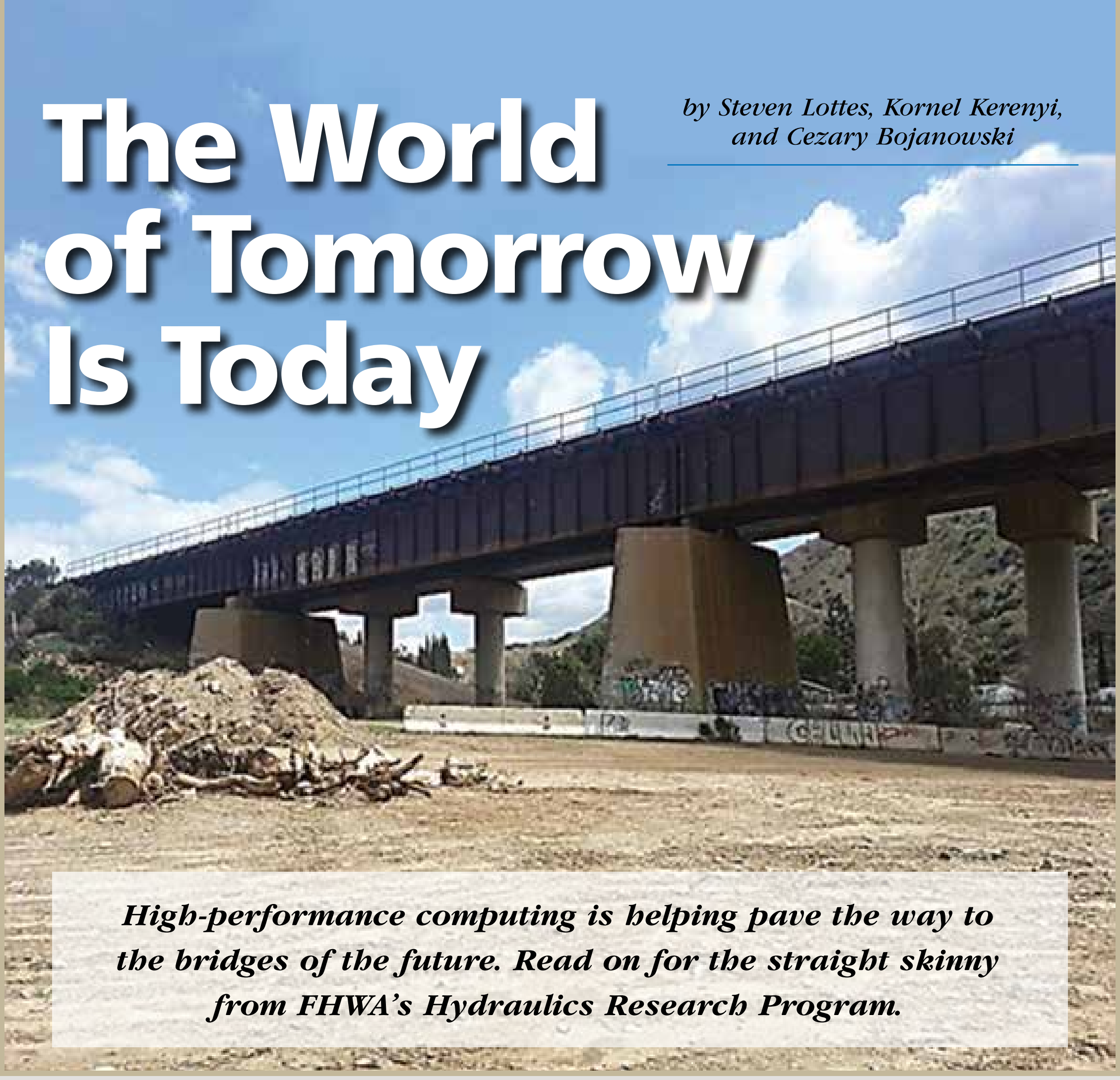
Carolyn Nelson is a project development/environmental specialist in FHWA's Office of Project Development and Environmental Review. She is responsible for providing technical and project assistance to FHWA division offices. She also assists with EJ, context sensitive solutions, and performance-based practical design guidance for FHWA. She is a licensed professional engineer and holds B.S. and M.S. degrees in civil engineering from Southern University and Agricultural and Mechanical College, and Michigan State University, respectively.

Candace Groudine is senior policy and regulatory specialist for the FHWA Office of Civil Rights, where she focuses on disability law, EJ, and limited English proficiency. She has a J.D. from Georgetown Law, a Ph.D. in educational administration and policy studies from the University at Albany, an M.A. in philosophy from Columbia University, and a B.A. in philosophy and psychology from Brooklyn College.

For more information, see www.fhwa.dot.gov/environment/environmental_justice or contact Brenda C. Kragh at 202-366-2064 or brenda.kragh@dot.gov, Carolyn Nelson at 502-223-6765 or carolyn.nelson@dot.gov, or Candace Groudine at 202-366-4634 or candace.groudine@dot.gov.

The World of Tomorrow Is Today

by Steven Lottes, Kornel Kerenyi, and Cezary Bojanowski



High-performance computing is helping pave the way to the bridges of the future. Read on for the straight skinny from FHWA's Hydraulics Research Program.

Many companies and organizations are now using advanced computer analysis to reduce the costs of developing products, improve their safety and reliability, and decrease the time needed to develop them. Computational fluid dynamics and computational structural mechanics now are routinely employed in the design of vehicles, ships, and aircraft. Computational analysis is applied to as many of the products' components as possible, including streamlining body shape to reduce drag and optimizing engine components to achieve fuel and cost savings.

Other industries and groups using computational advances include food and chemical processing, petroleum exploration and production, and medical research, including biomechanical engineering. In meteorology, high-performance computing is yielding much more accurate weather forecasts.

(Above) FHWA researchers used high-performance computational capabilities to do a virtual test of a scour countermeasure proposed for installation at this California railroad bridge, where countermeasures to control flood erosion are complicated by environmental restrictions. *Photo: U.S. Army Corps of Engineers, Los Angeles District.*

The successful application of modern computational mechanics in a wide variety of industries suggests that it can and should be applied to transportation research and development. To this end, the Federal Highway Administration's Hydraulics Research Program began expanding its computational capabilities as early as 2007.

Prior to these applications, researchers at FHWA's J. Sterling Jones Hydraulics Laboratory at the Turner-Fairbank Highway Research Center in McLean, VA, would conduct physical experiments using scaled models placed within a large hydraulic flume. Conducting these physical model experiments could be costly and lengthy. As a replacement approach, the researchers currently are using high-performance computing capabilities provided by Argonne National Laboratory's Transportation Research and Analysis Computing Center (Argonne TRACC). In addition to cost and time savings, another advantage of using advanced computing is the ability to conduct full-scale simulations of real-world hydraulic structures such as bridges and culverts, while avoiding difficult scaling issues that occur when using an experimental approach.

"Given ongoing funding challenges, spending available funds as effectively as possible is important," says Michael F. Trentacoste, FHWA associate administrator for research, development, and technology. "Not only can transportation researchers use computer analysis to conduct simulations of new structures, but also to evaluate old structures and scour countermeasures to see if they can withstand more frequent and larger weather events."

What Exactly Is Advanced Computing?

Currently, FHWA's hydraulics researchers are conducting detailed

Argonne TRACC

FHWA researchers are conducting advanced computing studies using these high-performance computer clusters at Argonne National Laboratory's Transportation Research and Analysis Computing Center.

and automated experimental work to calibrate computational fluid dynamics simulations, and they will be doing even more in the next 10 to 15 years. The computer simulations in a virtual world can be laboratory scale or full scale and include as much real-world detail as needed to compute storm surges, flood flows at bridges and culverts, and other events.

Most of the problems to which computational fluid mechanics is applied require far too much data for a typical or even a high-end office desktop computer. One example is assessing whether bridge foundations could be undermined and experience failure during a flood. This assessment requires computing the flow one-third of a mile (0.54 kilometer) upstream and downstream of a bridge to determine erosion forces.

For an accurate assessment of the risk of foundation failure, this kind of computation must solve equations governing the flow and related forces at millions or tens of millions of points distributed throughout the volume of a river. The huge amount of data on velocity and forces at millions of points is usually processed to produce detailed visualizations of what is happening in the flow. In addition, the data must be reduced by averaging or summing to obtain a much smaller number of numerical results, such as the flood forces on a bridge. This reduction is similar to high-resolution versus low-resolution photographs taken by a digital camera. High resolution gives a much better picture of what is happening.

Modern high-performance computer clusters are able to solve these kinds of large problems. The clusters consist of a large number of computers in racks, cabled together with both gigabit per second Internet plus an extremely high-speed InfiniBand interconnect. The high-speed interconnect is the key to enabling the machines to function together as one large computer.

In the case of a large flood flow problem, the analysis software breaks it into many smaller pieces and spreads them over a large number of processors. Each processor works on only a small part of the problem. The solutions to the pieces of the problem are highly dependent on what is happening at the interfaces with neighboring pieces, like a vortex moving with the flow from an upstream piece into a downstream piece. The needed information at the interfaces is communicated to processors working on neighboring pieces through the high-speed interconnect.

Using this methodology, high-performance computer clusters can solve problems in a couple of days—or even a few hours in some cases—that would take months on a desktop computer. And, frequently, these problems are too big to fit in the typical desktop computer's memory.

Several recent and current examples of this type of applied research illustrate some of the ways that FHWA and Argonne TRACC researchers are using high-performance computer clusters and computational mechanics to help solve transportation infrastructure problems, assess risks, and improve designs.

Assessing Scour Countermeasures at A California Bridge

The problem: How can you optimize a new design for a scour countermeasure when you have only enough time to set up and run a few physical model tests in the laboratory at one-thirtieth scale?

In the case of a California bridge, the answer turned out to be using high-performance computing to run more than 50 simulations of flood flows with varying full-scale design alternatives on a computer cluster. After FHWA and Argonne TRACC researchers selected the best candidate from this large number of simulations, researchers from the U.S. Army Corps of Engineers built a scale model and tested it in the Corps' laboratory to confirm that the optimized design provided the needed protection against scour.

The BNSF (formerly the Burlington Northern and Santa Fe) Railroad Bridge over the Santa Ana River, downstream of Prado Dam in Riverside County, CA, is classified as scour critical. This classification means that riverbed erosion around the foundation during major floods could compromise the bridge.

In addition, the presence of the threatened Santa Ana sucker fish in the river creates constraints on the type of countermeasures that could be used to protect the bridge. In fact, requirements for protecting the fish eliminate most of the common approaches, including riprap (stones or chunks of concrete piled together to prevent erosion), which would create a serious fish passage problem. To protect the bridge and satisfy the environmental constraints, the U.S. Army Corps of Engineers, Los Angeles District, developed a new countermeasure design.

The proposed design encases the four central sets of existing piers with driven sheet pile and the construction of triangular concrete pier extensions extending 50 to 200 feet (15 to 61 meters) upstream at each pier group. The pier extensions are tapered from a width of 26 feet (8 meters) at the piers to 2 feet (0.6 meter) at the noses of the pier extensions. The design goal was to shift the potential for scour upstream away from the bridge support piers and reduce local scour at the extension noses by using narrow sloping noses that direct the flow upward.

Researchers at Argonne's computing center performed a full-scale, three-dimensional computational fluid dynamics study of the pier extensions and design alternatives for the guide walls to find an optimal configuration for various flood flow conditions. The results of the study indicated that a pier extension length of 100 feet (30.5 meters) is sufficient to protect the piers. If the design length

U.S. Army Corps of Engineers, Los Angeles District

(Left) This artist rendering shows the pier extension concept for the California bridge after long-term erosion. The current riverbed and flood plain elevations will result in most of the left-most extensions being buried at completion of the project.

(Below) The U.S. Army Engineer Research and Development Center in Vicksburg, MS, installed these optimized triangular pier extensions at one-thirtieth scale for testing after a computational fluid dynamics analysis tweaked the design for the California bridge.

Argonne TRACC

had not been optimized using computational fluid dynamics, the final design would likely have included safe but much more costly 200-foot (61-meter) extensions.

The recommended orientation was about 11 degrees west of the centerline of the channel to better guide water coming from the west flood plain into the bridge approach flow during floods. Analysis showed that an initial design for the west guide wall, based on the guidelines provided in the *Hydraulic Engineering Circular* numbers 20 and 23, would not guide high water moving off the west flood plain smoothly back into the channel as it approached the bridge, and that would increase erosion risk at the piers.

Using computational fluid dynamics analysis, the Argonne researchers developed a longer and more curved guide wall conforming to the local topology for the west abutment. They determined that the longer wall would perform much better, so it became part of the final design. The U.S. Army Engineer Research and Development Center in Vicksburg, MS, tested the design with a one-thirtieth scale physical model. Construction of the project is scheduled to start in fall 2016. The project currently is in the design phase, which will be completed in summer 2016.

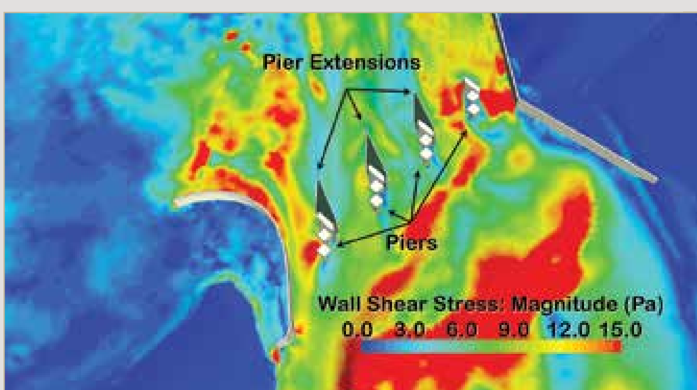
Complete details can be found in the Argonne report titled *Three Dimensional Analysis of Pier Extension and Guide Wall Design Alternatives to Mitigate Local Scour Risk at the BNSF Railroad Bridge Downstream of the Prado Dam* (ANL/ESD-15/7), available from the U.S. Department of Energy's Office of Scientific and Technical Information at www.osti.gov/scitech/biblio/1171963.

Sizing Riprap Installations

The technical procedures for sizing of riprap for scour countermeasures is based mostly on limited field observations and scaled laboratory tests under ideal controlled conditions. The actual size of riprap required for many field applications is too large for testing in the laboratory. As a consequence, significant uncertainty remains in the formulas for sizing riprap.

The problem: How do you determine riprap size for major projects or assess a riprap installation when many interrelated factors such as local riverbed bathymetry, pier orientation in the river, and the distribution of flood flow velocities are all important? Simulations on high-performance computer clusters can now account for all of the interrelated flow physics and geometry to determine how big the riprap needs to be and assess the capability of an arrangement to mitigate scour risk.

The FHWA and Argonne TRACC researchers developed an alternative computational technique that couples structural mechanics software with fluid dynamics software to anticipate incipient motion of large rocks in river environments. The



Shown is computational fluid dynamics modeling of the proposed pier extensions to reduce scour at the BNSF Railroad Bridge over the Santa Ana River. Red shows the high shear stress that will result in riverbed erosion. The area at the pier with extensions has lower shear stress, which will reduce erosion during a major flood. *Photo: Argonne TRACC.*

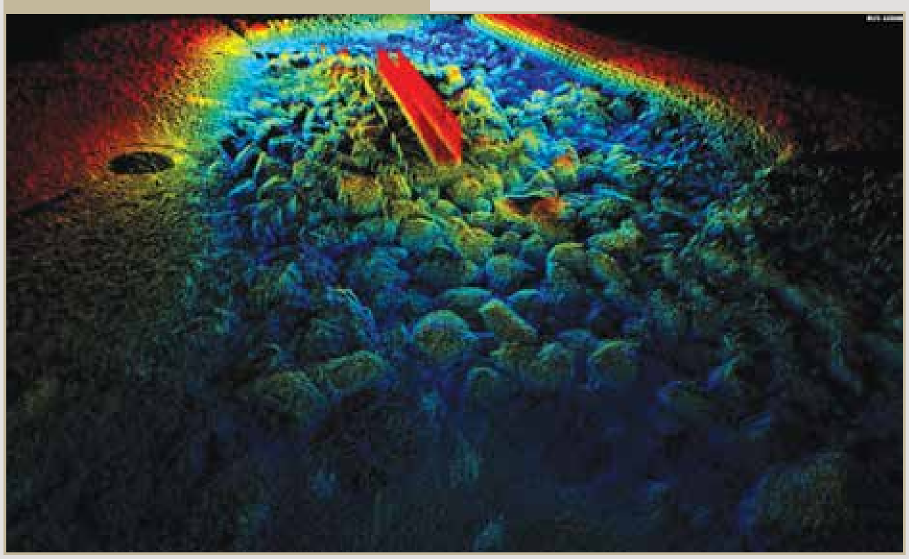
California Department of Transportation

A project using advanced computing is determining the size and placement of riprap needed to protect this pier at the Middle Fork Feather River Bridge in Plumas County, CA.

coupling method enables automated calculations of the large displacements of rocks that occur because of the constantly changing fluid forces. The software facilitates precise calculations of pressure distributions on the surface of the rocks in the riprap installations, while predicting the resulting motion of rocks because of those forces, as well as collisions between the individual rocks.

Argonne's high-performance computers are able to handle geometries of large stretches of rivers with highly detailed representations of bridge piers and dozens of movable rock riprap installations. The FHWA and Argonne TRACC researchers applied the results to verify the size and placement of riprap that had been installed to protect piers at the Middle Fork Feather River Bridge located on State Route 89 in Plumas County, CA, near the towns of Blairsden and Graeagle, close to the intersection with highway 70. The bridge was constructed in 1955 and is approximately 223 feet (68 meters) long and 32 feet (10 meters) wide. The researchers determined threshold water velocities for riprap motion to address possible extreme weather events. In future, the procedure is planned for use at other bridges.

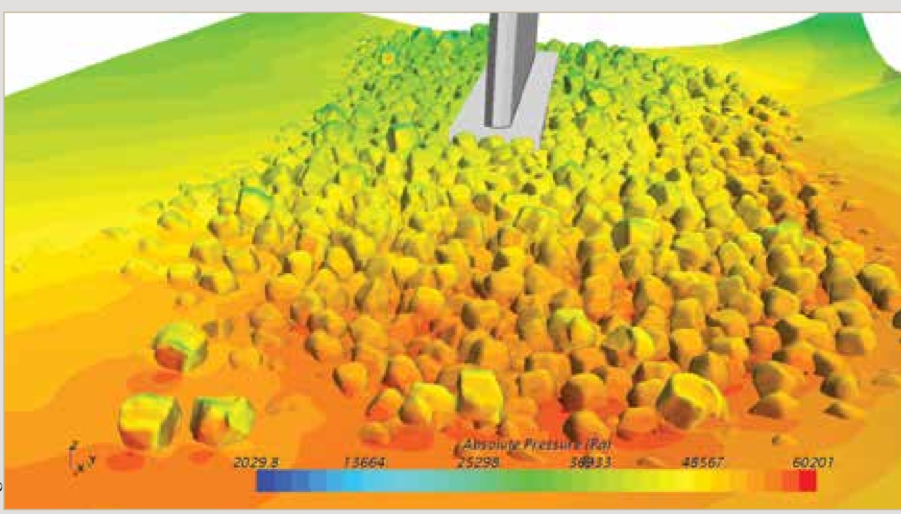
Shown here is a multibeam sonar scan of an existing installation of a riprap countermeasure at the Middle Fork Feather River Bridge in Plumas County, CA. The sonar scan was conducted to study the effectiveness of the riprap installation.



BlueView Teledyne Marine

Hydraulic Capacity of ADA-Compliant Grates

When making improvements to sidewalks and crosswalks in urban areas, the Minnesota Department of Transportation (MnDOT) needed to use new grate styles to comply with the Americans with Disabilities Act of 1990. ADA-safe grates are required wherever catch basins are located in a pedestrian access route. The ADA accessibility guidelines require that the openings in those grates prevent a 0.5-inch (1.3-centimeter) sphere from passing through. The grates are mainly used on retrofit projects where relocating the drainage structures is too costly.



Argonne TRACC

This computational fluid dynamics and structural mechanics modeling shows the existing installation of the riprap countermeasure at the Middle Fork Feather River Bridge.

The problem: The manufacturers of ADA-compliant grates, however, were unable to provide information on their hydraulic capacities. To quantify those capacities, researchers traditionally would run physical model testing, varying the flows and slope in a hydraulics laboratory. MnDOT opted for a less expensive and faster approach by modeling the grates at full scale using computational fluid dynamics on Argonne's high-performance computer clusters.

"MnDOT uses ADA-safe inlet grates for some inlets," says Lisa Sayler, P.E., assistant State hydraulics engineer with the MnDOT Bridge Office. "These grates have smaller openings, and presumably lower hydraulic capacity, than the current standard MnDOT grates, but the exact capacity is unknown for on-grade locations. The computational fluid dynamics analysis provided a quick and cost-effective way to analyze the grate capacity. The results produced by the analysis ensure that the retrofit project does not reduce the overall drainage capacity."

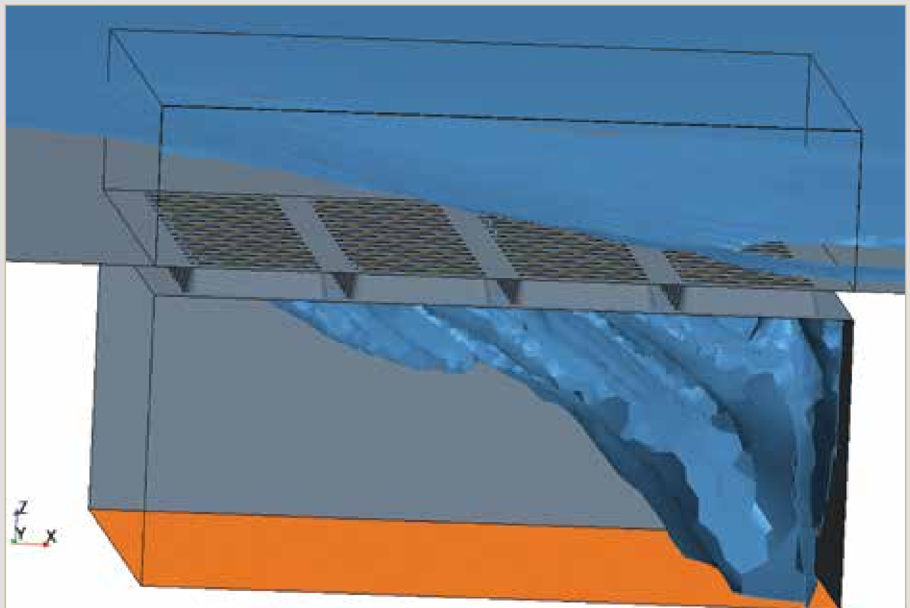
The researchers performed a computational fluid dynamics study of an ADA-compliant grate compared to a noncompliant vane grate. The study included 21 cases with varying street, cross street, and gutter slopes for each grate. The research team built the geometry for the simulations at full scale, an approach that could not be easily accomplished in a laboratory with a flume.

Hydraulic performance of the ADA-compliant grate was below that of the vane grate for all but the lowest volume flow rates of rainwater drainage, and the performance deficit rapidly grew larger as the flow rate increased. The narrow slots of an ADA-compliant grate, limited to a width of 0.5 inch (1.3 centimeters), create more resistance to flow through the grate than those of noncompliant grates with wider slots. Grate hydraulic performance correlated well with the upstream Reynolds number of the approach flow. To handle runoff, MnDOT is using a combination of traditional grates with larger slots and ADA-compliant grates.

Complete details are available in the Argonne report *Hydraulic Capacity of an ADA Compliant Street Drain Grate* (ANL/ESD-15/25), available from the U.S. Department of Energy's Office of Scientific and Technical Information at www.osti.gov/scitech/biblio/1221925.

The Minnesota Department of Transportation used computational fluid dynamics to analyze the hydraulic capacity of ADA-compliant grates such as this one.

Minnesota Department of Transportation



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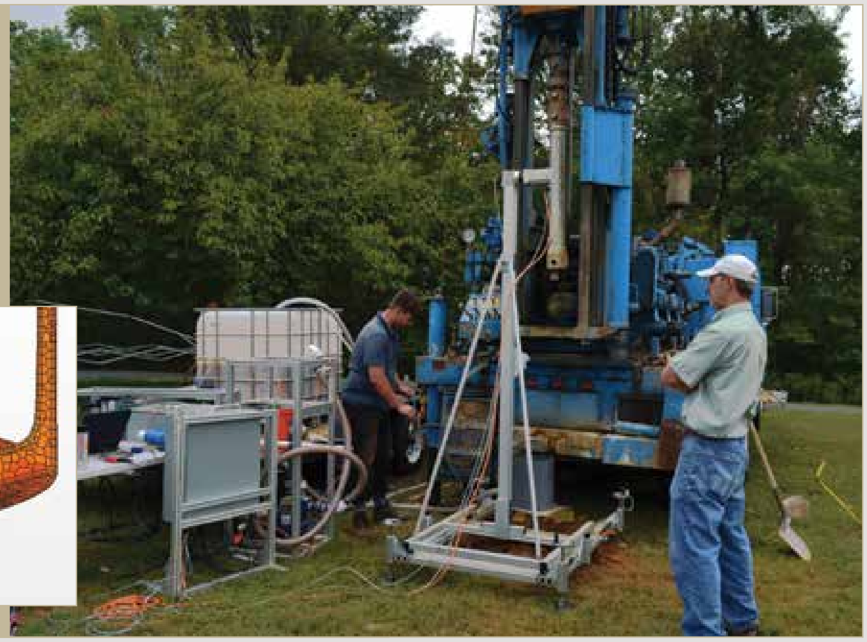
This computational fluid dynamics modeling of an ADA-compliant grate shows the water surface with the grate not capturing all of the water that flows directly over it.

Measuring Erosion In Stream Beds

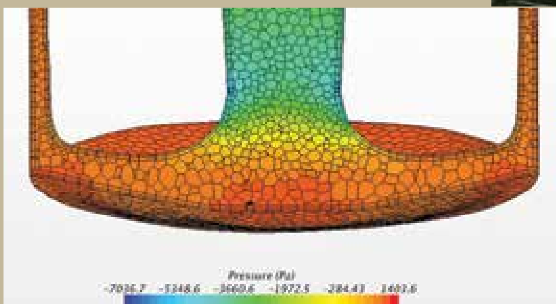
The problem: Historically, foundation scour has been a leading cause of bridge failures. FHWA and others have investigated scour and developed equations to predict the potential to scour. However, the existing equations, based on hydraulic modeling in sand, tend to overpredict scour. This conservative overprediction can result in overly deep and expensive foundations or reliance on unneeded countermeasures to prevent the scour, especially in cohesive soils.

A device incorporated into standard geotechnical drilling equipment to measure the erosion resistance of sediment material also is used to measure continuously the erosion resistance of fine-grained subsurface cohesive soils in situ. This measurement strategy is required because of the extreme difficulty associated with accurately characterizing the erosion resistance of such soils. This device is part of a new risk-based scour design methodology that FHWA's Hydraulics Research Program is currently developing. The research to develop this device and to make it market ready for the Every Day

(Right) **These FHWA researchers are conducting field tests of an in situ scour testing device.**



(Below) This computational fluid dynamics model shows the erosion head that is used for the in situ scour testing device, with the head contour optimized to maximize its efficiency by minimizing pressure drop in the head.



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Counts initiative was one of the agency's strategic objectives for 2014.

The FHWA hydraulics team designed and manufactured an erosion head for the in situ scour testing device to fit inside standard geotechnical sampling tubes. Sonar sensors monitor the erosion rate and maintain a required "working gap" at the soil-head interface. The researchers used computational fluid dynamics modeling to optimize and streamline the shape of the erosion head and to determine the system's capacity. The team also conducted several simulation runs using computational fluid dynamics to explore the flow limits of the erosion head and to fine-tune the flow requirements for in situ field tests.

Currently, the lab is conducting the first phase of the field tests. The second phase will start in the summer of 2016, and the researchers expect to complete the project with a market-ready device available in 2017.

Energy Dissipaters for Drainage on Steep Slopes

The problem: Energy dissipation for culverts discharging on slopes with a horizontal to vertical ratio of 2:1 (2H:1V) or greater is an ongoing issue. On steep slopes the discharge of collected water at a single pipe opening results in a high-speed stream that rapidly erodes the hillside.

The commonly used solution, riprap, works well for milder slopes but is unsuitable for steep ones. Not only is the riprap unstable by itself, but also it is difficult to install where access for heavy construction equipment is limited.

Culverts discharging on 2H:1V or steeper slopes are prone to failure because of the headcut at the outlets potentially migrating upstream. A headcut is the erosional process that occurs at abrupt vertical hydraulic drops. This erosional process takes place mostly because culverts channel the naturally occurring sheet flow—the film of rainwater that forms on roads and runs off to the roadside—and convert it into a point discharge, thus increasing velocities and shear stress. Protecting these outlets using traditional measures such as riprap is difficult because of the access issue.

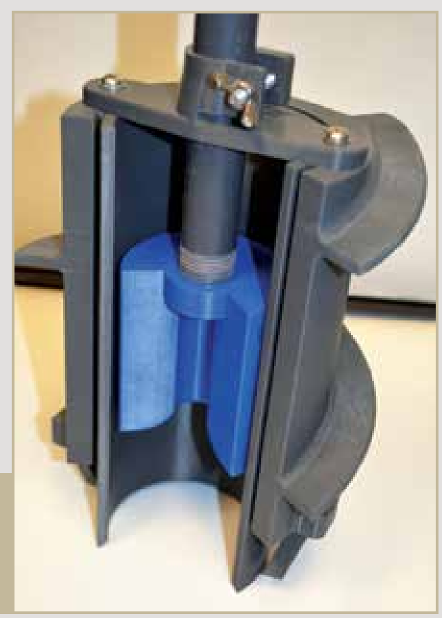
FHWA and Argonne TRACC researchers are studying methods to dissipate energy at culvert outlets discharging flow onto steep slopes. The researchers are using computational fluid dynamics modeling to study various conceptual solutions and their effectiveness in dissipating energy. These concepts include an upward-inclined ramp and a slotted discharge pipe to redistribute the flow over a much larger area.

The models have shown that these concepts will likely perform significantly better than current methods.

Currently, engineers with FHWA's Eastern Federal Lands Highway Division are identifying potential field sites for a test installation of the two alternatives. Once FHWA identifies an appropriate site, the researchers will add digitized bathymetries of the topography to the computer model and will then conduct full-scale simulations. The results of those simulations will guide the field installation.

Reaping the Benefits

These examples illustrate a few ways in which FHWA is using



Shown here is the 3–D printed erosion head that FHWA used for the in situ scour testing device.

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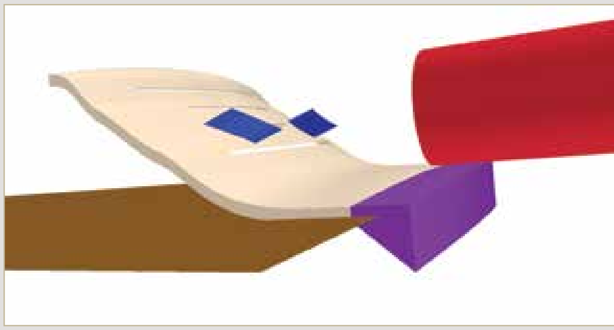

This computational fluid dynamics model shows an upward-inclined ramp concept with slots and guide vanes to spread the water flow exiting the red-colored culvert pipe onto a steep slope.

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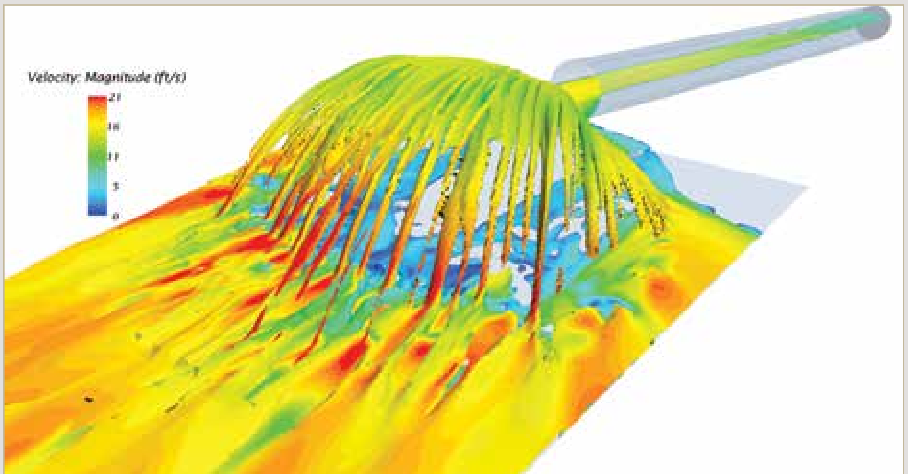


This computational fluid dynamics model of the water flow from a culvert discharging onto an upward-inclined ramp shows the water spreading to reduce erosion of the hillside.

advanced computational analysis to achieve applied research goals and optimize project designs. The software capabilities needed to do these analyses were unavailable a decade ago, and even the more limited computational mechanics and 3–D design software that was available at that time was very expensive. Generally, it was used only for high-profile projects such as those at the National Aeronautics and Space Administration or where huge economies of scale could justify the cost, such as in the automotive and aircraft industries.

Today, FHWA and Argonne TRACC researchers have applied advanced computational methods to optimize the design of a new scour countermeasure, determine riprap size and assess riprap configuration, determine the hydraulic capacity of an ADA-compliant street drain grate, streamline pier extensions, aid in the development of an in situ sediment erosion testing device, and investigate and optimize various concepts to dissipate the flow energy at drainage outlets on steep slopes.

Argonne TRACC

Another alternative is a horizontal slotted discharge pipe. A computational fluid dynamics model shows water spreading out over the slope to reduce erosion.

"We expect that projects and applied research studies in the FHWA hydraulics research program will employ 3–D computational fluid mechanics in the future," says FHWA Associate Administrator Trentacoste. "The hydraulics laboratory is integrating the use of advanced computational analysis on high-performance computer clusters into its operations and plans to use it on all projects that would benefit from it."

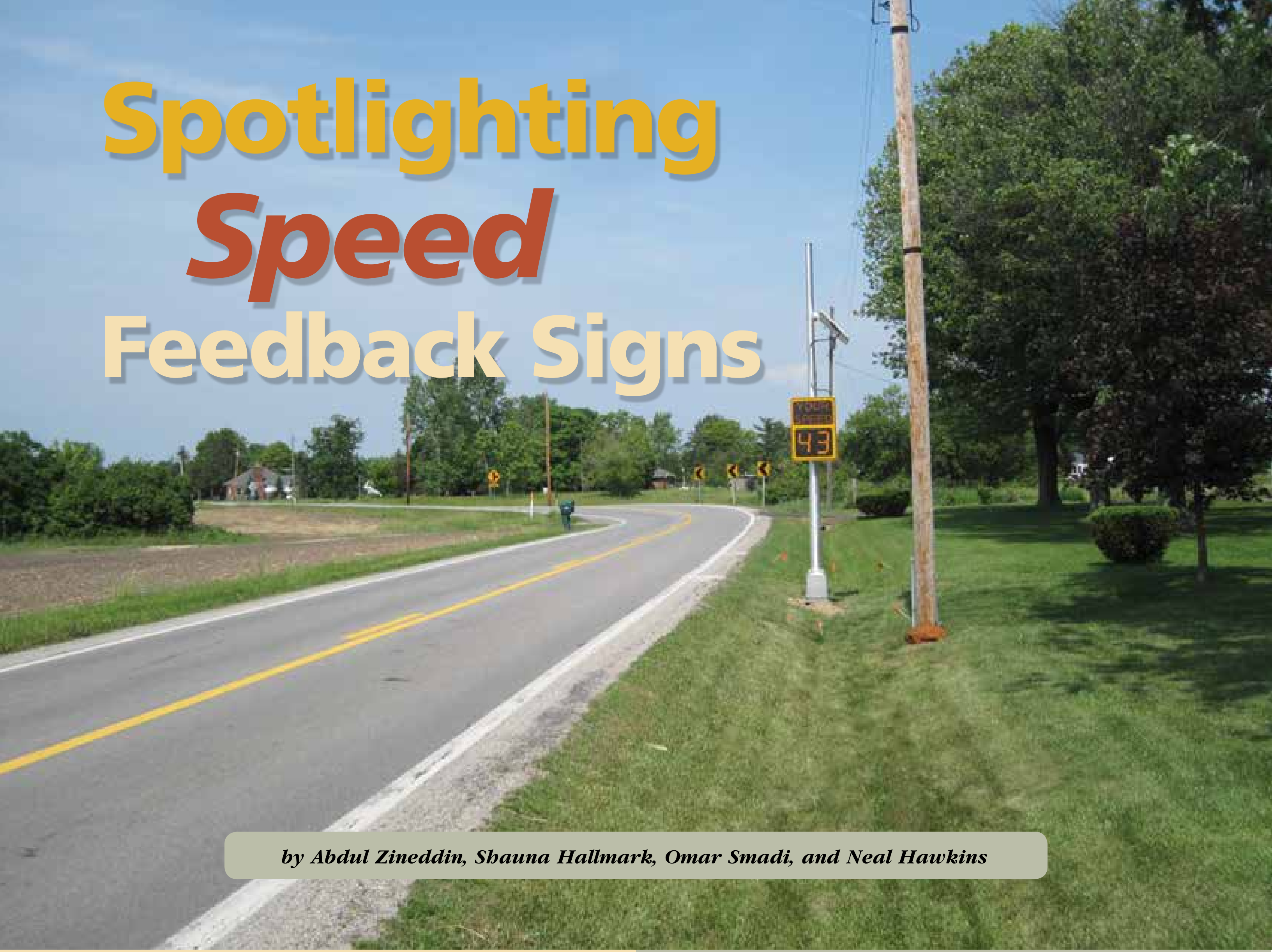
Steven Lottes, Ph.D., leads the computational mechanics group at Argonne TRACC. He has more than 25 years of experience in the modeling and analysis of complex multiphase flow systems. He plans, coordinates, and conducts computational research on transportation applications at Argonne's TRACC and provides technical support to the center's user community.

Kornel Kerenyi, Ph.D., is the manager of FHWA's Hydraulics Research Program in the Office of Infrastructure Research and Development. Kerenyi coordinates FHWA's hydraulic and hydrology research activities with the National Hydraulic Team, State and local agencies, academia, and various other partners and customers. He also manages the J. Sterling Jones Hydraulics Laboratory at the Turner-Fairbank Highway Research Center in McLean, VA.

Cezary Bojanowski, Ph.D., is an expert in computational mechanics at Argonne TRACC. His work includes computational fluid dynamics modeling of free surface flows applied to transportation infrastructure, fluid structure interaction in scour countermeasures, response of bridges to extreme loadings, and computational analysis of crashworthiness and vehicle occupant safety.

For more information, contact Kornel Kerenyi at 202–493–3142 or kornel.kerenyi@dot.gov, or Steven Lottes at 630–252–5290 or steven.lottes@anl.gov.

Spotlighting Speed Feedback Signs



by Abdul Zineddin, Shauna Hallmark, Omar Smadi, and Neal Hawkins

An FHWA study links dynamic messages to a reduction in roadway departures on two-lane rural curves that have high crash histories.

This speed display sign, one of the treatments used in the FHWA study, activates when drivers exceed the advisory or posted speed limit by 5 miles (8 kilometers) per hour. The speed sign displays the vehicle's actual speed, up to a specified threshold, so that drivers will not increase their speeds beyond what is safe on the approach to the curve. *Photo: Center for Transportation Research and Education, Iowa State University.*

Roadway departures are a significant safety concern on U.S. roads. According to the latest data from the National Highway Traffic Safety Administration's Fatality Analysis Reporting System, roadway departures continue to account for more than half of U.S. highway fatalities annually and nearly 40 percent of serious injuries.

Most departure crashes occur on rural two-lane roadways, with a disproportionate number taking place on horizontal curves. The average crash rate at horizontal curves is about three times that of other types of highway segments. These curves, which change the alignment or direction of the road, are associated with more than 25 percent of fatal crashes, and the majority of those fatalities are associated with roadway departures. In addition, about 75 percent of curve-related fatal crashes involve single vehicles leaving the roadway.

"The reduction of roadway departures must be a major emphasis if we want to significantly reduce fatalities and serious injuries in the United States," says Monique Evans, director of the Federal Highway Administration's Office of Safety Research and Development.

Not surprisingly, speed is a factor in whether drivers negotiate curves successfully. Dynamic speed feedback signs are one type of traffic control device that State departments of transportation use to reduce vehicle speeds, and therefore crashes, by giving drivers who are traveling over the posted or advisory speed a targeted message such as "YOUR SPEED XX" or "SLOW DOWN."

These sign systems include a speed-measuring device, which consists of loop detectors or radar, and a message sign that displays feedback to those drivers who exceed a predetermined speed threshold. The feedback can include displaying the driver's actual speed, showing a message such as SLOW DOWN, or activating some warning device, such as beacons or a curve warning sign.

To better understand the effectiveness of speed feedback signs in reducing speeds on curves, the Center for Transportation Research and Education at Iowa State University conducted a national field evaluation of the signs at horizontal curves on rural two-lane roadways. The study is described in a January 2015 report, *Evaluation of Dynamic Speed Feedback Signs on Curves: A National Demonstration Project* (FHWA-HRT-14-020).

Sponsors of the project included FHWA, the Midwest Transportation Center at Iowa State University, the Iowa Department of Transportation, the Iowa Highway Research Board, and the Texas Department of Transportation. In addition, the Texas A&M Transportation Institute and Portland State University were partners in the research. Here's how the researchers did the study and what they found.

Selection of Sites

Seven States participated in the field evaluation: Arizona, Florida, Iowa, Ohio, Oregon, Texas, and Washington. The researchers asked each State DOT or corresponding local agency to identify at least 20 high-crash curve sites on rural two-lane roadways. The research team defined "rural" as 1 mile (1.6 kilometers) or more outside an incorporated area.

The study started in 2007 and concluded in 2013. The team required that, during the 2-year evaluation period for each project site, the State DOTs or corresponding local agencies would schedule no rehabilitation or reconstruction activities that would change the geometry of the roadways under consideration. Nor were the DOTs to have conducted any geometric or cross-section changes for 3 years prior to the beginning of the study. In addition to these requirements, the posted speed limit on the preceding tangent section of road had to be 50 miles per hour (mi/h) (80 kilometers per hour, km/h) or greater.

The research team also asked each DOT to provide data on crash frequency, traffic volume (annual average daily traffic and percent of trucks), geometry (including lane and shoulder width), and the posted and advisory speed limits. The researchers ranked the sites in each State by the number of crashes. They also counted sites above a predetermined threshold as high-crash locations and included them on a list for site visits.

The team conducted a preliminary speed study using a radar gun at each site to determine whether a speeding problem existed, and those findings led to picking a final list of sites. Overall, the researchers selected 22 treatment sites and 46 control sites. They used the control sites only for crash analysis. For each treatment site, they randomly assigned one of the various types of speed feedback signs for the States to implement.

Selection of Signs

The selection of systems focused on what a sign can display. The most common sign simply shows a vehicle's speed when it exceeds a set threshold. This kind of sign also can activate a flashing beacon. Another type of sign can show a static message, such as SLOW DOWN or TOO FAST. More complex signs display unique messages, limited only by the number of alphanumeric characters the sign can show.

The research team developed the following set of minimum criteria to guide the final selection of the type of speed feedback sign:

- Can be mounted permanently on a standard wooden or metal pole.
- Can display a warning or a simple message (for example, TOO FAST or XX mi/h).
- Is durable enough to survive the 2-year study period and perform in various climates.
- Has self-contained power (for example, alternating current or solar).
- Costs less than $10,000 per sign (including installation, support, and maintenance).
- Meets all applicable *Manual on Uniform Traffic Control Devices* requirements or is capable of being approved under MUTCD.
- Provides repeatable and accurate speed measurements.
- Projects a clear, bright, nonglare message that motorists can read easily.

Center for Transportation Research and Education, Iowa State University

This curve warning sign (sometimes referred to as a curve display sign) activates when a driver exceeds the advisory or posted speed limit by 5 miles (8 kilometers) per hour.

Location of the Study's Treatment Sites

State	ID	Location	Posted Speed (mi/h)	Advisory Speed (mi/h)	ADT*	Crashes/ Year	Number of Control Sites
AZ	2	SR 95	45 NB** 55 SB	None NB 45 SB	5,088	2.4	3
	6	SR 377	65	None	1,715	1.4	
FL	6	3 SR 267	55	None	4,300	2.6	5
	8	3 SR 20	55	None	5,400	2.2	
	32	2 SR 20	55	45	8,100	1.0	
IA	10	US 30	55	None	8,400	5.2	20
	14	IA 136	50	45	1,450	1.2	
	31	US 67	55	None	3,610	1.2	
	33	US 69	55	50	1,880	1.0	
OH	6	Alkire Rd	55	30	2,403	1.7	4
	8	Norton Rd	55	35	6,391	1.7	
	14	Pontius Rd	55	30	2,225	4.3	
OR	4	US 101	55	45	2,600	2.8	5
	5	OR 42	55	35	3,000	2.4	
	9	OR 238	55	30	2,900	2.2	
	12	OR 126	55	40	4,700	1.6	
TX	4	FM 755	65 Truck 60 day Truck 55 night	50	970	2.0	6
	30	SH 359	70 Truck 70 day Truck 65 night	None	3,490	1.3	
	38	FM 481	65 Truck 60 day Truck 55 night	50	890	1.3	
	39	US 90	70	None	3,160	1.3	
WA	15	US 101	50	40	3,778	3.5***	3
	18	SR 7	50	40 NB/35 SB	1,976	3.3	
Average for Treatment Sites					**3,565**	**2.2**	
Average for Crash Control Sites					**3,362**	**1.8**	

Source: FHWA.
**ADT = Average daily traffic.*
***NB = Northbound, SB = Southbound.*
****Crashes were over several curves.*

For the first message type, the team selected the dynamic display of YOUR SPEED XX or SPEED LIMIT XX, with the message determined by the speed threshold.

For the second message type, the researchers chose a sign that displays an advance curve warning symbol. When activated, the sign displays a standard curve warning symbol as specified by the MUTCD and the words SLOW DOWN. The sign also has two lights on the top and bottom that blink in an alternating pattern while the curve warning symbol is displayed. Popular in Europe, this message type has had limited application in the United States.

A commonly accepted view is that speed displays should have an upper speed threshold above which they no longer display speed, so that drivers do not "test" the sign at unsafe speeds. The researchers settled upon 20 mi/h (32 km/h) over the posted speed limit as the upper threshold. For each site, they also selected a unique lower threshold—the lowest speed at which the speed display would be activated.

Based on the upper and lower speed thresholds, the sign face for the speed display showed the following for each situation (driver speed was measured at the point of curvature):

- Blank sign: When a curve advisory sign was present, no message was given for drivers who were traveling at or below the advisory speed limit plus 5 mi/h (8 km/h). When no advisory sign was present, the sign was blank for drivers traveling at or below the posted speed plus 5 mi/h (8 km/h).
- YOUR SPEED followed by the vehicle's speed XX in miles per hour: When drivers were traveling 5 mi/h (8 km/h) or more over the advisory speed if present or posted speed limit with no advisory speed, up to 20 mi/h (32 km/h) over the posted speed limit.
- SPEED LIMIT XX with the actual speed limit displayed: When drivers were traveling 20 mi/h (32 km/h) or more over the posted speed limit.

Based on the upper and lower speed thresholds, the sign face for the curve warning display showed the following for each situation:

- Blank sign: When a curve advisory sign was present, no message was given for drivers who were traveling at or below the advisory speed plus 5 mi/h (8 km/h). When no advisory sign was present, the sign was blank for drivers traveling at or below the posted speed plus 5 mi/h (8 km/h).
- Curve warning sign plus alternating lights and the words SLOW DOWN: When drivers were traveling 5 mi/h (8 km/h) or more over the advisory speed if present or posted speed limit with no advisory speed.

Methodology of the Study

The researchers conducted a full-scale, before-and-after speed study. They collected speed and volume data at the 22 test sites for 2 days about 1 month before the State DOTs installed the signs, and again about 1 month, 1 year, and 2 years after installation. Altogether, the research team collected data for 2 years to determine whether the effectiveness of the speed feedback signs decreases over time as drivers habituate to the signs.

The researchers used pneumatic road tubes and counters for data collection. The advantage of the road tubes is that they are fairly accurate, can collect individual vehicle speeds (enabling spot-checking of the data), are relatively low cost, and can be placed without cutting the pavement. The team also decided they are practical because other technologies, such as video, are more cumbersome, less accurate, or more expensive.

For each data collection period, the counters recorded time, vehicle speed, and vehicle class for individual vehicles. The team calculated other metrics, such as volume, headway, and average speed, from the data collected by the counters.

At each site, the team placed the speed-activated feedback sign near the point of curvature for one direction of travel. For each data collection period, the team collected data from the road tubes approximately 0.5 mile (0.8 kilometer) upstream of the point of curvature, at the point of curvature, and at the center of the curve.

Each collection period consisted of 48 hours and took place from Mondays through Fridays. The researchers chose the 48-hour period to ensure that a large sample size would result and that the data would not be biased toward a specific time of day.

Speed Analysis

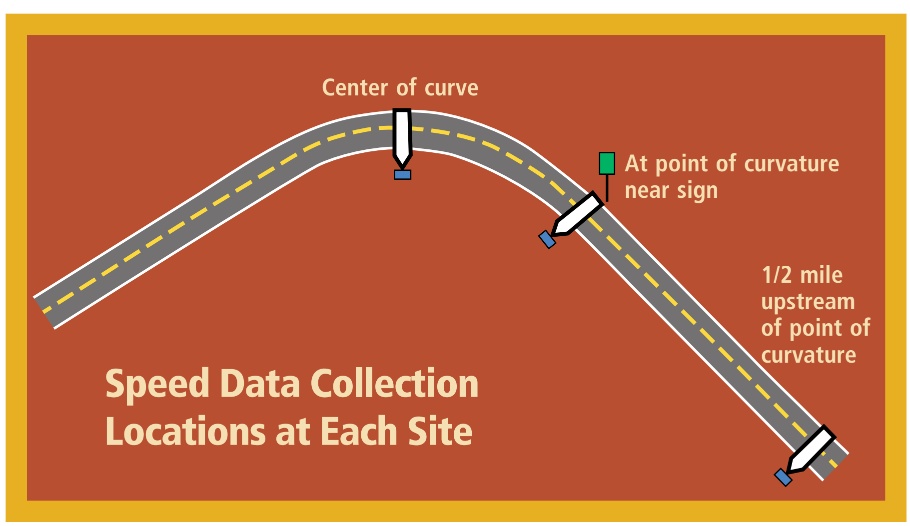
The team calculated several speed metrics for the direction of travel toward the sign. The metrics included average speed, standard deviation, 50th percentile speed, 85th percentile speed, and the number of vehicles traveling 5, 10, 15, or 20 mi/h (8, 16, 24, or 32 km/h) over the posted or advisory speed limit. The team expected the signs to affect driver behavior shortly upstream of the curve and throughout it. As a result, the researchers evaluated the effectiveness of the signs by the change in speed at the point of curvature and at the curve's center.

Point of Curvature. The team examined the change in speed metrics averaged over all treatment sites at the point of curvature. The speed data facilitated determining the difference between the before-period speeds (1 month before sign installation) and the after-period speeds (1, 12, and 24 months after sign installation).

Comparing the difference, the average mean speed for all sites was reduced 1.82 mi/h (2.93 km/h) after 1 month, 2.57 mi/h (4.14 km/h) after 12 months, and 1.97 mi/h (3.17 km/h) after 24 months. Changes in the 85th percentile speeds were similar, with reductions of 2.19, 2.86, and 2.17 mi/h (3.52, 4.60, and 3.49 km/h) after 1, 12, and 24 months, respectively.

Strong decreases also occurred in the average percent of change in the fraction of vehicles exceeding posted or advisory speeds. After 1 month, the number of vehicles traveling 5, 10, 15, and 20 mi/h (8, 16, 24, and 32 km/h) or more over the posted or advisory speed limits decreased 11.8, 29.9, 36.3, and 28.5 percent, respectively. Similar decreases were recorded after 12 and 24 months. The highest decrease (49.8 percent) came from vehicles going 20 mi/h (32 km/h) or more over the posted or advisory limit at the 12-month mark.

The team also tabulated and compared data by sign type. In general,



Average Change in Speeds at the Point of Curvature

		1 Month			12 Months			24 Months		
		All Sites	Curve Sign Sites	Speed Sign Sites	All Sites	Curve Sign Sites	Speed Sign Sites	All Sites	Curve Sign Sites	Speed Sign Sites
Average Mean Speed (mi/h)		-1.82	-1.68	-1.95	-2.57	-2.47	-2.66	-1.97	-1.99	-1.96
Average 85th Percentile Speed (mi/h)		-2.19	-1.90	-2.45	-2.86	-2.40	-2.70	-2.17	-2.00	-2.30
Average change in fraction of vehicles exceeding posted or advisory speed by	5 mi/h	-11.8%	-9.8%	-13.7%	-18.6%	-22.1%	-15.0%	-19.8%	-27.1%	-13.3%
	10 mi/h	-29.9%	-30.4%	-29.4%	-34.4%	-36.5%	-32.2%	-29.3%	-42.5%	-17.7%
	15 mi/h	-36.3%	-39.4%	-33.5%	-36.2%	-27.3%	-45.2%	-29.6%	-42.5%	-18.2%
	20 mi/h	-28.5%	-29.6%	-27.6%	-49.8%	-46.1%	-53.5%	-30.0%	-42.6%	-18.7%

Source: FHWA.

the researchers noted larger decreases for the speed signs than for the curve signs, although the differences were not statistically significant.

Center of Curve. Similar to the data from the point of curvature, the average change in mean speed for all sites at the center of the curve also decreased. Reductions of 2.08, 1.65, and 1.76 mi/h (3.35, 2.66, and 2.83 km/h) were recorded after 1, 12, and 24 months, respectively. For the 85th percentile speed at the center of the curve, the average decreases were 2.52, 1.55, and 1.89 mi/h (4.06, 2.49, and 3.04 km/h) after 1 month, 1 year, and 2 years, respectively.

The average percent change in the fraction of vehicles exceeding the posted or advisory speed tended to have greater decreases at the center of the curve when compared to the point of the curve. After the first month, the fraction of vehicles exceeding posted or advisory speeds at 5, 10, 15, and 20 mi/h (8, 16, 24, and 32 km/h) decreased 28, 42, 57, and 31 percent, respectively. After 12 months, the decreases ranged from 14 to 37 percent, and after 2 years ranged from 26 to 44 percent.

These data anecdotally suggest that the signs remained effective over time. However, the researchers used a statistical test to determine whether the differences were due to the treatment for the 1-, 12-, and 24-month-after periods. The analysis indicated no statistically significant differences among changes in mean speeds at the point of curvature and the center of the curve for any of the time periods. This finding suggests that the signs might have a long-term impact on reducing speeds.

Crash Analysis

The researchers modeled the crashes by quarter rather than by year. By using quarters, they could exclude from the analysis the quarter in which installation occurred without having to exclude the entire installation year. In addition, the signs stopped functioning at several sites for various periods, so the quarter in which the signs were nonfunctional also could be excluded from the analysis without discarding the entire year's data.

Total crashes in both directions decreased by 0.08 crashes per quarter for the control sites, while crashes per quarter at the treatment sites decreased by 0.22 (17-percent reduction compared to 40-percent reduction). Single vehicle crashes for both directions decreased by 0.07 crashes per quarter at the control sites and by 0.21 at the treatment sites (19-percent decrease compared to 47-percent decrease). Reductions at treatment sites were 2.75 and 3.0 times greater than at control sites. Fluctuations in speed at the control sites could be due to a number of factors that were not known and could not be controlled. For instance, short-term maintenance in the vicinity of one of the curves could have impacted speeds. Every attempt was made to collect data under similar circumstances, but it was impossible to be aware of every situation that might have impacted speed.

Total crashes in the direction of the outside of the curve increased by 0.02 crash per quarter for control sites and decreased by 0.12 crash per quarter in the direction of the sign for the treatment sites (9-percent increase compared to 35-percent decrease). Similarly, single vehicle crashes decreased by 0.01 crash per quarter at the control sites compared with a decrease of 0.14 at treatment sites (4-percent decrease compared to 49-percent decrease). Reductions at treatment sites were 6 to 14 times greater than at control sites.

The results show that a much greater decrease in crashes per quarter occurred for treatment sites compared to control sites. However, caution should be used in applying the results for the simple analysis because the data are not adjusted to account for the seasons, and more quarters of a particular season might have been present in the before period than the after period.

Before-and-After Analysis

The team also conducted a before-and-after analysis using a full Bayes model to develop crash modification factors. The model accounts for trends in the data that cannot be accounted for using other models. For instance, crashes might increase or decrease at a treatment site due to random fluctuations in the data not related to the treatment. Full Bayes is able to account for this phenomenon.

The researchers developed predictive models using data from control sites for all periods and before data for treatment sites. The models accounted for season, differences in the length of sites,

Average Change in Speeds at the Center of the Curve

		1 Month			12 Months			24 Months		
		All Sites	Curve Sign Sites	Speed Sign Sites	All Sites	Curve Sign Sites	Speed Sign Sites	All Sites	Curve Sign Sites	Speed Sign Sites
Avg. Mean Speed (mi/h)		-2.08	-2.01	-2.15	-1.65	-1.47	-1.84	-1.76	-1.46	-2.00
Avg. 85th Percentile Speed (mi/h)		-2.52	-2.50	-2.55	-1.55	-0.82	-2.27	-1.89	-1.25	-2.40
Average change in fraction of vehicles exceeding posted by	5 mi/h	28%	28%	27%	20%	21%	18%	26%	30%	23%
	10 mi/h	42%	43%	41%	33%	32%	33%	42%	43%	40%
	15 mi/h	57%	71%	44%	37%	42%	33%	44%	38%	50%
	20 mi/h	31%	55%	9%	14%	35%	7%	37%	25%	47%

Source: FHWA.

and multiple measures at the same site. The team then used the models to calculate the number of crashes for the after period for treatment sites that would have been expected had no treatment been applied. They also calculated crash modification factors by dividing the observed crashes by the predicted values.

The model indicated that expected total crashes for both directions would decrease by 5 percent (0.95 crash modification factor) with installation of the speed feedback signs. The team expected total crashes in the direction of the signs to decrease by 7 percent (0.93 crash modification factor). Both figures are statistically significant.

The model indicated that expected single vehicle crashes in both directions would decrease by 5 percent, and single vehicle crashes in the direction of the sign to decrease by 5 percent as well. Both changes are statistically significant.

Conclusions

The goal of this national demonstration project was to evaluate the effectiveness of two types of speed feedback signs in reducing speed and crashes on rural horizontal curves. If the signs were effective, that would provide traffic safety engineers with additional tools to improve roadway safety.

The results indicate that the systems are reasonably effective in reducing both vehicle speeds and crashes. And, it is noteworthy, the reductions were maintained for more than 2 years, indicating drivers did not habituate to the dynamic signs, although the study did not specifically look at this.

On average, most sites had decreases in mean speeds, with decreases up to 10.9 mi/h (17.5 km/h) noted for both the point of curvature and center of curve. Most sites experienced changes in the 85th percentile speed of 3 mi/h (4.8 km/h) or more at the point of curvature, with the majority of sites having a decrease of 2 mi/h (3.2 km/h) at the center of the curve.

Large reductions in the number of vehicles traveling over the posted or advisory speeds occurred for all of the after periods at the beginning and center of the curves, indicating that the signs were effective in reducing high-end speeds, as well as average and 85th percentile speeds.

"In the right place and for the right situation, dynamic speed feedback signs are a good option to consider to reduce vehicle speeds," says Sandra Larson, systems operations bureau director, highway division, Iowa DOT. "We have used these signs effectively for interstate and noninterstate work zones, rural expressway intersections where there is a speed limit reduction, school zones, and with pavement painting operations."

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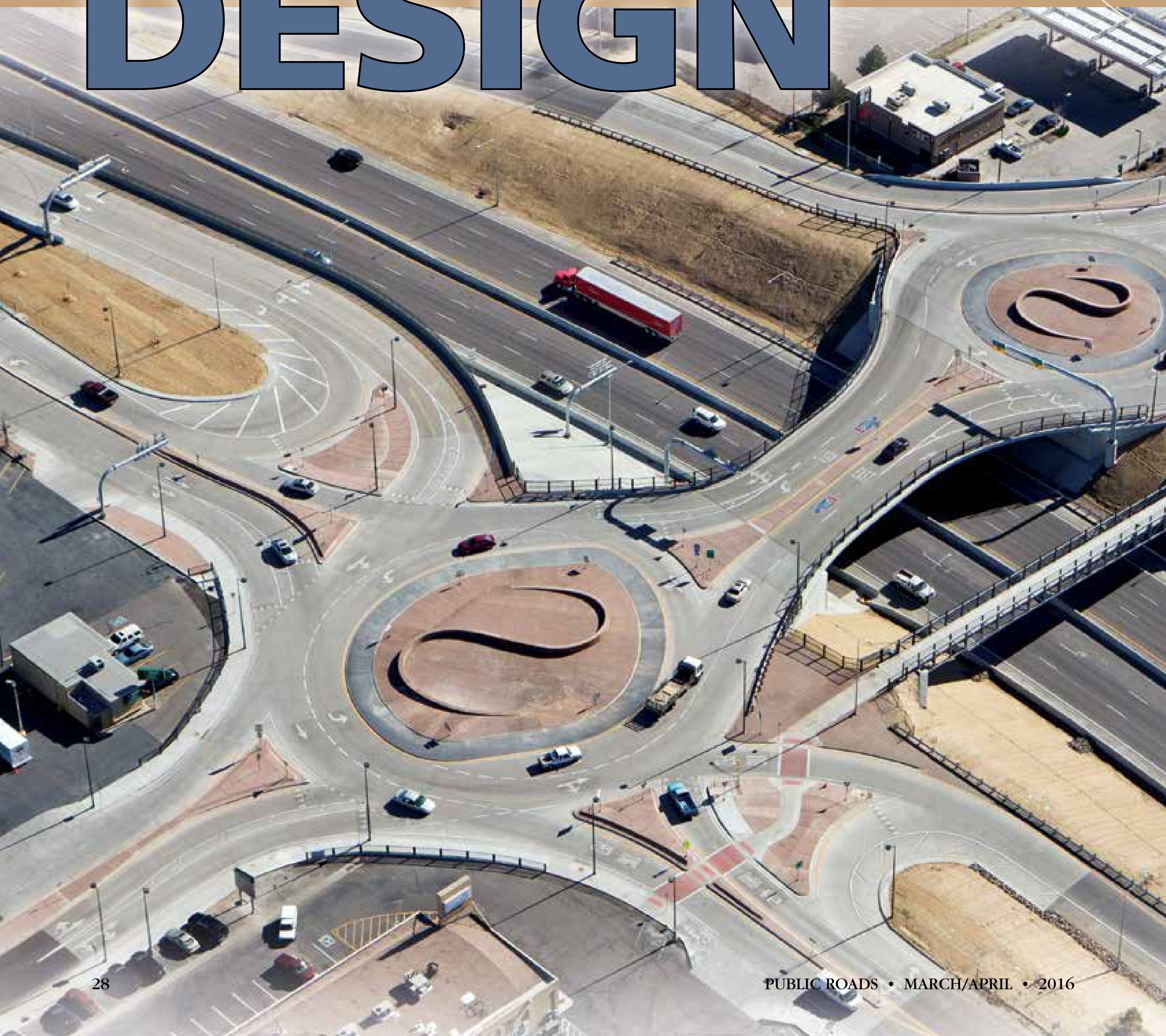
The Evolution of Geometric DESIGN



Enhanced guidelines, analysis tools, and decision-making approaches are driving the latest innovations available to transportation professionals.

by Brooke Struve, Mark Doctor, Deanna Maifield, and Clayton Chen

Geometric design plays a key role in meeting the needs of transportation users. Here, at the I–70 interchange at Pecos Road in Denver, CO, designers needed to weigh a number of competing factors, such as heavy truck movements, safe passage for students and other pedestrians, and preservation of a grocery store deemed vital to the community. *Photo: Kiewit Infrastructure Co.*

Today's transportation landscape is fraught with challenges spurred by limited budgets and competing demands. Revenue streams for infrastructure projects are less certain, while aging infrastructure requires repair or replacement as congestion grows in many urban areas. Design decisions have become increasingly complex, demanding analyses of many factors and potential outcomes.

Balancing competing demands is essential to providing a safe and reliable system for automobiles, freight carriers, pedestrians, bicyclists, and transit users while reducing environmental impacts and enhancing surrounding communities. To address these challenges and meet transportation goals for the future, State and local departments of transportation are embracing innovative approaches to guide decisionmaking and using emerging tools to achieve performance objectives.

By linking design and engineering decisions to explicit performance outcomes, agencies are striving to be more strategic in their allocation of resources. A quality design must satisfy the needs of users and balance cost, safety, and mobility with historical, cultural, and environmental impacts. Designers work with complex relationships between these competing interests, enabling flexibility and managing the related risks, such as designing intersections for freight mobility and pedestrian safety.

Recently, transportation agencies across the United States have been bridging knowledge gaps and enabling engineers to design with increased flexibility and to employ context-sensitive approaches with greater confidence and regularity.

What follows is a detailed look at the status of principles and practices affecting geometric design in the United States. The American Association of State Highway and Transportation Officials and the Federal Highway Administration presented these innovations in a detailed report at the Transportation Research Board's International Symposium on Highway Geometric Design in June 2015.

Practical and Performance-Based Practical Design

To address system performance, mobility, and safety needs, some State DOTs have moved toward a practical design process, while others are moving toward a performance-based practical design approach.

Practical design emphasizes a renewed focus on scoping projects to stay within the core purpose. The name, definition, and approach of practical design varies from State to State. However, the principle and goal are the same: exercising a greater level of discipline to eliminate nonessential design elements, resulting in lower project costs and improved value. This approach could enable transportation agencies to deliver a greater number of projects than was possible under their traditional project development mechanisms. Practical design enables agencies to look beyond individual projects and consider the overall system benefits during design decisionmaking.

Performance-based practical design helps agencies further refine their focus by incorporating performance goals into their decisionmaking. This helps ensure that agencies do not overemphasize short-term cost savings without a clear understanding of how such decisions could affect other objectives, such as safety and operational performance, pedestrian and bicycle connectivity, context sensitivity, life-cycle costs, long-range corridor goals, livability, and sustainability. For example, performance-based practical design can be as simple as modifying a traditional design approach to a "design up" approach, where transportation decisionmakers exercise engineering judgment to build up the improvements from existing conditions to meet both project and system objectives.

According to Robert Mooney, preconstruction team leader in FHWA's Office of Infrastructure, performance-based practical design provides a flexible means to meet improvement objectives. "As we focus on improving system performance," he says, "we are excited about using the flexibility and performance analysis associated with performance-based practical design to support transportation investments in project- and program-level decisions."

Context-Sensitive Solutions

Context-sensitive solutions (CSS) represent another aspect of geometric design that can influence transportation processes, outcomes, and decisionmaking. FHWA describes CSS as a collaborative, interdisciplinary approach to the transportation planning and development process that involves all stakeholders in designing a facility that complements its physical setting and preserves scenic, aesthetic, and historic and environmental resources while maintaining safety and mobility. CSS help meet community and national goals of environmental sustainability, improve cost-effectiveness, and streamline the delivery of transportation programs.

Transportation agencies have made progress on institutionalizing CSS in their business processes, but a recent informal survey by FHWA revealed that more work is necessary. Nearly one-quarter of the States rated themselves as either in the "Initiating Progress" or "Early Implementation" stages of institutionalizing CSS.

To help fuel faster implementation, in 2015 the Institute of Transportation Engineers published the informational report *Integration of Safety in the Project Development Process and Beyond: A Context-Sensitive Approach*. The report aims to expand understanding of CSS principles and practices within the transportation community and to help agencies incorporate highway safety elements from a quantitative, analytical, and technical perspective.

Safety Performance Analysis

Several innovative research efforts are deploying a new generation of tools for analyzing highway safety. Efforts include the *Highway Safety Manual* (HSM) and supporting tools such as the Interactive Highway Safety Design Model (IHSDM) and road safety audits (RSAs). These tools are helping to advance State and local highway agencies' ability to incorporate explicit, quantitative consideration of safety into their decisionmaking during planning and project development.

Safety has been consistently among the highest priorities for transportation agencies. But, until publication of the HSM in 2010, DOTs lacked a widely accepted tool to quantifiably predict the impact of infrastructure decisions on safety. The HSM includes predictive methods that transportation agencies can use to anticipate the safety performance of new facilities, to assess the safety performance of existing facilities, and to estimate the expected effectiveness of proposed improvements to existing facilities.

Two additional chapters of the HSM, released in 2014, add predictive methods for estimating the expected average crash frequencies on freeways and ramps. The predictive method for freeways includes evaluation of segments with and without speed change lanes. The predictive method for ramps includes evaluation of interchange components (ramps, collector-distributor roads, and ramp terminals).

AASHTO's Standing Committee on Highway Traffic Safety aims to institutionalize the HSM and its associated analytical tools to support national goals to reduce highway fatalities and serious injuries. Current implementation of the HSM varies by State. Some lead States are executing comprehensive implementation plans, while others are moving toward implementation at a more moderate pace.

"Implementation of the HSM by States is reaching beyond the Highway Safety Improvement Program [HSIP], and they are using it in various phases of the overall transportation management process, including network screening, alternative analysis, exceptions to design policy, operations, and overall evaluation of effectiveness," says Priscilla Tobias, State safety engineer for the Illinois Department of Transportation. "States can focus more on safety efforts and quantify the impacts of their safety decisions, which is critical as they work to leverage limited funding to have the greatest impact."

FHWA's IHSDM software offers a suite of analysis tools that engineers can use to evaluate the safety and operational effects of geometric design decisions on highways. IHSDM is a decision-support tool that provides estimates of a highway design's expected safety and operational

A multidisciplinary team performs a road safety audit in Klamath Falls, OR, to identify safety concerns and potential improvements.

performance, and checks existing or proposed highway designs against relevant design policy values. Results generated using IHSDM can support better decisionmaking.

Another important tool for safety analysis is conducting RSAs during the project design phase. An RSA is a formal examination of the safety performance of an existing or future facility by an independent, interdisciplinary audit team. RSAs are a popular tool for evaluating the safety performance of inservice roads, and DOTs are now adapting them for use in evaluating design choices and opportunities for enhancing safety on projects in the design stage.

A 2004 publication of the National Cooperative Highway Research Program, Synthesis 336 *Road Safety Audits: A Synthesis of Highway Practice*, examined the practices and benefits of RSAs worldwide. The use of RSAs across the country has increased with all 50 States plus the District of Columbia and Puerto Rico having piloted an RSA and 16 States having established RSA programs by 2014.

SHRP2 Safety Data

An important factor for transportation design is the availability of safety data. A project supported by FHWA and AASHTO enables State transportation agencies and their research partners to use data developed through the second Strategic Highway Research Program (SHRP2) to improve methods for reducing crashes and enhancing highway safety. The Implementation Assistance Program is making datasets available to State DOTs to identify crash causation factors and to develop effective countermeasures, such as improved road designs, that will address their common safety concerns.

The SHRP2 safety data include two large databases: a Naturalistic Driving Study database and a Roadway Information Database. The data from the Naturalistic Driving Study database provide a wealth of information regarding driving behavior, and the Roadway Information Database houses data on roadway elements and conditions. These two databases are linked in order to associate driver behavior with actual roadway geometry and driving conditions.

Integrating Human Factors in Design

Knowledge of human factors is a critical component in designing safe and efficient roads. Human factors pertain to the capabilities and limitations of human beings as vehicle drivers, bicyclists, and pedestrians. Knowing how certain user groups are likely to respond to given conditions can help designers reduce the risk of user error, or at least minimize the consequences when an error occurs.

The NCHRP Report 600 *Human Factors Guidelines for Road Systems, Second Edition*, released in 2012, focuses on providing specific, actionable design guidance, supported by a discussion and review of key research and analyses. The guidelines help designers more effectively accommodate roadway users' capabilities and limitations in the design and operation of highway facilities.

In addition, demographic trends in the United States indicate that by 2030, one-fifth of road users will be age 65 or older. This means that a steadily increasing proportion of road users will experience declining vision; slowed decisionmaking and reaction times; exaggerated difficulty when dividing attention between traffic demands and other important sources of information; and reductions in strength, flexibility, and general fitness. In a proactive response to the pending increase in aging road users, FHWA released the updated *Handbook for Designing Roadways for the Aging Population* (FHWA-SA-14-015) in 2014. The handbook provides practitioners with a practical source that links the performance of aging road users to highway design, operations, and traffic engineering features.

FHWA also sponsored research that investigated driver expectations and signage at complex interchanges. The results of *Driver Expectations When Navigating Complex Interchanges* (FHWA-HRT-13-048) and *Simulator Study of Signs for a Complex Interchange and Complex Interchange Spreadsheet Tool* (FHWA-HRT-13-047) indicate that complex interchanges pose significant challenges to most drivers, and that many of these problems arise from basic human factors issues related to various aspects of interchanges. For example, when a guide sign displays information that is unclear or is located too close to a decision point, drivers may miss their desired path or make risky maneuvers. FHWA is continuing research efforts on complex interchanges with the goal of developing useful design guidance related to perceptual elements of guide signs.

"Integrating human factors methods and techniques into research and design efforts allows researchers and roadway designers to better match driver expectations and behavior with signing and roadway geometry characteristics," says Brian Philips, senior research psychologist with FHWA's Human Factors Team in the Office of Safety Research and Development. "This facilitates better decisionmaking [for] all roadway users, promotes safer driving, and decreases the risk of crashes."

Two pedestrians, one using a walker, descend a ramp from the sidewalk to the crosswalk in Saugutuck, MI. Accessibility is a major factor in decisions about geometric design. *Photo: Dan Burden, www.pedbikeimages.org.*

Accessible Transportation

Another special consideration for geometric design is making transportation accessible and safe for all users. The Americans with Disabilities Act influences design decisions with its requirements to assure equal access to government programs (such as transportation) and to public places for people with physical or mental disabilities.

The current design standards for accessibility are the *Americans with Disabilities Act Accessibility Guidelines*; however, these standards are more applicable to building and site construction than to public right-of-way. Therefore, transportation agencies have been left to translate these standards, where applicable, to highways and streets and make judgments on issues not fully addressed by the standards.

The U.S. Architectural and Transportation Barriers Compliance Board (also known as the Access Board) is finalizing its *Guidelines for Pedestrian Facilities in the Public Right-of-Way* with its release anticipated this year. With these guidelines, considering accessibility early in the development of design alternatives will be more imperative than ever. For example, explicit guidelines for the cross-slope and grade of crosswalks will influence intersection grading and storm drainage.

When designers leave consideration of accessible pedestrian facilities until later in the design process, they may severely limit their opportunities—and inflate their costs—to develop a design that provides optimum functionality for all users.

Designing for Pedestrians And Bicyclists

Integrating features that respond to the needs of all pedestrians and bicyclists into street and highway infrastructure is another competing demand for transportation designers. Today's transportation systems are placing increased emphasis on pedestrian and bicycle networks that are safe, comfortable, and convenient for people of all ages and abilities.

In 2015, Secretary of Transportation Anthony Foxx challenged mayors and other elected city officials across the country to "take significant action to improve safety for bicycle riders and pedestrians of all ages and abilities." Key elements of this challenge include using designs that are appropriate to the context of the street and its uses, and taking advantage of opportunities to create and complete pedestrian and bicycle networks.

One of the challenge's recommendations is to gather and track data on walking and bicycling. Communities that routinely collect such data are better positioned to track trends and prioritize investments.

FHWA also released updates to the Pedestrian Safety Guide and Countermeasure Selection System (PEDSAFE) in 2013 and the Bicycle Safety Guide and Countermeasure Selection System (BIKESAFE) in 2014. The guides assist transportation planners and engineers in selecting countermeasures to improve safety for these roadway users. For more information, visit www.pedbikesafe.org.

These two-way bike lanes on 15th Street in Washington, DC, are separated from the adjacent traffic lanes by a striped buffer with flexible posts. Separated bike lanes, or cycle tracks, are one of the designs featured in the *Urban Bikeway Design Guide*.

Another available resource is the 4th edition of AASHTO's *Guide for the Development of Bicycle Facilities*. This guide includes information on the dimensions and operational characteristics of a range of facility designs for bicycles, recommendations for selecting the type of bikeway based on the characteristics of the roadway, and design details for a variety of roadway configurations that accommodate bicycle travel. The guide is a comprehensive treatment of the planning, design, safety, and operational considerations for bicycle facilities. To address some innovative techniques for onstreet bikeways not included in this guide, such as two-stage left turn boxes and bicycle signals, the National Association of City Transportation Officials released the *Urban Bikeway Design Guide* at http://nacto.org/publication/urban-bikeway-design-guide.

Several municipalities already are using separated bike lanes—sometimes referred to as cycle tracks—which created a need for guidance on designing these types of facilities. In response, FHWA released the *Separated Bike Lane Planning and Design Guide* (FHWA-HEP-15-025) in 2015. These guidelines address the benefits and challenges with the various design treatments and provide designers with background information on what is currently known about the safety of these designs. For more on separted bike lanes, see "Let's Ride!" in the May/June 2015 issue of PUBLIC ROADS.

Considerations for Managed Lanes

Facilities with high-occupancy toll (HOT) and high-occupancy vehicle (HOV) lanes have a number of features that require special attention with respect to geometric design. HOT/HOV lanes are examples of "managed lanes," which involve a range of strategies and techniques to control the usage of freeway lanes to improve the efficiency of traffic flow. These strategies and techniques may be permanent or vary as conditions change. Transportation agencies use managed lanes to reduce congestion and travel time and improve trip reliability, while avoiding the costs and impacts associated with constructing additional lanes.

The HOT/HOV lanes are usually the left-most lanes on the freeway and typically operate at higher travel speeds than the adjacent general purpose lanes. The differential in speeds between adjacent lanes and the HOT/HOV lanes presents a potential crash risk. Roadway designers manage this risk by providing a buffer between the lanes and controlling ingress and egress from the HOT/HOV lanes. In zones where vehicles can change lanes between the general purpose lanes and the HOT/HOV lanes, the design needs to consider the location of the interchanges and required lane changes for entering or exiting the freeway. In many locations, designs incorporate direct access ramps between cross streets and the HOT/HOV lanes. At freeway-to-freeway interchanges, additional ramps enable motorists in the HOT/HOV facility to move directly to the HOT/HOV lanes of the other facility without traversing the general purpose lanes.

Where congestion is high and space to add new lanes is limited, shoulder running is another managed-lane strategy that is becoming more prevalent. With shoulder running, DOTs use the existing shoulder as another travel lane, either for set periods when congestion is usually high, or they can designate use of the shoulder dynamically in response to conditions. Because shoulders serve many purposes—clear roadside, breakdown lane, enforcement activities, maintenance activities, and drainage—the need for additional lane capacity must be balanced with these other needs. Shoulder running strategies necessitate careful consideration of lane configurations at interchanges, reduced clear zone on the roadside, speed, emergency pulloffs, and enforcement.

For more information, visit www.ops.fhwa.dot.gov/atdm/approaches/atm.htm.

Emerging Technical Areas

FHWA is encouraging greater flexibility in geometric design through its Every Day Counts (EDC) initiative. EDC aims to accelerate the deployment of innovative practices and technologies to deliver safer, more efficient projects with shorter delivery times. Several EDC initiatives relate to improving safety through better design: alternative intersections and interchanges, road diets, high-friction surface treatments, the Safety Edge℠, and three-dimensional (3–D) modeling. Each is briefly described below, and more information is available at www.fhwa.dot.gov/innovation/everydaycounts.

"Innovations are being tried and proven locally throughout the Nation," says Thomas Harman, director of FHWA's Center for Accelerating Innovation. "Every Day Counts takes those market-ready breakthroughs and fosters widespread adoption, so the transportation community and the traveling public benefit sooner."

This high-occupancy toll lane, indicated with a red arrow, on northbound I–85 in Gwinnett County, GA, is delineated with a striped buffer and reflective markers. HOT and HOV lanes represent a type of design flexibility that agencies can use to maximize use of existing highway capacity.

Innovative Intersection and Interchange Geometrics

At many highway junctions, traffic and safety problems are more complicated than ever because of increased congestion. Conventional intersection designs might be insufficient to mitigate some transportation challenges. Increasingly, designers are investigating and implementing innovative intersection treatments.

EDC is advancing select alternative intersection and interchange designs with substantial and proven benefits compared to conventional designs. Among those designs are displaced left-turn intersections, variations on U-turn intersections, diverging diamond interchanges, and modern roundabouts.

Traffic navigates this diverging diamond interchange, an innovative intersection design, at I–270 and Dorsett Road in St. Louis, MO. The clearly defined sidewalks and crosswalks guide pedestrians across the islands and ramps at the interchange.

The original configuration of Soapstone Drive in Reston, VA, shown here (top), was four lanes, with two lanes in each direction. The road had no shoulders. After the Virginia Department of Transportation completed a road diet (bottom), the new configuration features one lane in each direction, a two-way center left-turn lane, and bike lanes. *Photos: Randy Dittberner, Virginia Department of Transportation.*

In the *Alternative Intersections/Interchanges: Informational Report* (FHWA-HRT-09-060), published in 2009, FHWA presents information on these intersection and interchange designs. Since then, much additional experience and information has become available. Through EDC, FHWA is updating information on the geometric design features, operational and safety issues, access management issues, costs and construction sequencing, and applicability of several innovative intersection and interchange designs. Four new informational guides provide details on the restricted crossing U-turn, median U-turn, displaced left-turn intersections, and diverging diamond interchanges. The guides are available at http://safety.fhwa.dot.gov/intersection under Innovative Intersections.

Road Diets

Roadway reconfigurations, also known as road diets, are another safety innovation promoted through EDC. A typical road diet converts an existing four-lane, undivided roadway to three lanes: two through lanes and a center, two-way left-turn lane. However, a road diet may be applied to streets with more than four lanes, and may simply narrow lanes rather than reduce their number. Although they may take many forms, the key feature of a road diet is that it reallocates space for other uses, such as turn lanes, bus lanes, pedestrian refuge islands, bike lanes, sidewalks, bus shelters, parking, or landscaping.

Road diets offer several benefits including reduced crashes, traffic calming, enhanced access for all road users, and a complete streets environment to accommodate a variety of transportation modes. Transportation agencies often can implement a road diet at relatively low cost by incorporating it into a planned resurfacing project with adjusted signing and marking.

FHWA recently produced a *Road Diet Informational Guide* (FHWA-SA-14-028) to help communities understand the safety and operational benefits and determine if road diets could be helpful on their roads. A complementary publication, *Road Diet Case Studies* (FHWA-SA-15-052), lists real-world examples of road diets already implemented across the country.

High-Friction Surface Treatments

High-friction surface treatments (HFST) are site-specific applications of very high-quality, durable aggregates using a polymer binder that restores and maintains pavement friction. Maintaining the appropriate amount of pavement friction is critical for safe driving, especially at horizontal curves and intersections. Vehicles traversing horizontal curves require a greater side force friction, and vehicles at intersections require greater longitudinal force friction.

Horizontal curves make up only 5 percent of U.S. highway miles, but more than 25 percent of highway fatalities occur at or near horizontal curves each year. Although some of the factors contributing to these crashes include excessive vehicle speed or distracted driving and driver error, at some locations, the deterioration of pavement surface friction may also be a contributing factor. Variable friction creates the need for pavement surface improvements, particularly for friction, at certain locations to increase safety. Although the largest numbers of problem locations are likely on local and collector systems, these treatments could prove beneficial at high-volume intersections, interchange ramps, and selected segments of interstate alignments.

Safety Edge

Roadway departures account for more than half of all fatal crashes in the United States. The dropoff of the pavement edge on roadways is a contributing cause of many of these crashes. The Safety Edge, another EDC innovation, is a low-cost technology that enables drivers who drift off highways to return to the pavement safely. Simply shaping the edge of the pavement to 30 degrees mitigates the safety problem of vertical dropoffs. The angled Safety Edge provides a durable transition on which vehicles can return to the paved road smoothly and easily, even at relatively high speeds.

3–D Engineered Models

Three-dimensional (3–D) engineered models are used widely by the highway community to more effectively connect a project's design and construction phases. These models and the as-found, digital geospatial data that support them also can be applied to other phases in the project delivery cycle to positively affect safety, project scheduling, project costs, contracting, maintenance, and asset management. Today, construction firms of all sizes are investing in automated machine guidance for their equipment. The equipment has advanced to a point that even precision work, such as paving, is possible without traditional survey and staking.

To take full advantage of their investment, the contracting industry is working with State DOTs to expedite the transition to electronic files. Many States are now using design software to export 3–D terrain files, which they can transfer directly to contractors' equipment. The direct transfer reduces the chance of survey errors and typos that can occur when contractors have to copy the data out of paper plans. As the contract documents move away from traditional paper formats and toward electronic transfer of data, States are placing an increased emphasis on accuracy of the models, consistency of data formats, the integrity of data during usage, file security, digital signatures, and related issues.

The 3–D models that States are using also can provide valuable insights that can help designers evaluate complex features such as intersection alignment, sight distance from a driver's view, and conflicts or "clashes" that may occur during construction. This type of modeling enables designers to view future projects in a simulated environment, with much less work than was previously required. They also can evaluate nontraditional designs in much greater detail. With the success of 3–D design, some States are moving to 4–D and 5–D design, which incorporate schedule (4–D) and cost (5–D), to take even greater advantage of the model as a project management tool.

In addition to 3–D modeling, agencies are using data collection tools that can create virtual models of existing features with greater accuracy and precision. For example, light detection and ranging (LiDAR) uses laser pulses to measure distance, providing significantly more data points with less disruption to traffic. As LiDAR usage increases and the quality of mobile data collection improves, designers have the opportunity to develop high-resolution models with even more information in greater detail and accuracy than was possible with

Iowa Department of Transportation

Here, a paving crew is using equipment with automated machine guidance to place concrete. Automation avoids the need to use string lines for siting placement of the concrete.

Road designers now use computer-generated visualizations to help make design decisions. This visualization of an intersection from the perspective of someone driving on the roadway includes lifelike images of cars, signs, curbs, striping, lighting, landscaping, and the skyline.

Iowa Department of Transportation

traditional survey and photogrammetric practices. Using these models with historical design details and crash data, designers can identify locations that present an increased crash risk and make cost-effective asset management decisions.

What's Next: V2I and V2V Technologies

As communication and mapping technologies become more sophisticated, the U.S. Department of Transportation, automobile manufacturers, and others are investigating opportunities and developing plans to use these technologies to improve highway safety and mobility.

For example, vehicle-to-infrastructure (V2I) and vehicle-to-vehicle (V2V) communications enable drivers to receive enhanced information based on their speed and location with respect to roadway features and other travelers, including pedestrians and bicyclists. Analyses of V2I applications reveal an opportunity to eliminate 59 percent of single-vehicle crashes and 29 percent of multivehicle crashes. This significant reduction could be possible without making physical changes to roadway geometry.

The potential for development of more V2I and V2V applications and the implementation of automated driving tasks raise questions about the traditional way of thinking about geometric design. The implications of these technologies will play a significant role in the evolution of decisions regarding geometric design.

Looking to the Future

Although safety continues to be among the highest priorities in highway design decisions, increasingly State DOTs are being called upon to achieve safety goals in balance with other priorities. Many States and localities are embracing the national strategy Toward Zero Deaths to emphasize the need to continue making improvements to prevent traffic fatalities. Meanwhile, the U.S. Congress has enacted legislation requiring the evolution toward performance-based administration of the transportation system, with agencies setting specific targets to realize improvements in planning, safety, highway conditions, and transit.

Geometric design is the means by which agencies achieve many transportation goals and uphold values in communities. Agencies across the Nation are employing new approaches to design decisionmaking to assure the best use of their resources in achieving their transportation performance goals. The newer and evolving tools and knowledge are changing how designers perceive their roles.

"With improved knowledge about the needs of all road users and emerging means of predicting and modeling the effects of our decisions, designers can more fully understand the performance implications of complex design decisions," says Mike Griffith, director of FHWA's Office of Safety Technologies. "These exciting changes provide greater opportunities to incorporate innovation into design decisionmaking and assure that these choices truly contribute to a successful transportation system for the future."

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For more information, see the full report at www.fhwa.dot.gov/design/standards/county.pdf.

Along the Road

Along the Road is the place to look for information about current and upcoming activities, developments, trends, and items of general interest to the highway community. This information comes from U.S. Department of Transportation sources unless otherwise indicated. Your suggestions and input are welcome. Let's meet along the road.

Management and Administration

White House and USDOT Recognize Champions of Change

In October, Secretary of Transportation Anthony Foxx and the White House honored 11 individuals as White House Transportation Champions of Change for 2015 for their exemplary leadership and innovation in transportation. The event brought together individuals from across the country, various modes of transportation, and unique backgrounds. The work of these individuals represents the types of innovative solutions required to usher in a 21st-century transportation system that is safe, accessible, and equitable.

To underscore the progress transportation innovators are making to address the country's future transportation needs, this year's theme was "Beyond Traffic: Innovators in Transportation for the Future."

Several USDOT senior officials recognized the champions for their achievements and contributions that have set standards for the future. In addition to Secretary Foxx, Deputy Secretary Victor Mendez, Under Secretary for Transportation Policy Peter Rogoff, Federal Highway Administrator Gregory Nadeau, National Highway Traffic Safety Administrator Mark Rosekind, Pipeline and Hazardous Materials Safety Administrator Marie Therese Dominguez, Federal Motor Carrier Safety Acting Administrator Scott Darling, and Senior Counselor to the Secretary Stephanie Jones participated in the event.

For more information, including the list of champions, visit www.transportation.gov/briefing-room/white-house-us-department-transportation-recognize-"transportation-champions-change".

Technical News

USDOT Selects Connected Vehicle Pilots

Secretary of Transportation Anthony Foxx recently announced three pilot programs for connected vehicle technology. Projects in Florida, New York, and Wyoming will receive a total of up to $42 million for next-generation technology that will enable infrastructure and vehicles to share and communicate anonymous information with each other and their surroundings in real time. The goals are to reduce congestion and greenhouse gas emissions, and cut the crash rate for vehicles operated by unimpaired drivers by as much as 80 percent.

As part of USDOT's Connected Vehicle Pilot Deployment Program, the locations were selected in a competitive process to go beyond traditional vehicle technologies to help motorists better use the roadways to drive to work and appointments, relieve the stress caused by

USDOT

Connected vehicle technologies can help to mitigate crashes on busy urban streets.

bottlenecks, and communicate with pedestrians on cell phones to warn them of approaching vehicles.

The pilot program in Tampa, FL, aims to solve peak congestion during rush hour in the city's downtown area and to protect pedestrians by equipping their smartphones with the same connected technology being put into the vehicles. Tampa also committed to measuring the environmental benefits of using this technology.

New York City will install vehicle-to-vehicle technology in 10,000 city-owned vehicles that frequently travel in midtown Manhattan, as well as vehicle-to-infrastructure technology in that area. The technology includes upgrading traffic signals along avenues between 14th Street and 66th Street in Manhattan and throughout Brooklyn. In addition, roadside units will be equipped with connected vehicle technology along Franklin D. Roosevelt East River Drive (FDR Drive) between 50th Street and 90th Street.

In Wyoming, the focus is on the efficient and safe movement of freight through the I–80 east-west corridor, which is critical to commercial heavy-duty vehicles moving across the northern portion of the Nation. Approximately 11,000 to 16,000 vehicles travel this corridor every day. By using connected technology in infrastructure, the Wyoming Department of Transportation will both collect information from and disseminate it to vehicles not equipped with the new technologies.

For more information, visit www.its.dot.gov/pilots.

Public Information and Information Exchange

Improved Access to Information On Highway Innovations

FHWA's Center for Accelerating Innovation recently launched an updated Web site to provide access to the latest information on deployment of highway innovations, including news, resources, and tools. The streamlined site at www.fhwa.dot.gov/innovation makes it easier to find information on FHWA programs that advance innovation in collaboration with transportation partners.

These programs include Every Day Counts, FHWA's stakeholder-based initiative to rapidly deploy proven

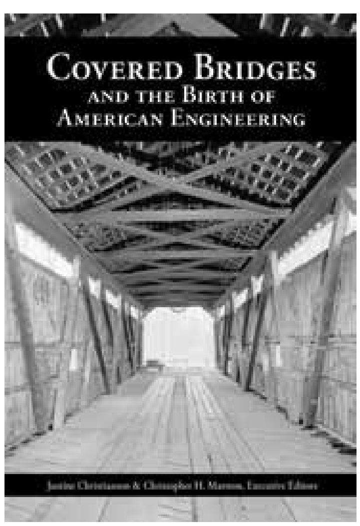
innovations and create a culture of innovation; the State Transportation Innovation Council Network, a national movement to bring together stakeholders in each State to spearhead the deployment of innovations; and the Accelerated Innovation Deployment Demonstration program, which provides incentives for innovation deployment. The site also features innovation-related resources, such as funding opportunities, reports, events, contacts, and newsletters, including the weekly *EDC News* and bimonthly *Innovator*.

FHWA and NPS Publish Book on Historic Covered Bridges

FHWA's Office of Infrastructure Research and Development and the Historic American Engineering Record, a division of the National Park Service (NPS), have maintained a joint research and technology program for historic covered bridges since 2002. One of the culminations of this multiyear program is the publication of *Covered Bridges and the Birth of American Engineering*, edited by Justine Christianson and Christopher H. Marston.

The book examines the development of wood trusses and the construction of covered bridges, profiles the pioneering craftsmen and engineers involved, explores the function of trusses in covered bridges, and looks at the preservation and future of these distinctly American bridges. Illustrations chosen from the thousands of photographs and drawings from the Historic American Buildings Survey/Historic American Engineering Record/Historic American Landscapes Survey Collection at the Library of Congress, as well as other historic images and engineering diagrams, illustrate the book. The work is intended to show a new appreciation for the role that covered bridges played in the development of the Nation and in bridge engineering.

The publication is available at www.nps.gov/hdp/coveredbridges.htm. A limited number of hardcopies are available; contact Sheila Duwadi at sheila.duwadi@dot.gov or Christopher Marston at christopher_marston@nps.gov.



Library of Congress HAER PA-662-7, Jet Lowe, 2006

FHWA and NPS recently published a book on the history of the Nation's covered bridges. The book's cover shows the Kidd's Mill Bridge, built in 1868 in Mercer County, PA. The bridge is an early example of a truss patented by Robert Smith of Ohio, whose prefabricated wooden bridges successfully competed with iron ones during the late 1800s.

Report Now Available on Active Transportation Surveillance

Physical activity is well known to enhance health, but most adults in the United States do not meet the *2008 Physical Activity Guidelines for Americans*. One method to increase physical activity is through active transportation, such as walking or bicycling. However, until recently, no comprehensive, multiyear assessments of data from surveys of active transportation in the United States had been conducted.

The Centers for Disease Control and Prevention recently published a report, *Active Transportation Surveillance—United States, 1999–2012*, analyzing data from five surveys that assess one or more components of active transportation. The surveys used for the report include the American Community Survey, National Household Travel Survey, American Time Use Survey, National Health and Nutrition Examination Survey, and National Health Interview Survey.

From these surveys, researchers determined the occurrence of active transportation as the primary commute mode to work, any single-day active transportation trips, or any habitual active transportation. The study found no consistent trends in active transportation across time periods or across all surveys as a group. Within each survey, data show that active transportation is usually more common among men, younger respondents, and minority racial and ethnic groups. Active transportation tends to be more prevalent in densely populated, urban areas.

Active transportation is assessed by Federal agencies in a variety of ways in multiple surveillance systems, resulting in a range of data estimates depending upon definitions and techniques. Although each type of assessment (such as transportation to work, any purpose, or habitual behavior) measures a different component of active transportation, all can be used to monitor participation trends.

To correctly evaluate findings from the various surveys, transportation agencies need to have an understanding of the strengths, limitations, and lack of comparability of the techniques used to assess active transportation. Public health and transportation professionals can use these systems appropriately to monitor participation and plan and evaluate interventions that influence active transportation.

For more information, visit www.cdc.gov/mmwr/pdf/ss/ss6407.pdf.

Transportation Research Board

Integrating Pedestrian and Bicycle Concepts Into College Courses

Sustainable, livable communities require successful integration of pedestrian and bicycle concepts into transportation planning, and entry-level transportation professionals need experience planning and designing for all modes. That is why the Pedestrian and Bicycle Information Center (PBIC) updated the Pedestrian and Bicycle Transportation Short Series. The three-part series is designed to augment existing undergraduate courses in basic civil engineering and transportation planning with information on pedestrian and bicycle concepts.

The short series now includes up-to-date presentation slides for three modules with 50-minute lectures, speaker notes for instructors, references, and suggested additional readings. The series also includes four assignments—a walkability assessment, an existing conditions analysis, a level of service assessment, and bicycle level of service and level of traffic stress analyses—that students may work on individually or as part of a small group.

The three modules focus on planning, facility design, and data and performance. The module on planning covers the motivations to plan for pedestrians and bicyclists, the relationship between land use and transportation, and the interaction between pedestrian and bike planning and other planning processes. The module on facility design explains how streetscape influences design, gives examples of roadways designed to accommodate pedestrians and bicyclists, and identifies opportunities to retrofit existing streets for pedestrian and bicycle use. The third module, which covers data and performance, describes the data needs for monitoring, analysis, and planning; explains how to collect and analyze that data; and demonstrates how to use facility analysis tools.

Laura Sandt, www.pedbikeimages.org

The Pedestrian and Bicycle Information Center developed content to supplement undergraduate transportation courses with information on accommodating pedestrians and bicyclists. One module includes ways to retrofit existing streets like this one in Boston, MA, with no designated bicycle lane.

These course materials are intended for undergraduate students studying introductory transportation planning or engineering, but they also may be suitable for graduate students.

For more information and to download the course materials, visit www.pedbikeinfo.org/training/courses_short.cfm.

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Thank you for your order!

by Lucia Olivera and Amana Hayes

SBIR Program Makes Street Crossings Safer

Simply crossing the street has become a dangerous daily activity for many, as drivers and pedestrians alike are increasingly distracted by their hand-held devices. Although the Federal Highway Administration cannot prevent pedestrians from using their phones, the agency is working to make them safer, even when the user is distracted. For example, what if your smartphone could alert you when it is unsafe to cross the street? In that case, a smartphone would be an asset to pedestrian safety, not a detriment.

FHWA, through the U.S. Department of Transportation's Small Business Innovation Research (SBIR) Program, awarded a contract to Savari, Inc., to develop a smartphone application called SmartCross to interface with traffic signals. Every year, the SBIR Program supports projects, such as the SmartCross app, to develop technological innovation using the highest level of expertise in the small business community throughout the United States.

Savari, Inc.

How the App Works

By sending signals between the pedestrian's phone and the nearest traffic signal box, the SmartCross app provides an alert to notify pedestrians when it is safe to step into the crosswalk. The application also enables users to request the pedestrian signal. For enhanced safety, the application provides audio, visual, and haptic (or physical, typically vibration) feedback to the user.

The app has different modes for pedestrians, bicyclists, visually impaired individuals, and people in wheelchairs, and can be of immense help to the elderly and the physically impaired. For example, the app can request an extension of pedestrian crosswalk time if a pedestrian has not been able to fully cross the street within the designated time.

In a connected vehicle environment, many drivers also will benefit from this technology. Vehicles equipped with an onboard unit receive notification of a pedestrian in an active crosswalk via an invehicle display. The display also includes the current color of the traffic light and how much time remains before the light changes.

"The app uses GPS to determine the trajectory of the pedestrian and the nearest signal controller," says James Pol, the technical director of FHWA's Office of Safety Research and Development. "Because the app continues running in the smartphone's background even when the app is not open, the user does not have to remember to turn it on in order to benefit from its safety features."

The SmartCross app is currently under development but will be available to iPhone® and Android™ users.

Expanding Its Use

After the initial SmartCross launch, developers will continue to update the app to leverage the latest technology. For example, developers plan to link the app to work with connected vehicles as use of that technology increases. In addition, the app may be expanded in its use to people with disabilities and older pedestrians and road users. The accessibility community often has high poverty rates, and any improvements to their mobility could make a meaningful difference in their everyday lives. Enhancements to the app will not only be useful to the disabled but also will help to advance new research for accessibility and mobility. Systems developed with accessibility in mind require more rigor to meet the needs of vulnerable users. Overcoming the development challenges for accessibility may lead to design breakthroughs and requirements that could be introduced into other mobility and safety applications.

SmartCross put the majority of its SBIR funding toward the app's concept development, focus groups, and design development. The contractor responsible for the project also participates in USDOT's connected vehicles research program, which is developing the capability to identify threats and hazards on the roadway and communicate this information to drivers over wireless networks.

"Through this SBIR project," says Pol. "We are working toward achieving a vision in which technology brings all of the pieces together—vehicles, infrastructure networks, sensors, intelligence, and people—to bring the future of transportation to fruition."

For more information, contact Lucia Olivera at lucia.olivera@dot.gov.

Lucia Olivera is a senior legislative and budget analyst with FHWA's Office of Corporate Research, Technology, and Innovation Management.

Amana Hayes is a former FHWA intern.

NATIONAL HIGHWAY INSTITUTE

Training Update

by Judy Francis

NHI Celebrates 45 Years of Excellence

Since opening its doors in 1970, the National Highway Institute has equipped thousands of transportation professionals with the skills to keep the Nation's highway system moving forward.

The need for a national transportation college existed almost as long as the transportation system itself. Federal, State, and local highway professionals rely on up-to-date, accurate, and timely training on the latest skills and techniques to do their jobs effectively and efficiently. Without such training, highway professionals could face ineffective project planning, mistakes in construction, and the risk of spending more time and money on projects than necessary. To address these potential issues, section 115 of the Federal-aid Highway Act of 1970 called for the creation of a transportation college. This legislation is responsible for the formation of NHI.

NHI offers opportunities for continuing education to the transportation workforce. Since its inception, Federal, State, and local highway professionals have relied on NHI's training and expertise to provide new information and skills. Like the industry it serves, NHI has become larger, more diverse, and more innovative over the past 45 years.

A History of Partnership

Today's transportation workforce operates in a rapidly changing environment. The need for fast, reliable training is intensified by the swift growth of technology. NHI's partnerships with Federal program offices, State departments of transportation, and local agencies are essential to staying ahead of transportation training needs.

When NHI realizes a training need, it works with individual program offices at FHWA to analyze the gap and formulate a solution. "Agencies are looking for training solutions that are within budget but also that will equip their employees with applicable skills to improve their job performance," says Thomas Elliott, training program manager at NHI. "For today's transportation agencies, the answer isn't always traditional classroom training. Sometimes it's a job aide or Web-based solution that works best."

NHI's hosts are vital to its success as well. Any organization with a transportation training need can ask to host an NHI session, either in a classroom or via Web conference. These training requests help NHI keep a pulse on program area needs across the country. By tracking the popularity and demand of its offerings, NHI can provide opportunities for continuing education in programs of interest.

Evolution of Training

When NHI was first formed, a small number of employees registered students by hand for instructor-led trainings in local classrooms. The introduction of the Internet and large increase of personal computers in the 1990s changed everything. Paper forms moved online,

NHI

Over its 45-year existence, NHI has evolved hand in hand with industry needs. Today's demand for high-quality, easily accessible training led NHI to develop award-winning technology for virtual training in bridge inspection.

certificates became downloadable, and eventually focus shifted to distance learning.

NHI's course offerings expanded beyond instructor-led trainings to include Web-based trainings in 2007. Moving some training online enabled practitioners working in rural areas, and others unable to travel to a classroom, to earn continuing education units from any location with online access. In 2010, NHI introduced Web-conference trainings, placing qualified classroom instructors within virtual classrooms for live training sessions.

NHI's instructor-led trainings are evolving too. In September 2015, the Federal Highway Administration received the International Association for Continuing Education and Training's (IACET) 2015 Innovation of the Year Award – Technology Integration for the development of a virtual bridge technology used in the Safety Inspection of In-Service Bridges (130055) course. IACET presented the award to recognize the "best of the best" in technology integration and innovation. For more information on the course, see the Training Update article "Bridge Inspection Goes Virtual" in the May/June 2013 issue of PUBLIC ROADS.

Future of NHI

NHI is striving to think differently about learning. But while training techniques and technical platforms may vary over time, NHI remains committed to quality.

"We're constantly looking for ways to make training more accessible and engaging for the participants," says Valerie Briggs, NHI's director of training. "NHI has a rich history of success and innovation spanning 45 years. We're excited to continue working on solutions for the transportation workforce that will adapt with their needs."

The transportation community can continue to rely on NHI's partnerships, technical expertise, and outstanding customer service. By embracing data and technology to extend its services, NHI officials hope to reach an even broader audience with more innovative training solutions.

Judy Francis is a contracted marketing analyst for NHI.

Communication Product Updates

Compiled by Lisa A. Shuler of FHWA's Office of Corporate Research, Technology, and Innovation Management

Below are brief descriptions of communications products recently developed by the Federal Highway Administration's (FHWA) Office of Research, Development, and Technology. All of the reports are or will soon be available from the National Technical Information Service (NTIS). In some cases, limited copies of the communications products are available from FHWA's Research and Technology (R&T) Product Distribution Center (PDC).

When ordering from NTIS, include the NTIS publication number (PB number) and the publication title. You also may visit the NTIS Web site at www.ntis.gov to order publications online. Call NTIS for current prices. For customers outside the United States, Canada, and Mexico, the cost is usually double the listed price. Address requests to:

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For more information on R&T communications products available from FHWA, visit FHWA's Web site at www.fhwa.dot.gov, the FHWA Research Library at www.fhwa.dot.gov/research/library (or email fhwalibrary@dot.gov), or the National Transportation Library at ntl.bts.gov (or email library@dot.gov).

Strength Characterization of Open-Graded Aggregates for Structural Backfills (Report)
Publication Number: FHWA-HRT-15-034

Open-graded aggregates are compacted aggregates with relatively large void spaces not filled with intermediate-sized particles. These aggregates are becoming more common in road and bridge construction because they are easy to place, require simple testing for quality assurance, and have the advantages of very low fine particle content, lighter unit weight, free-draining characteristics, and low potential for frost heave.

State and local transportation agencies frequently use crushed, manufactured open-graded aggregates as structural backfill material for retaining walls, bridge foundations, and other ground improvement applications. However, the strength characteristics of this material are not fully understood or applied. Designers need to know the friction angle to account for lateral earth pressures and bearing resistance. But because of the large size of the standard American Association of State Highway and Transportation Officials (AASHTO) open-graded aggregates, this parameter cannot be measured with standard testing equipment. Instead, current practice is to select aggregates with low default friction angles, which can lead to overly conservative, less cost-effective designs.

This report discusses a study to establish a knowledge base featuring the most commonly used AASHTO open-graded aggregates. The study included a systematic approach to fully characterize the strength parameters using a large-scale direct shear and triaxial device in FHWA's geotechnical laboratory at the Turner-Fairbank Highway Research Center (TFHRC). The researchers also investigated relationships between other important soil parameters and the friction angle, as well as the effect of various automated testing devices and methods to interpret the data.

The report presents strength characteristics of 16 open-graded aggregates representative of commonly selected structural backfills. The test results indicate higher strengths for these materials than current default values typically assumed in design. Aside from strength, researchers measured gradation, density, repose angle, angularity, and texture. They also examined correlations between various soil properties and strength parameters and found that the mean grain size, sphericity, angularity, and void ratio play a role in the measured friction angles.

The document is available to download at www.fhwa.dot.gov/publications/research/infrastructure/structures/bridge/15034/index.cfm.

Evaluation of the Impact of Spectral Power Distribution on Driver Performance (Report)
Publication Number: FHWA-HRT-15-047

Traditional roadway lighting uses high-pressure sodium light sources, which provide high photometric efficacy. However, this type of light is amber and does not render the color of objects accurately. With the advent of light-emitting diode technology in roadway lighting, a new aspect of a light source is now being considered—its spectral power distribution. Broad-spectrum sources, with significant spectral output across the entire visible spectrum, potentially provide additional benefits to the driver; these light sources can provide better color information and can activate all of the photoreceptors in the eye more efficiently. This report discusses a project that investigates these effects and considers the potential benefits of a broad-spectrum light source.

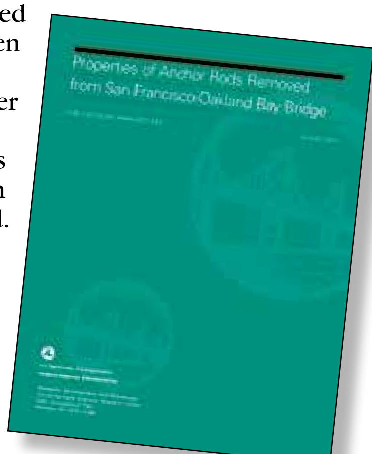
The potential benefits relate to mesopic vision—the transition in the human eye from cone sensitivity to rod sensitivity in lower light situations. In a series of human factors experiments, researchers evaluated the effect of the spectral power distribution of overhead lighting and headlamps with respect to driver detection and recognition of large and small objects as well as pedestrians. The report includes an evaluation of the effects of a momentary peripheral illumination mechanism on visual performance and eye-glance behavior of drivers. Researchers also evaluated the potential for applying mesopic multiplying factors to roadway lighting.

Results of these experiments show that in a natural driving environment at the speeds tested, there is limited applicability of the mesopic model to lighting design. Researchers found that the spectral component of the light source affects driver visual performance, but only in certain conditions. The speed of the vehicle also affects the driver's visual performance. For high-speed roadways, researchers recommend that spectral effects not be included in the design of the lighting systems. For lower speed roadways where the lighting system is predominantly for pedestrians, spectral effects may still apply.

The report is available to download at www.fhwa.dot.gov/publications/research/safety/15047/index.cfm.

Properties of Anchor Rods Removed From San Francisco-Oakland Bay Bridge (Report)
Publication Number: FHWA-HRT-15-057

In March 2013, the construction contractor for the new self-anchored suspension bridge between San Francisco and Oakland, CA, tensioned the threaded rods between the bearings and shear keys and the concrete pier cap. Soon after completion, one-third of the rods for the two shear keys on the eastern pier fractured. This report discusses the investigation, requested by the FHWA California Division, to determine the root cause of the fractures. The document includes data on the mechanical, chemical, and microstructural properties of two samples removed from the pier.



The two samples were shipped to TFHRC. One was from a threaded portion of a rod and was approximately 3 inches (7.6 centimeters) long. The second sample was from an unthreaded portion and was approximately 13.5 inches (34.3 centimeters) long. Researchers at TFHRC were asked to test impact toughness, hardness, strength, and elongation, in addition to conducting microscopic inspection of thread roots for cracks.

Testing showed a variation in material properties between the surface and core of the rods. Researchers concluded that improper heat treatment of the rods caused this variation. In addition, the tensile and hardness properties could have been judged to be in nonconformance depending on interpretation of the relevant ASTM standards. Researchers recommend that the ASTM A354 and/or F606 standards be revised to provide more guidance on sampling for tensile and hardness properties for large-diameter products as well as guidance on impact toughness.

The report is available to download at www.fhwa.dot.gov/publications/research/infrastructure/structures/bridge/15057/index.cfm.

Assessing Pavement Surface Splash and Spray Impact on Road Users (TechBrief)
Publication Number: FHWA-HRT-15-062

The effects of vehicle splash and spray are well known to motorists who have driven in wet weather conditions. Research indicates that splash and spray contribute to a small but measureable portion of vehicle crashes and are sources of considerable nuisance to motorists. Splash and spray from highway pavements can also carry a number of pollutants and contaminants. When deposited on roadsides, these contaminants can be detrimental to plant life and accelerate the corrosion of roadway appurtenances. This technical brief describes the development of an assessment tool to characterize the propensity of highway sections to generate splash and spray during rainfall and the impact of splash and spray on road users.

The development of the assessment tool involved a combination of laboratory and field experiments, theoretical developments, and computer simulations. Researchers assessed prior work in the area of splash and spray mechanisms and found that the main factors affecting splash and spray are water film thickness, vehicle speed, tire geometry, tire tread depth, vehicle aerodynamics, and devices to suppress vehicle spray. They also found that none of the techniques that have been used to measure splash and spray are widely accepted or readily available for routine evaluations of pavement surfaces. A review of the available literature suggests that there are four prevailing splash and spray mechanisms: bow wave, side wave, tread pickup, and capillary adhesion.

Researchers developed three submodules for the splash and spray assessment tool: (1) a water film thickness model, (2) an exposure model for estimating the amount of water that will be projected by the tire, and (3) a splash and spray model that predicts the likelihood of the occurrence of splash and spray based on the other two models.

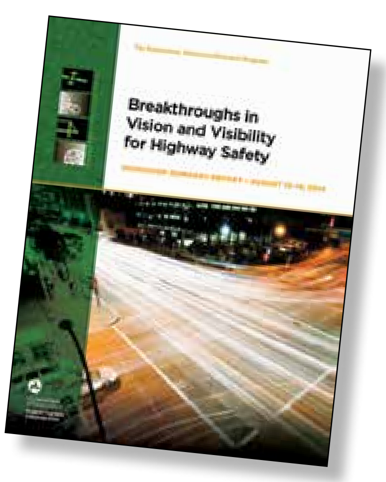
The study's submodels comprise a model that can be used to predict splash and spray based on the characteristics of a pavement surface and climatic conditions. The model computes water film thickness based on rainfall intensity and pavement surface properties, the maximum amount of water available for splash and spray, and the contribution of each splash and spray mechanism until the total amount of available water is exhausted. The model can also determine the spray density corresponding to each mechanism and the total spray density, and convert the spray density level to a subjective nuisance index. These computations can provide useful information for supporting highway design and maintenance processes.

The technical brief is available to download at www.fhwa.dot.gov/publications/research/infrastructure/pavements/ltpp/15062/index.cfm.

Breakthroughs in Vision and Visibility for Highway Safety (Workshop Summary Report) Publication Number: FHWA-HRT-15-067

On August 13 and 14, 2014, FHWA's Office of Safety Research and Development and Office of Safety, with support from the Exploratory Advanced Research Program, convened a 2-day workshop at TFHRC. The workshop, "Breakthroughs in Vision and Visibility for Highway Safety," aimed to identify gaps in highway visibility research, explore innovative tools and techniques to fill those gaps, and determine the role for FHWA.

Researchers have investigated a variety of visibility issues related to transportation, including efforts to explore retroreflectivity, pavement-marking signs, and legibility of fonts; however, much of this work has been tapering off in recent years. The workshop resulted in meaningful dialogue about necessary future research and FHWA's role.



Much of the research conducted on visibility has focused on the energy sector and the vehicle side, not transportation infrastructure. The research has resulted in several advances in sight and cognition that move beyond existing processes and frameworks used in highway visibility.

The workshop included presentations from five experts, covering topics such as FHWA's previous research, visibility needs for vehicles of the future, roadway lighting limitations, eye-movement analysis, and retroreflectivity. After the presentations, the participants discussed current issues and identified gaps where further research could help move the field forward. Participants also considered exploratory research needed and how that research could be coordinated across disciplines.

A key takeaway from the workshop is that current visibility standards and guidelines for new technologies and the roadway implications of these technologies need to be revisited and reestablished. Another takeaway is that driver, pedestrian, and night simulation studies are needed to provide insight into a driver's decisionmaking processes when visibility is low.

The report is available to download at www.fhwa.dot.gov/advancedresearch/pubs/15067/index.cfm.

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