Public Roads

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Innovation on Rural Roads
Choosing a Research Method
Clearing Crashes

U.S. Department of Transportation
Federal Highway Administration

Public Roads

—featuring developments in Federal highway policies, programs, and research and technology—

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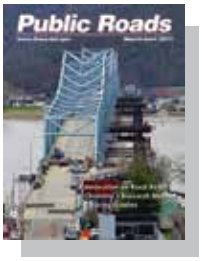

Front cover—The Kentucky Transportation Cabinet and the Indiana Department of Transportation applied practical solutions and innovations to replace the U.S. 421 bridge over the Ohio River between Milton, KY, and Madison, IN. Crews built this new structure on temporary piers (on the right) first and then slid it onto the refurbished original piers. For more information, see "Leading with Innovation at the Helm" on page 10 in this issue of PUBLIC ROADS. *Photo: Milton-Madison Bridge Project.*

Back cover—The Federal Highway Administration's Human Factors Team, housed in the Office of Safety Research and Development, created these images for use in a driving simulator to study driver behavior. The top image is the wireframe schematic, and the bottom one is the completed rendering used onscreen in the simulator. For more information, see "The Science and Art of Putting Drivers under the Microscope" on page 24 in this issue of PUBLIC ROADS.

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Guest Editorial

All Innovation Is Local

One of the most famous quotes in U.S. political history came from the late Speaker of the House of Representatives, Thomas "Tip" O'Neill, Jr., who famously said, "All politics is local." Something very similar could be said about deploying innovation to improve the Nation's system of roads and bridges: All innovation is local.

The concept is simple. States and local organizations know their particular needs, regulations, and circumstances better than anyone. And so they are best suited to choose and deploy new ideas and technologies that improve the way they plan, design, build, and maintain their transportation infrastructure.

This issue of PUBLIC ROADS offers several articles highlighting how transportation organizations across the country are saving time and money, and enhancing the safety of both workers and the traveling public, by choosing and using innovations that work for them.

In the article titled "Leading with Innovation at the Helm" on page 10, Michael Hancock, immediate past president of the American Association of State Highway and Transportation Officials and secretary of the Kentucky Transportation Cabinet, outlines how his State deploys innovation to better serve the people and businesses of Kentucky. Hancock also provides a list of keys to successfully applying innovation within any organization.

In "On the Frontlines of Innovation" on page 2, Jeffrey Paniati and Frederick G. "Bud" Wright, executive directors of the Federal Highway Administration and AASHTO, respectively, discuss three major national deployment programs. Combined, the programs provide more than 130 innovations from which organizations can choose, enabling them to use their resources more efficiently and effectively to meet the expectations of the traveling public.

Paniati and Wright also discuss the importance of the national innovation deployment network made up of 46 State Transportation Innovation Councils, known as STICs. I believe the councils play an important role

in innovation deployment. Each STIC pulls together under one banner all the stakeholders involved in a State's highway program. The STIC puts the "all innovation is local" philosophy into practice by taking a comprehensive look at all sources of innovation and deploying the ones that best fit the State's needs. The authors highlight several projects from across the country in which agencies and their partners have done outstanding work responding to customer needs by employing innovative approaches.

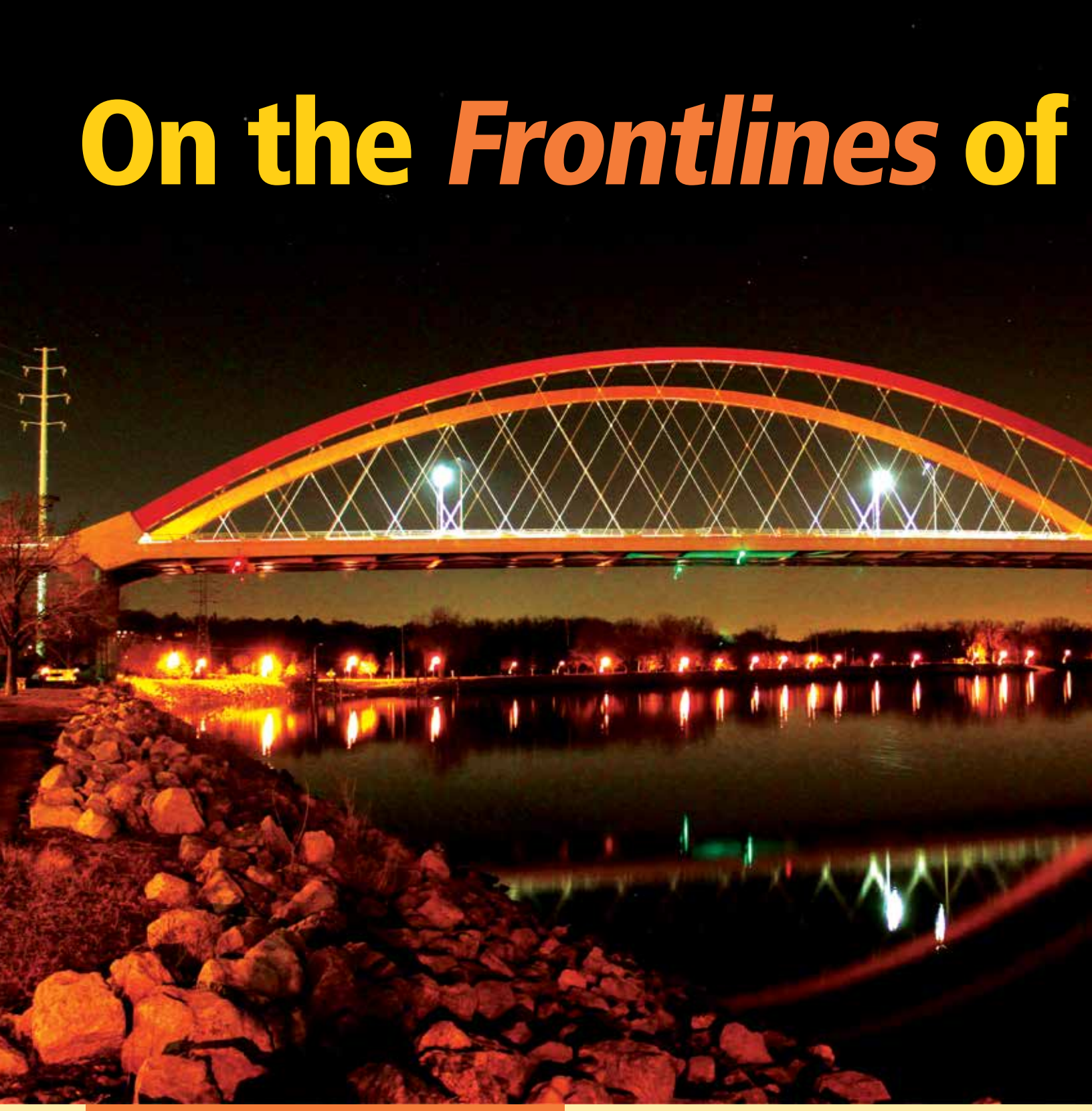
Other articles in this issue tackle diverse topics such as rural safety innovations, handling traffic incidents in a safe and efficient way, and selecting research methodologies to measure driver behavior. The menu of articles offers plenty of food for thought, and the common ingredient is innovation.

As you read, enjoy, and absorb these articles, perhaps something will capture your interest and you will think, "I bet that could work for us!" That's the goal. By all means, seek out more information, arrange for a demonstration, or attend a webinar on the topic. As always, each article provides contact information for the authors—a great way to get the ball rolling.

But most important, think about ways that innovation can work to improve transportation in your community.

Gregory Nadeau
Acting Administrator
Federal Highway Administration

On the *Frontlines* of

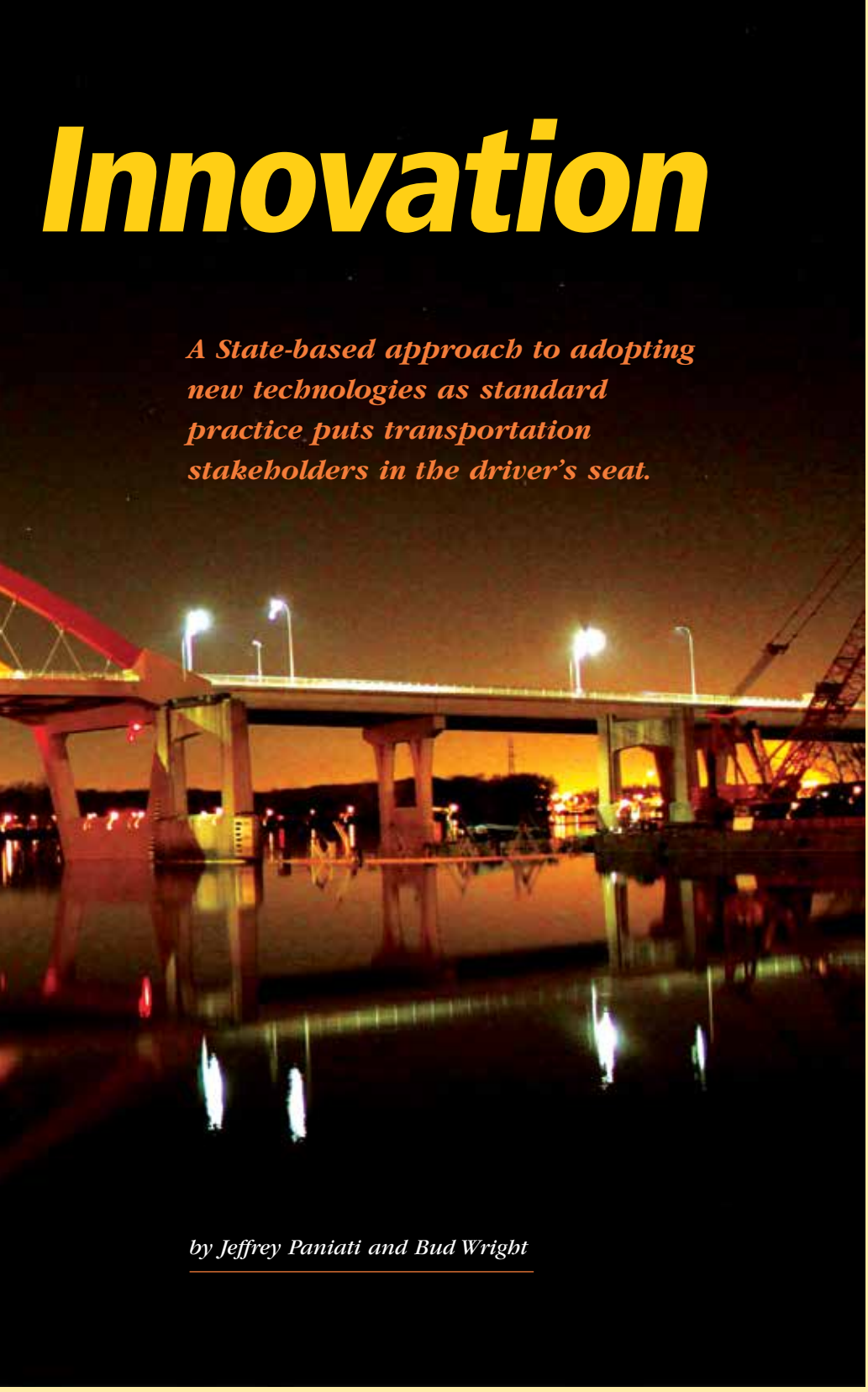


Minnesota is one of a number of States championing the use of innovations. The Minnesota DOT built this Highway 61 Hastings Bridge over the Mississippi River on an accelerated schedule using a design-build approach. The Hastings Bridge now boasts the longest freestanding arch main span in North America. *Photo: Minnesota DOT.*

Road users in the United States value personal mobility and freedom of movement, so they expect a lot from their highway system. They want it to be safe, accessible, and convenient. They want to experience minimum traffic congestion. And they want the best value for the tax dollars that support the building and repair of roads and bridges.

Innovation

A State-based approach to adopting new technologies as standard practice puts transportation stakeholders in the driver's seat.



by Jeffrey Paniati and Bud Wright

But the Nation's highway system faces a significant challenge: an aging infrastructure requiring extensive rehabilitation, coupled with heavy and growing traffic volumes throughout the country. This combination means that necessary repair and construction activities often result in lengthy traffic backups. Facing such a difficult environment, highway agencies need to figure out how to use their limited resources more efficiently and effectively while providing a transportation system that meets the expectations of the traveling public.

One solution is more extensive use of innovative but proven technologies and processes that can help highway agencies complete construction projects faster, more safely, with fewer negative effects on drivers, and sometimes at lower cost. It is in the best interest of the motoring public and State departments of transportation for these innovations to be deployed quickly and extensively.

To that end, State DOTs have adopted new processes and technologies to transform how they plan, design, construct, and maintain highway projects. Several State DOTs across the country are leading the way by embracing innovation. In many cases, long-held methods have given way to approaches that are faster, safer, more cost effective, and of better quality, all with less impact on both the environment and existing traffic during construction.

The Time Is Right

There was a time when innovation was not a focus in the transportation sector, and practices were driven by tradition. In fact, the norm was for it to take years for a new technology to become a standard practice. In many cases, highway agencies reserved innovation only for emergency situations, such as the rapid repair of a bridge damaged by a major crash or a road wiped out by a powerful flood or a hurricane's storm surge. Also, it was common to see an important innovation fully used in some States, but unheard of in others.

Today, transportation organizations recognize that widespread use of innovation is essential to meet customer needs and expectations. The American Association of State Highway and Transportation Officials, the Federal Highway Administration, the Transportation Research Board, other Federal agencies, State DOTs, local and regional public agencies, industry groups, and private companies are collaborating to deploy innovations quickly and mainstream their use across the country.

To facilitate the innovation movement, national transportation organizations have developed several programs to help States implement new technologies and

New York State DOT

The New York State DOT used accelerated bridge construction techniques to erect two bridges on I–84 over Dingle Ridge Road in southeast Putnam County in just two weekends. The project leveraged research from SHRP2 and FHWA funding to minimize delays to motorists on this major route between New York and Connecticut.

processes. These programs include AASHTO's Innovation Initiative (AII); FHWA's Every Day Counts (EDC) initiative; and the second Strategic Highway Research Program (SHRP2).

These programs focus on encouraging DOTs and their partners to try innovations and make them standard practice for developing and delivering highway projects. The initiatives emphasize using proven marketing approaches and dedicated teams to deploy innovations faster and more effectively. Some also offer incentives to implement innovations when constructing projects or to demonstrate the use of new tools, techniques, processes, and training.

State-Based Approach

A common feature that contributes to the success of programs such as AII, EDC, and SHRP2 is a State-based approach to innovation deployment. This approach recognizes that the diverse characteristics that make each State unique—people, geography, climate, economy, urban and rural areas, laws and regulations—also make their transportation requirements different.

Although all States can benefit from using proven innovations to build and maintain transportation infrastructure better, faster, and smarter, the importance or usefulness of any given technology or practice will vary by State. For example, using accelerated techniques for bridge construction to reduce traffic disruption may be a priority in some States, while applying alternative contracting methods to speed up project delivery and save money may be a higher priority in others.

The State-based approach enables DOTs to make decisions about trying innovations and adopting those that benefit their agencies and customers. It recognizes that DOTs serve as innovation leaders for their States and, working with local, county, and industry stakeholders, play a pivotal role in innovation deployment. This approach also acknowledges that State DOTs and their partners are in the best position to determine how to apply specific innovations in their transportation programs and to implement them quickly.

Many States have formed councils, task forces, committees, or similar groups to aid with innovation deployment. These State Transportation Innovation Councils (STICs) bring together transportation stakeholders from all levels of the transportation community to evaluate which innovations are most appropriate for their States. Members come from public agencies, metropolitan planning organizations, transportation associations, environmental and historical preservation groups, industry, and academia.

Each State council meets regularly to consider all types of innovation, including those fostered by AII, EDC, and SHRP2 as well as other sources. The councils decide which innovations to adopt, develop implementation plans and performance goals, and set the pace for implementation. The councils put their respective States' transportation stakeholders in the driver's seat to select the innovations that best consider a variety of perspectives, from government to industry, and that fit each State's particular business needs and challenges. These councils also affirm their stakeholders' commitment to institutionalize innovations and ensure that innovation deployment will continue as a routine practice for years to come.

Combined, the State councils create a national network to exchange best practices on innovations and encourage their widespread use. For more information on State Transportation Innovation Councils, see "Implementing Innovations" in the July/August 2013 issue of PUBLIC ROADS.

For example, the Iowa Highway Research Board, founded in 1950, serves as the State's innovation council. According to a resolution it adopted in 2014, the council will "decide the number of innovations to adopt and set the pace for implementation by establishing a baseline and setting a target goal."

Similarly, the Pennsylvania council, created in 2010 as part of the Pennsylvania Department of Transportation's (PennDOT) Next Generation initiative to modernize processes and technologies, acts as "a catalyst for rapid deployment of those nationally and State-identified technologies, techniques, and tactics that have been demonstrated in 'real-world' applications and can offer improved performance/effectiveness in Pennsylvania."

AASHTO's Innovation Initiative

In 2001, AASHTO created AII, then known as the Technology Implementation Group, to identify proven advancements in transportation technology and to accelerate their adoption. Each year, the program selects a group of worthwhile, but underused technologies, processes, software, or other innovations to promote as focus technologies. Each technology has been adopted by at least one State agency, is market ready, and is available for use by other agencies.

AII advances innovation through a peer-to-peer model. Once AII has chosen a technology to fast-track, a team from a lead State develops

Current Programs to Deploy Highway Innovations

Program	Date Started	Administered By	Number of Technologies Promoted to Date	List of Current Focuses
AASHTO Innovation Initiative http://aii.transportation.org/Pages/FocusTechs.aspx	2001 (as the Technology Implementation Group)	AASHTO	34 focus technologies, plus 21 selected technologies	• Carbon Fiber Reinforced Polymer Strands • e-Construction • Right of Way Plans Index Site • Automated Traffic Signal Performance Measures • Intelligent Roadway Information System • UPlan Phase II • Watershed Resources Registry • Embedded Data Collector • Sequential Flashing Warning Lights for Work Zones • Towing and Recovery Service Partnership
Every Day Counts www.fhwa.dot.gov/everydaycounts	2009	FHWA	32	• Smarter Work Zones • Data-Driven Safety Analysis • Road Diets (Roadway Reconfiguration) • Ultra-High Performance Concrete Connections for Prefabricated Bridge Elements • Improving Collaboration and Quality Environmental Documentation (eNEPA and IQED) • 3D Engineered Models: Schedule, Cost, and Post-Construction • e-Construction (also an AII innovation) • Regional Models of Cooperation • Improving DOT and Railroad Coordination (also a SHRP2 Solution) • Locally Administered Federal-Aid Projects: Stakeholder Partnering • Geosynthetic Reinforced Soil–Integrated Bridge System
Second Strategic Highway Research Program www.fhwa.dot.gov/goshrp2	2005	FHWA and AASHTO, in partnership with TRB	64 products implemented as 41 product/product bundles (resulting from more than 100 research projects)	• PlanWorks (C01) • Utility Locating Technologies (R01B) • Precast Concrete Pavement (R05) • Identifying and Managing Utility Conflicts (R15B) • New Composite Pavement Systems (R21) • Guidelines for the Preservation of High Traffic Volume Roadways (R26) • WISE: Work Zone Impact Estimation Software (R11) *(Note: This list includes those products anticipated in Round 6 only.)*

a plan to deliver the technology to users. They tailor activities to each technology, which may include developing training programs and materials, as well as sending out teams to help agencies learn how to apply the technology. Each lead State team is made up of individuals representing agencies, industry, and other organizations with experience using the focus technology, or a knowledge and commitment to supporting its broad implementation.

AII selected three new focus technologies in 2014: carbon fiber reinforced polymer strands, e-Construction, and the Right of Way Plans Index Site. Carbon fiber reinforced polymer strands are prestressing and post-tensioning materials for bridge construction that offer a noncorrosive alternative to traditional steel materials. e-Construction uses technological tools, such as digital data and secure file sharing, to improve document management and save time and money on construction projects. A user-friendly Web site, "Right of Way Plans Index Site," provides existing right-of-way plans and maps with the click of a key.

Since AII's establishment as the AASHTO Technology Implementation Group more than a decade ago, the program has promoted a number of innovations now used throughout the country. These innovations include cable median barriers, which are a cost-effective way to help prevent crossover crashes on highways separated by traversable medians; self-propelled modular transporters, which are computer-controlled platform vehicles used in accelerated bridge construction to move prefabricated bridge components into place quickly; and TowPlow, a trailer-mounted plow that can be pulled by a snowplow truck and swung out to the side to double the truck's plow width.

Every Day Counts

Launched by FHWA in 2009, the EDC initiative aims to shorten project delivery times and accelerate deployment of market-ready innovations. Like the other initiatives, EDC also has a collaborative, State-based focus. Through the initiative, FHWA works with State DOTs and their partners to make innovations standard practice, but States take the lead in determining which innovations to try and how to deploy them.

Every 2 years, FHWA introduces a new round of a dozen or so proven innovations with potential to benefit the Nation's transportation system. FHWA then encourages States to adopt those that fit their needs. Collaborative planning techniques, smarter work zones, and easier-to-build bridges are among the 11 technologies and practices included in the third round of EDC, announced in August 2014. Transportation stakeholders learned about these

North Dakota DOT

Roundabouts were one of the innovations FHWA promoted during the second round of EDC. The North Dakota DOT built this roundabout, its first, at the intersection of State Highway 22 and Highway 200 south of Killdeer in 2012.

innovations at regional summits, and State agencies are developing plans for implementing their chosen innovations in 2015 and 2016.

FHWA's role in the EDC deployment process is to provide national leadership in incorporating key innovations into the transportation system. The agency assembles teams of experts to offer technical assistance and training to help the transportation community deploy the EDC innovations. It also offers funding to kickstart use of innovations of all types through its Accelerated Innovation Deployment Demonstration and State Transportation Innovation Council Incentive programs.

Since the initiative's launch, every State DOT has used two or more innovations promoted through EDC, and several are now standard practices in many States. Forty-seven State DOTs and all Federal Lands Highway divisions, for example, now have specifications or contractual language allowing the use of energy-saving warm-mix asphalt, which is produced and placed at lower temperatures than traditional hot-mix asphalt. Warm-mix reduces paving cost, extends the paving season, improves compaction, enables asphalt mix to be hauled longer distances, and improves working conditions. Plus, with reduced emissions, fumes, and odors, warm-mix is better for the environment.

Second Strategic Highway Research Program

The SHRP2 partnership of FHWA, AASHTO, and TRB is designed to advance highway performance and safety for users and complement other research programs. The program has addressed critical State and local challenges, such as aging infrastructure, congestion, and safety, by undertaking more than 100 research projects in four strategic focus areas. It builds on the success of the first SHRP (1988 to 1993), which produced, among other innovations, Superpave (SUperior PERforming Asphalt PAVEments)—a process for creating more durable roads—and new technology for addressing snow and ice on roadways.

The SHRP2 research produced results that are now available in a series of ready-to-use solutions that agencies can apply in their transportation programs. Through its Implementation Assistance Program, SHRP2 helps State DOTs, local transportation agencies, metropolitan planning organizations, and other groups deploy and implement SHRP2 Solutions. Few of the SHRP2 Solutions introduce totally new products or technologies.

The Checkered House Bridge in Richmond, VT, needed upgrading or replacement to widen the lanes, and to fix aging steel elements and a deteriorating road surface. To preserve the historic structure, VTrans opted to use an innovative design-build approach in which the contractors cut the structure in half lengthwise and widened it by 12.5 feet (3.8 meters).

VTrans

Texas DOT

Like Vermont, Texas is using innovative design-build contracting to speed up project delivery time and reduce associated costs. The Texas DOT's $1.1 billion Dallas-Fort Worth Connector, shown here, links the two cities, the airport, and numerous other communities in the metroplex. This design-build project simultaneously designed and built 8.4 miles (13.5 kilometers) in Grapevine, Irving, and Southlake, and it doubled the size of the existing highway system around the north entrance to the Dallas/Fort Worth International Airport. The initial project reached final acceptance in March 2014.

Instead, most improve on, broaden the application of, or standardize known approaches in ways that can save lives, money, and time.

Organizations can apply for pilot incentives to evaluate the readiness of a product, lead adopter incentives to help offset the costs of implementing a product, or take advantage of user incentives to carry out implementation activities. Those activities include executing changes to system processes or organizing peer exchanges to accelerate knowledge transfer from early users.

The SHRP2 Implementation Assistance Program has issued four rounds of incentives to the States, beginning in 2013 and running through 2014. The program has engaged all 50 States, utilizing SHRP2 products on more than 250 transportation projects. SHRP2 Solutions for which organizations received implementation aid in the fourth round include nondestructive testing of concrete bridges, technologies for enhancing quality control on asphalt pavements, and managing risk in rapid renewal projects, among others related to improved planning and safety. The program will continue to offer SHRP2 products and the opportunity for incentives through additional rounds of implementation assistance planned in 2015.

Standardizing Innovations

Many State Transportation Innovation Councils use FHWA's STIC Incentive Program to boost their efforts to mainstream the new technologies and practices that they choose to implement. Under the program, groups can apply for up to $100,000 a year to carry out projects to standardize innovative practices. States are using these funds to advance a variety of innovations—from alternative contracting methods to three-dimensional engineered models for construction to ground-penetrating radar. For more information on the incentive program, visit www.fhwa.dot.gov/stic/guidance.cfm.

"With dwindling revenues, it can be difficult to get new things implemented," says Jennifer Harper, research engineer for the Missouri Department of Transportation (MoDOT). "Providing an incentive to offset costs is sometimes the only way to get that initial deployment." For example, Missouri's STIC voted to apply incentives to MoDOT's collaborative project with the Missouri University of Science and Technology to design a full-depth, fiber-reinforced polymer bridge deck panel that is stronger and more economical than those currently in use. The incentives helped fund research on developing connection details and specifications, working through constructability issues, and compiling the information in a report, all to support adoption of the innovation.

Innovations at Work

In Vermont, the STIC used FHWA funds for a project to institutionalize the design-build contracting method. In contrast to the traditional design-bid-build method, design-build combines the design and construction phases of a project into one contract, speeding up project completion and offering potential cost savings. The Vermont Agency of Transportation (VTrans) has used design-build on five bridge projects since 2009 and has another in procurement. After relying on a small team to implement design-build on early projects, VTrans is documenting key design-build processes and procedures for consistent use throughout the agency to help make the method a standard practice.

Ohio DOT

This portion of U.S. 33 through Nelsonville, OH, had a history of safety problems. Ohio DOT's recent $200 million Nelsonville Bypass project included construction of a four-lane bypass highway and other local road improvements. The project reduced travel time through the area by 30 minutes. To protect the nearby natural habitat of the Wayne National Forest, Ohio DOT invested $10 million for a wildlife bridge and tunnel, wildlife fences, and lighting.

The New Hampshire Department of Transportation (NHDOT) used incentives to buy computer-aided design workstations and to develop design standards that support its transition to 3-D modeling from the traditional two-dimensional design process. The project is part of a push to make 3-D modeling—a technology that can expedite project completion, increase productivity, and reduce manual tasks associated with construction projects—an everyday practice in New Hampshire.

Another project enabled NHDOT to obtain ground-penetrating radar equipment and software to expedite project development and improve design practices. Ground-penetrating radar uses radio waves to collect data on the thickness and other properties of pavement layers, information traditionally obtained by drilling core samples. The agency is using the equipment to assess concrete bridge components, including validating estimates of concrete quality on rehabilitation projects for bridge decks and determining rebar depths on new construction. The data gathered from these rapid collection methods enable projects to advance more quickly with more accurate information.

The Ohio STIC obtained funds through the STIC Incentive Program to develop guidance on how to improve the quality and streamline the production of feasibility studies and alternative evaluation reports, environmental documents important to project development. The Ohio Department of Transportation will use the guidance to produce documents that ensure more efficient decisionmaking. The project is part of Ohio DOT's ongoing effort to improve the quality of project documents required under the National Environmental Policy Act.

"By using these two types as examples of how to develop quality documentation, we hope to greatly influence all other documents in our process," says Tim Hill, administrator of Ohio DOT's Office of Environmental Services. "This is the start of reworking many documents [Ohio] DOT uses and hopefully a realization of the money and time we can save by simply communicating better."

Pennsylvania's innovation group is another example of the many success stories for the State-based approach to mainstreaming innovation. STIC members meet quarterly to discuss potential innovations and deployment plans. In addition to its leadership group, the STIC has technical advisory groups that evaluate innovations from a variety of sources and produce papers on their benefits and impacts. STIC leaders

use the papers to help them make decisions about implementation.

As a result of STIC efforts, some 50 initiatives are in the deployment phase or in the works with the technical advisory groups. Several are already making a difference on Pennsylvania roads.

For example, Pennsylvania has constructed 10 bridges using geosynthetic reinforced soil–integrated bridge system technology, which combines alternating layers of compacted granular fill and geotextile sheets to support bridges. The technology enables agencies to build bridges more quickly and at a lower cost, from 25 to 60 percent less than conventional construction methods.

Pennsylvania also is using several SHRP2 Solutions. PennDOT, for example, is applying tools and techniques to manage risk in rapid renewal projects (R09), such as on its proposed Potters Mills Gap project to improve a section of U.S. 322 in Centre County. The agency also is implementing railroad-DOT mitigation strategies (R16) that streamline the permitting processes and support rapid decisionmaking to reduce delays on highway projects in the vicinity of railways.

According to former Pennsylvania Secretary of Transportation Barry Schoch, the State is putting these innovations into mainstream practice to enhance safety and reduce costs, project delivery time, and construction congestion. "The faster we can get innovations into action, the better," he says, "because it demonstrates that the industry is pushing hard to best use taxpayer dollars and make the transportation system better."

Creating an Innovative Culture

With the help of coordinated programs to advance innovation, the Nation's transportation community has adopted many new technologies and processes to solve transportation challenges and established the foundation for a culture committed to innovation. The key to the success of this effort is the national leadership from AASHTO, FHWA, and TRB, combined with a State-based approach. The State-based approach enables DOTs and their partners to determine how to use innovation for maximum benefit, and it has fostered the creation of State groups that involve stakeholders in turning innovations into everyday practices.

"The State-based approach has led to the development of a national network of transportation professionals skilled in the rapid deployment of innovation," says U.S. Deputy Secretary of Transportation Victor Mendez, who launched EDC when he was FHWA administrator. "We have an ambitious goal, which is to change the culture of the transportation community to one that embraces innovation as the standard way of doing business."

Jeffrey F. Paniati, P.E., is executive director of FHWA and serves as the agency's chief operating officer. A 30-year veteran of FHWA, he also worked as associate administrator for operations. He earned a bachelor's degree in civil engineering from the University of Connecticut and a master's degree in civil engineering from the University of Maryland.

Frederick G. "Bud" Wright is executive director of AASHTO. Before becoming a transportation policy consultant, Wright spent 33 years with FHWA in various posts, including executive director. He has a bachelor's degree in economics from Virginia Polytechnic Institute and State University.

For more information, contact Jeffrey Paniati at jeffrey.paniati@dot.gov, or Bud Wright at bwright@aashto.org.

All photos are from entries in AASHTO's 2014 America's Transportation Awards. For more information, visit http://americastransportationawards.org/2014-entries.

Oregon DOT

The Oregon Department of Transportation constructed this Willamette River Bridge along I–5 between Eugene and Springfield. The project employed an innovative management method called construction manager/general contractor, in which the agency had the design firm and contractor on board at the same time so that the construction contractor informed the designer during the design process.

Leading with *Innovation* at the Helm

Kentucky uses practical, right-sized solutions to meet its transportation needs. Check out the benefits—they're significant.

by Michael W. Hancock

(Above) This rendering shows the new Downtown Crossing bridge for I–65 northbound traffic between Louisville, KY, and Jeffersonville, IN. It is adjacent to the John F. Kennedy Memorial Bridge, which now carries I–65 and will carry I–65 southbound upon project completion. KYTC and INDOT used innovative solutions to reduce costs and shorten project delivery time. *Photo: Louisville-Southern Indiana Ohio River Bridges Project.*

Innovation leadership is a mindset rooted in a desire for continuous improvement at the Kentucky Transportation Cabinet (KYTC), the Commonwealth of Kentucky's transportation department. As the cabinet seeks to satisfy the needs of transportation customers, innovation leaders throughout the agency strive to be more efficient across the spectrum of transportation programs it delivers.

KYTC is responsible for overseeing the development and maintenance of a safe, efficient, multimodal transportation system throughout the Commonwealth. The cabinet manages more than 27,000 miles (43,450 kilometers) of highways, provides direction for 230 licensed airports and heliports, and oversees licensure for motor vehicles and for more than 3 million drivers.

To improve the quality of these facilities and services while using transportation dollars more efficiently, KYTC embarked on a journey more than 10 years ago that focuses on customer service, visionary leadership, performance measurement, and management by fact (that is, measuring and analyzing performance data to guide decisionmaking). Using these principles, KYTC has successfully implemented customer-oriented, innovative solutions—from development of a customer service center in the Department of Vehicle Regulation to incorporation of nonemergency Medicaid transportation services into transit programs. In addition, the cabinet has developed ways to promote and assist with rail, waterway, and aviation projects despite limited funding for nonhighway programs.

Within KYTC's highway programs, the application of quality principles to both services and products led the cabinet to embrace context-sensitive solutions. Over the years, the agency expanded context-sensitive solutions to become "practical solutions," in which it considers project cost a primary context. Through practical solutions, KYTC has been able to improve the quality of projects by right-sizing them to address their intended purpose appropriately.

The application of practical solutions, such as those associated with the second Strategic Highway Research Program (SHRP2) or the Federal Highway Administration's Every Day Counts initiative to accelerate innovation deployment and cut project delivery times, is manifested in Kentucky's highway program in many ways. What follows are examples of innovations that KYTC has implemented in recent years as the cabinet sought practical solutions for all projects, regardless of size.

Ohio River Bridges

For nearly 40 years, Kentucky and Indiana sought to complete an eastern highway loop around metropolitan Louisville, KY, by constructing an east-end crossing over the Ohio River and connecting I–265 in Kentucky with I–265 in Indiana. Then, in 2003, the National Environmental Policy Act process for the proposed project yielded a record of decision that included both a new East End Bridge and the reconstruction of the I–65 downtown crossing and its companion I–65/I–64/I–71 Kennedy Interchange on the Kentucky side of the river in Louisville. Linking the two major projects was deemed essential to the defined purpose of the project, which was to enhance cross-river mobility in the region. Accordingly, the focus became "two bridges, one project," and the year-of-expenditure cost estimate for the total project was $4.1 billion.

In late 2011, KYTC applied the practical solutions metric and trimmed more than $1.1 billion from the Kentucky portion of the project. The savings was accomplished primarily by scaling back the single

Construction of the new I–65 cable-stayed bridge is shown here well underway in downtown Louisville, KY, with the older steel truss bridge behind the new structure.

Louisville-Southern Indiana Ohio River Bridges Project

Keith Todd, KYTC

In January 2012, a span of the U.S. 68/KY–80 bridge over Kentucky Lake was destroyed in a late-night collision involving an ocean-going vessel navigating the Tennessee-Tombigbee Waterway.

most costly section of the project—reconstruction of the Kennedy Interchange. Rather than building a new interchange, the cabinet decided to reconstruct the existing interchange, essentially softening its curves and reducing the severity of traffic weaves. Further savings came from eliminating a flyover ramp on the Indiana approach and relocating pedestrian/bicycle access to an adjacent unused railroad bridge.

KYTC also worked with the Indiana Department of Transportation (INDOT) and FHWA to further decrease the $4.1 billion cost of the overall project to $2.6 billion by reducing the width of the new East End Bridge from six travel lanes to four, but with sufficient right-of-way to allow for expansion to six lanes by restriping. KYTC and partners reasoned that four lanes would meet traffic demands for several years. They also envisioned a design-build approach to shorten the completion timetable from 2024 to 2018.

The two States ultimately decided to bifurcate the procurement process for financing, with Kentucky procuring the $1.3 billion downtown portion and Indiana procuring the $1.3 billion east-end portion.

Indiana used a public-private partnership with an availability payment mechanism on the East End Bridge. Under an availability payment system, the public sponsor makes periodic payments to the private concessionaire on the condition that the facility meets defined performance specifications.

Kentucky used nonrecourse toll revenue bonds and bond anticipation notes sold through the Kentucky Public Transportation Infrastructure Authority, with no State-supported backstop for debt. Kentucky also was successful in obtaining a $452.2 million Transportation Infrastructure Finance and Innovation Act loan to round out its financial package.

When the two design-build procurements were completed in November 2012, the result was an even further reduced total project cost of $2.3 billion—$1.8 billion less than the original $4.1 billion cost—and a further improved project completion date of December 2016, 8 years ahead of the initial schedule.

The two States and FHWA intertwined their innovative procurement and financing processes to produce this result. In addition, both then Indiana Governor Mitch Daniels and Kentucky Governor Steve Beshear, who jointly led the cooperative effort, were essential to getting the project done.

Both Ohio River bridges and approaches are proceeding on schedule to be finished in late 2016. Upon completion of the project, the agencies will apply tolling equally at each bridge location. The tolling proceeds will be combined and split equally as well—half to Kentucky, half to Indiana—to provide the necessary revenue streams to support both States' financial packages.

The technical and financial innovations used in the Ohio River Bridges Project yielded positive results (such as drastically reduced cost and timeframe for completion), but they were not the only innovations applied to the project. Other initiatives included creation of a minority workforce development program, Bridges to Opportunities. The program set up a partnership of contractors and trade unions with local and Commonwealth agencies and educators to develop a trained minority workforce that could be hired for construction projects now and in the future. The innovative partnership that formed Bridges to Opportunities provides avenues for employment that were previously unavailable to the local people.

Milton-Madison Bridge

The U.S. 421 bridge over the Ohio River between Milton, KY, and Madison, IN, is another example of bistate cooperation and applied innovation. The 1930s-era bridge underwent major rehabilitation in 1997, but in 2009 it was necessary for KYTC to post a 15-ton (13.6-metric-ton) weight limit. The need for a replacement span became clear.

Recognizing that time was a factor, the two States and the communities of Milton and Madison agreed that the replacement bridge should remain in the same location. Again applying the principles of practical solutions and Every Day Counts, KYTC proposed that the existing piers be used for the new bridge, if possible, eliminating the need to build new piers in the river. After verifying that the old piers were suitable for use, KYTC made plans to strengthen them and close the Milton-Madison U.S. 421 crossing for 1 year while

it removed the old structure and constructed a new, wider bridge on the strengthened piers.

Using INDOT's design-build authority, the two States let the project to construction. The winning contractor proposed building a 2,428-foot (740-meter)-long superstructure on temporary piers next to the old bridge and then sliding the new bridge onto the strengthened permanent piers. Surprisingly, the cost of this approach was lower than the proposed costs of other bidders. Also, using the bridge slide approach, the contract required that the U.S. 421 Milton-Madison river crossing be closed for only 10 days instead of 1 year. The bridge slide project would be the longest ever undertaken in North America.

Although construction circumstances dictated that the actual bridge closure was 41 days rather than 10 days, it still represented a considerable improvement over the original estimate. Reopened to traffic in April 2014, the project is a testament to both practicality and innovation as the partners worked seamlessly to minimize the disruption that a longer bridge closure would have caused for local road users.

Kentucky Lake Bridge

In western Kentucky, U.S. 68/KY–80 extends through the Land Between the Lakes National Recreation Area, a well-known destination for sportsmen and vacationers. On a late evening in January 2012, an ocean-going vessel using the Tennessee-Tombigbee Waterway to haul rocket parts from Decatur, AL, to Cape Canaveral, FL, struck a span of the 3,495-foot (1,065-meter)-long Kentucky Lake bridge. A 322-foot (98-meter)-long span of the 83-year-old bridge collapsed in seconds. The incident did not cause any injuries or fatalities, but it did necessitate a 42-mile (68-kilometer) detour around the closure and severely threatened the viability of the summer tourist season for the region.

Once KYTC determined the extent of the damage, the cabinet developed a design and replacement project to build a new span onto the existing structure. Using innovative construction techniques (including prefabricated elements), the contractor assembled the span at the Eddyville, KY, river port and floated it upstream to the bridge site. There, the contractor lifted the span into place on May 15, and the bridge opened to traffic on May 25, 3 days before Memorial Day, which was the start of the 2012 recreational season at the Land Between the Lakes. When the Governor initially announced the construction timetable to complete the project by Memorial Day, local road users cheered. Through its innovative and practical approach, KYTC succeeded in reopening the Kentucky Lake bridge in just 4 months.

High-Friction Surface Treatment

Roadway departure incidents account for nearly 70 percent of crashes on Kentucky highways. Because these crashes are frequently severe and may lead to injury or death, KYTC has made it a top priority to identify and treat those areas where they occur most often. Over recent years, KYTC has applied high-friction surface

KYTC constructed the new replacement span on land, floated it to the bridge site, lifted it into place, poured the concrete deck, and reopened the U.S. 68/KY–80 Kentucky Lake bridge to traffic before Memorial Day 2012.

Keith Todd, KYTC

treatments (HFST) to numerous horizontal curves where crash data indicated that enhanced skid resistance may help to reduce crashes.

KYTC also installed HFST to address rear-end crashes. In one example, at the intersection of U.S. 25 and KY–1629 in Knox County, KYTC applied the friction treatment only in the southbound lane of U.S. 25, which has a downhill approach to the KY–1629 intersection. During the 3 years before the installation, there were 6 wet-weather crashes and 27 dry-weather crashes—an average of 11 crashes a year—at this location. Most were rear-end crashes. During the 16 months after the installation, the location saw a decrease in crashes to 2 wet-weather crashes and 5 dry-weather crashes, an average of 5.38 crashes a year.

Another HFST project addressed a horizontal curve on KY–22 in Oldham County that had a higher-than-average crash rate. Before the installation of the HFST, the location saw 53 wet-weather crashes and 3 dry-weather crashes over a 3-year period, an average of 18.67 crashes a year. In just over 3 years after KYTC applied the HFST treatment, 5 wet-weather crashes and no dry-weather crashes occurred, an average of 1.57 crashes a year.

KYTC considers its use of this technology a success based on observed decreases in crash rates at the vast majority of locations where KYTC applied HFST.

Warm-Mix Asphalt

KYTC also demonstrated innovative leadership when it partnered with the Plantmix Asphalt Industry of Kentucky to adopt warm-mix asphalt (WMA). WMA is produced and installed at lower temperatures than traditional hot-mix asphalt. By producing a product that is of equal or greater quality while using less energy, contractors are able to help KYTC deliver pavement surfaces in a more environmentally sound manner. In addition, the ability to haul WMA for longer distances has increased pavement quality for some of the most rural areas of Kentucky and has improved the density of the asphalt mix, leading to more durable pavements. The organizations worked together to integrate the technology quickly to the benefit of both contractors and the public.

Widespread use of WMA began in Kentucky in 2008, when KYTC applied about 160,000 tons (145,000 metric tons). Annual quantities of WMA have steadily increased since then, with more than 4.1 million tons (3.7 million metric tons) of WMA applied in 2013.

Kentucky now embraces WMA as a standard specification and allows several methods of producing the asphalt, including the water-injection method to create asphalt foaming and the use of chemical additives. In 2014, more than 50 percent of the asphalt applied to the Commonwealth's highway system was WMA.

The benefits of use in Kentucky include reduced emissions and burner fuel use at asphalt plants, higher levels of asphalt mix density, and the ability to pave in cooler weather and to haul the mix over longer distances. WMA also provides a benefit to workers: The mix can be worked at a cooler temperature, a plus for crews in close proximity to the asphalt paving operation.

SHRP2 Product Implementation

KYTC is using opportunities presented by SHRP2 to bring new technologies and concepts to the Commonwealth. KYTC applied for implementation assistance for SHRP2 products through FHWA and the American Association of State Highway and Transportation Officials and is deploying those products on Kentucky projects. The products touch many KYTC processes, from planning with reliability data and analysis tools to maintenance and preservation.

With the help of the SHRP2 Innovative Bridge Designs for Rapid Renewal (R04) product, KYTC is working with its District 11 office to evaluate the use of an innovative bridge design in Knox County on KY–6 at the Stewarts Creek Bridge. Using accelerated construction techniques will enable KYTC to reduce closure time on small structure replacements by 75 percent or more, minimizing the effect on the traveling public.

The use of high-friction surface treatments, as shown on this two-lane road, has become widespread in Kentucky where slippery pavements have been a contributing factor in roadway departure crashes. As a result, crashes have decreased dramatically at the treated locations.

KYTC

KYTC also is evaluating new ways to backfill behind bridge end bents and abutments to ensure maximum long-term stability through the SHRP2 GeoTech Tools (R02) product. Through use of this product, KYTC is considering methods to minimize pavement settlement at bridge ends. Improving the stability of these areas will reduce costly periodic maintenance for resurfacing and will improve performance for the traveling public by eliminating "bumps" at the start and end of bridges.

Using Pavement Renewal Solutions (R23), KYTC plans to evaluate methods for keeping existing pavement structures in place when constructing rehabilitation and renewal projects. One method the cabinet will consider is the use of a paving grid as a crack-relieving interlayer. This method would enable KYTC to use the existing pavement structure instead of rebuilding the roadway from the subgrade to the surface. Quantifying the benefits of this and other techniques will help KYTC maximize the effectiveness of limited rehabilitation dollars.

In addition, through the Identifying and Managing Utility Conflicts (R15B) product, KYTC will incorporate a utility conflict matrix into the Kentucky Utilities and Rail Tracking System. The matrix will provide a centralized venue for project-specific data sharing between affected agencies and utility companies. Reducing utility delays and associated costs for project delivery will result in faster delivery of critical transportation projects.

KYTC also plans to use Reliability Data and Analysis Tools (L02/L05/L07/L08/C11) to evaluate the reliability of key transportation corridors in three areas in Kentucky. By implementing these products, KYTC will evaluate proposed solutions to congestion and reliability challenges that have the potential to increase efficiency for road users.

Lastly, KYTC is evaluating six preventive maintenance products to develop guidelines for preservation activities on high-volume roadways by using the *Guidelines for the Preservation of High-Traffic Volume Roadways* (R26) product. Preventive maintenance treatments can extend the service life of the Commonwealth's infrastructure, making efficient use of limited financial resources, as well as reducing traveler delays from construction activities.

Keys to Success in Innovation

Inspire innovation throughout the entire organization. Innovation cannot be limited to one specific area or office. Employees across the entire spectrum should be encouraged to find a better way to do things and then celebrated when they do. The need for innovation must be built into the organization's business strategies, reflecting that this is a basic principle of operation.

Have an engaged leadership. Organization leaders cannot simply announce that they support innovation. They have to live it as an example to others. They have to actively, constantly look for opportunities to show their support for innovation.

Understand the customer. Realize that innovation will only be good for the organization if it is ultimately good for the customer. Learn as much as possible about the customer, either through formal surveys and polls, or through email, letters, phone calls, and other communications received from customers. Also, when implementing an innovation that will benefit them, let customers know about it through various communication channels.

Partner with other individuals and organizations. Doing so can often bring about change much faster. The more people who are using an innovation, the faster it will reach the tipping point and become a standard practice. Getting others involved in championing an innovation will supercharge the efforts.

Take advantage of the experience and support of others. Find someone who has already used an innovation that the organization is considering, and learn from his or her experience. Ask him or her to talk frankly about what worked and also about any difficulties encountered along the way.

Overcome resistance to change. Be prepared to deal with resistance and do not get discouraged when change does not happen overnight. With patience and persistence, people will begin to embrace the idea of change and to see its benefits.

Looking Ahead

As KYTC looks to the future, the cabinet will continue to seek value in practical solutions. The successful implementation of more efficient and innovative tools and processes has enabled the agency to demonstrate the delivery of timely, quality projects to the public, Commonwealth legislature, and members of the U.S. Congress.

KYTC is working to develop performance metrics that will assist the cabinet in communicating needs and successes to the public. Growth in public trust will help ensure that the agency is able to allocate resources to projects that are critical to maintaining, reconstructing, and widening roads and bridges; managing traffic through intelligent transportation system technologies; and adding roadways where there is technical and community consensus to do so.

Whether the cabinet uses the Kentucky Public Transportation Infrastructure Authority to pursue other toll revenue-based megaprojects, such as the I-75/I-71 Brent Spence Bridge between Covington, KY, and Cincinnati, OH, or it seeks innovative ways to deliver off-system bridge replacement projects more efficiently through the expedited bridge replacement program, it will do so with a desire for constant improvement. Because at KYTC, innovation leadership is a mindset.

Michael W. Hancock, P.E., is Secretary of the Kentucky Transportation Cabinet and immediate past president of AASHTO. His experience with KYTC includes 10 years in rural and urban transportation planning, 10 years leading the cabinet's program management function, and 8 years as deputy State highway engineer for program planning and management. In addition, Hancock currently serves as chairman of the AASHTO Standing Committee on Planning and as a member of the Executive Committee of the Transportation Research Board.

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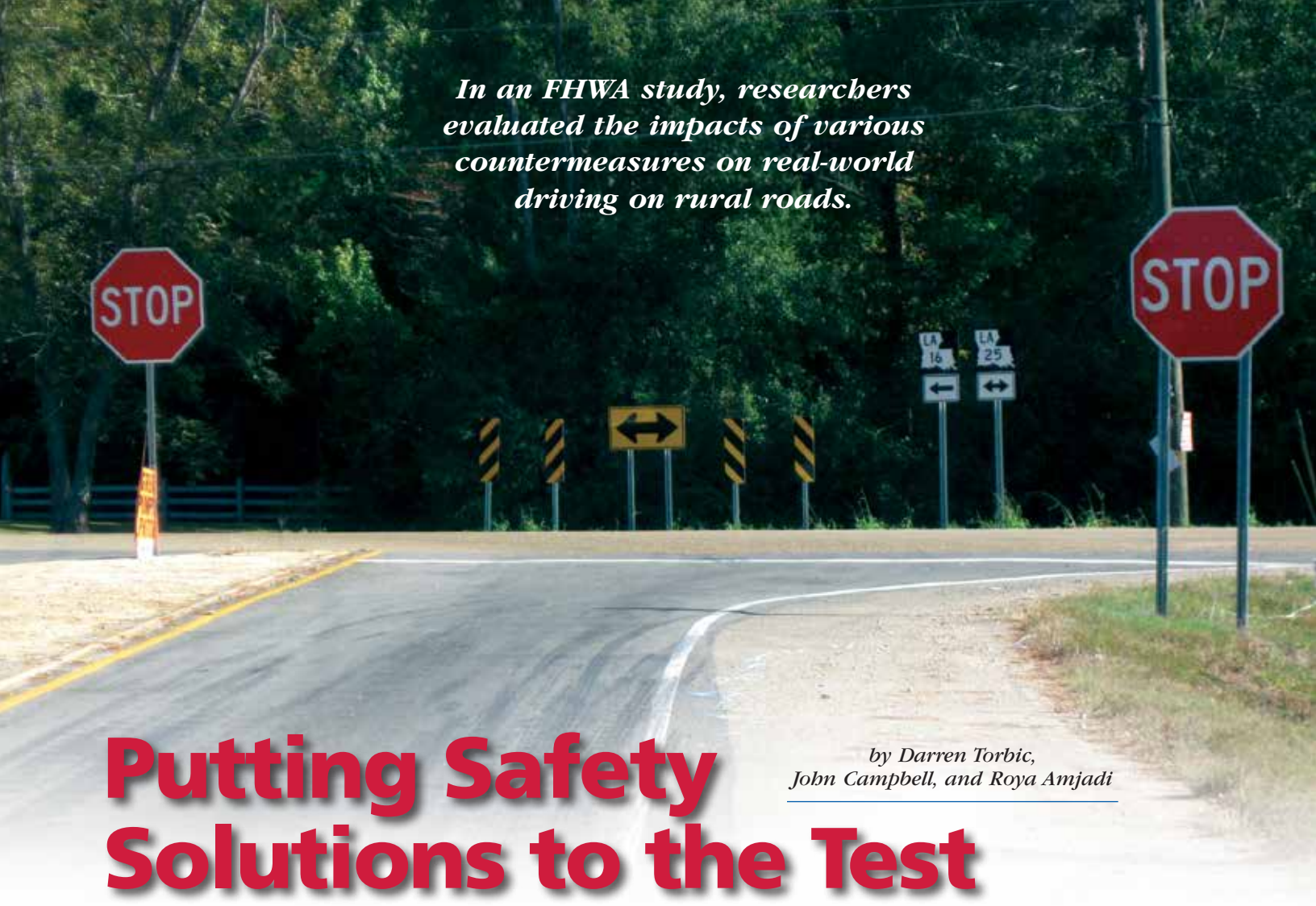

In an FHWA study, researchers evaluated the impacts of various countermeasures on real-world driving on rural roads.

Putting Safety Solutions to the Test

by Darren Torbic, John Campbell, and Roya Amjadi

Of the 8.7 million lane-miles of roads in the United States, more than 6 million are rural. Almost 71 percent of the lane-miles of rural roads are owned and operated by local entities, making the sharing of highway safety information with local officials and the public critical to improving safety on rural roads nationwide.

Rural areas face a number of distinct safety challenges. Rural crashes are more likely to involve vehicles traveling at higher speeds than urban crashes. Victims of fatal crashes in rural areas are more likely to be unbelted than their urban counterparts, and it often takes first responders longer to arrive at the scene of a rural crash, leaving victims waiting longer for medical attention. Outdated roadway designs and roadside hazards such as utility poles, sharp-edged pavement dropoffs, and trees close to the roadway also are major contributors to the severity of crashes in rural areas.

According to the latest data from the National Highway Traffic Safety Administration's Fatality Analysis Reporting System (FARS), the fatality rate for rural crashes is statistically higher than that of urban crashes. Specifically, NHTSA reports that from 2010 to 2012, 48,852 people were killed in rural motor vehicle crashes (an average of 16,284 per year), accounting for 54 percent of motor vehicle fatalities that occurred on both urban and rural roads.

To address these challenges, the U.S. Department of Transportation launched the Rural Safety Initiative in 2008 as a comprehensive way to help State and local leaders raise awareness of highway safety issues and implement solutions in rural areas more quickly. As part of this initiative, the Federal Highway Administration launched the Rural Safety Innovation Program in February 2008 as a one-time opportunity for rural communities to compete for project funding to address safety problems. The program encouraged rural communities to develop creative, locally crafted solutions to their roadway safety problems, document their efforts and outcomes, and share the results with other communities across the country.

In August 2008, USDOT awarded $14.7 million to 14 States, 3 counties, and 2 parishes under the Rural Safety Innovation Program. The funds were drawn from the Delta Region Transportation Development Program (the Delta Program) and USDOT's Intelligent Transportation Systems (ITS) program.

(Above) Louisiana installed enhanced signing, such as the duplicate STOP signs at this three-legged intersection on a rural road, under the Rural Safety Innovation Program. *Photo: MRIGlobal.*

MRIGlobal

Louisiana installed this advance STOP sign ahead of a three-legged intersection as part of the Rural Safety Innovation Program.

What follows is an assessment of the effectiveness of nine highway safety improvement projects implemented in eight States as part of the Rural Safety Innovation Program under the Delta Program. The Delta Program supports transportation development efforts in Alabama, Arkansas, Illinois, Kentucky, Louisiana, Mississippi, Missouri, and Tennessee. Also included is an in-depth look at projects from two of those States: Mississippi and Missouri. The assessments help shed light on the types of analysis that are appropriate for evaluating the effectiveness of projects to improve highway safety on rural roads.

Assessing the Effectiveness Of Safety Improvements

Nine transportation agencies implemented safety improvement projects in eight States as part of the Delta Program. In general, the agencies identified high-risk locations such as curves and intersections for safety improvements based on crash data and local knowledge. They then selected and installed countermeasures that they believed would be effective and appropriate for systemic implementation.

FHWA's research objective was to evaluate the effectiveness of these projects, but doing so depended upon the availability of data and the nature of the projects. The Arkansas State Highway and Transportation Department, for example, installed cable median barriers on various rural sections of several interstate highways to reduce the number and severity of crashes related to crossing over the median. The FHWA researchers could use available crash statistics to evaluate the effectiveness of the project.

"A statistical review of the number of crashes and fatalities or serious injuries that took place in past years revealed that installing cable median barriers is a promising crash countermeasure," says Mojtaba Mohammadi, a traffic safety engineer at the Arkansas State Highway and Transportation Department. "A decreasing trend was observed in the number of fatalities and severe injuries from 2009 to 2012, the period when crash statistics were examined."

After an initial assessment of all nine projects, the researchers selected three for detailed quantitative evaluations (Illinois, Louisiana, and Mississippi), and one for a simpler quantitative analysis (Arkansas), because it lacked a sufficient number of treatment sites and mileage. Two projects were more suited to a qualitative, rather than quantitative, analysis (Missouri and Tennessee), focusing on lessons learned by the agencies during implementation. The three remaining projects (two Louisiana parishes and one county in Mississippi) were excluded from the evaluation due to insufficient data or challenges in preparing the data for analysis.

Methodology for the Study

The researchers first contacted the nine State and local highway agencies involved to gain a detailed understanding of each project and discuss implementation of the safety countermeasures. The team also identified specific evaluation opportunities, discussed the availability of data for use in its analyses, and identified key contacts within each agency for data requests.

The next step was to develop an evaluation plan for each project. The researchers planned to evaluate the differences in crash frequency and severity before and after specific countermeasures were installed under the Rural Safety Innovation Program. To estimate the safety effectiveness of these projects objectively, the researchers employed Empirical Bayes statistical method. This method makes use of before and after crash data and safety performance functions to estimate the safety effectiveness of a treatment, accounting for factors that change over time, such as traffic volume and weather. A safety performance function is an equation used to predict the average number of crashes per year at a location as a function of exposure and, in some cases, roadway or intersection characteristics (such as number of lanes, traffic control, and median type).

The researchers obtained data on crashes, traffic volumes, roadway characteristics, and countermeasures from project personnel, electronic databases, aerial mapping tools, and field visits. Using this data, the research team estimated the safety effectiveness of treatments installed under the Rural Safety Innovation Program by applying the following steps:

1. Calculated predicted crash frequencies for the treatment sites for the period prior to installation, using existing safety performance functions found in the *Highway Safety Manual* and the "Safety Analyst" software tools, both of which were developed by the American Association of State Highway and Transportation Officials with the help of the Transportation Research Board and FHWA.

Countermeasures Evaluated Under the Rural Safety Innovation Program – Project Evaluation

Agency	Countermeasure	General Site Attributes	Type of Evaluation
Arkansas State Highway and Transportation Department	Cable median barrier on an interstate highway	Rural interstate	Simpler quantitative
Grant Parish, LA	Striping, rumble strips, raised pavement markers, flashing beacon warning signs, large arrow signs, chevrons, and other warning signs	Rural two-lane roads	Not evaluated
Hinds County, MS	Signing, striping, and rumble strips	Rural two-lane roads	Not evaluated
Illinois Department of Transportation	Advance curve warning signs, speed plates, chevrons, and raised pavement markings	Horizontal curves on rural two-lane roads	Detailed quantitative
Louisiana Department of Transportation and Development	Signing and marking improvements at intersections	Intersections on rural roads	Detailed quantitative
Mississippi Department of Transportation	Centerline rumble strips and clear zone restoration	Rural two-lane roads	Detailed quantitative
Missouri Department of Transportation	Dynamic message signs on interstate highways	Rural interstates	Qualitative
Rapides Parish, LA	Striping, rumble strips, raised pavement markers, flashing beacon warning signs, large arrow signs, chevrons, and other warning signs	Rural two-lane roads	Not evaluated
Tennessee Department of Transportation	Signing inventory/assessment system	Rural State highways	Qualitative

Source: FHWA's Delta Region Transportation Development Program: Rural Safety Innovation Program Evaluation Final Report.

2. Combined those figures with observed crashes during the period prior to installation using a weighted average to calculate an expected crash frequency for the treatment sites prior to installation.
3. Calculated the expected crash frequency had the treatment not been applied by adjusting the expected crash frequency before installation for differences in duration and traffic volumes between the before and after periods.
4. Compared the expected crash frequency had the treatment not been applied to the observed crash frequency after installation to assess the safety effectiveness of the treatment.

For projects that did not lend themselves to a detailed quantitative analysis using the Empirical Bayes method, the researchers either applied a simpler before and after comparison or qualitatively evaluated data from available reports and interviews with project personnel.

"Ideally we would like to have as much high-quality data as possible so we can conduct quantitative safety analyses using approaches like the Empirical Bayes method," says Monique Evans, who is director of the Office of Safety Research and Development at FHWA's Turner-Fairbank Highway Research Center. "However, in the absence of ideal data conditions, we can still learn a lot from some quantitative analyses that use limited data and from qualitative assessments."

The researchers' qualitative evaluations included analysis of lessons learned from projects in Tennessee and Missouri to develop a sign inventory system and install dynamic message signs and closed-circuit video, respectively. Researchers asked personnel involved in the projects whether the countermeasures improved safety and operations and helped them better manage incidents. They also asked questions about implementation: How did the agencies implement the countermeasures? Did they encounter any challenges?

Overall, many of the projects examined did improve safety on rural highways. Projects implemented by the Mississippi and Missouri departments of transportation highlight these outcomes and serve as examples of the research team's quantitative and qualitative evaluations.

Mississippi Applies Centerline Rumble Strips

The Mississippi Department of Transportation (MDOT) received funding through the Rural Safety Innovation Program to implement two types of safety improvements along rural State highways. The first was installation of centerline rumble strips. The second was restoration of a clear zone, which included removing roadside objects, regrading side slopes, and installing cable barriers along about 5 miles (8 kilometers) of roadway. These improvements focused on reducing the number and severity of lane departure crashes.

MDOT installed approximately 350 miles (563 kilometers) of centerline rumble strips under the program. Many of the target locations already had shoulder rumble strips that had themselves, in most cases, been installed within 1–2 years of deploying the new centerline rumble strips.

Analysis. Because the project to restore the clear zone covered only a few miles of roadway, the researchers decided to focus their evaluation on the effectiveness of installing the centerline rumble strips. They evaluated locations, referred to as treatment sites, where MDOT had installed centerline rumble strips on routes that also had shoulder rumble strips. In addition, the research team analyzed data for nontreatment sites: stretches of rural two-lane highway that had geometrics and traffic volumes similar to the treatment sites but had no rumble strips of any kind during the entire analysis period.

Next the researchers compared data from years prior to the installation of either the shoulder or centerline rumble strips against data from years after the installation of the

Statistics Before and After Countermeasures Implemented in Mississippi

Site No.	Number Of Segments Per Site	Total Site Length (mi)	Before Period					After Period				
			Number Of Years	Average AADT	Total Crashes*	Fatal And All Injury Crashes	Fatal And Serious Injury Crashes	Number Of Years	Average AADT	Total Crashes	Fatal And All Injury Crashes	Fatal And Serious Injury Crashes
1	3	6.1	4	1,742	3	3	1	3	1,333	2	2	2
2	1	3.5	4	2,000	0	0	0	3	1,300	0	0	0
3	3	7.1	4	1,567	11	10	1	3	1,589	5	4	1
4	4	11.3	4	3,338	16	10	4	3	2,792	5	1	1
5	2	5.0	3	4,633	10	7	4	3	4,333	3	1	0
6	4	15.0	1	2,650	13	8	1	3	3,050	14	7	0
7	2	8.6	4	2,338	9	6	0	3	2,267	3	0	0
8	2	9.0	1	2,700	3	1	1	3	1,850	5	4	4
9	1	4.1	1	3,500	0	0	0	3	3,000	0	0	0
10	1	4.0	4	238	7	5	0	3	190	6	4	0
11	2	6.4	4	1,413	24	12	1	3	1,417	20	12	2
Total	**N/A**	**80.1**	**N/A**	**N/A**	**96**	**62**	**13**	**N/A**	**N/A**	**63**	**35**	**10**

**Crash types include only single vehicle run-off-road crashes (right or left), sideswipe-opposite direction crashes, and head-on crashes.*
Source: FHWA's Delta Region Transportation Development Program: Rural Safety Innovation Program Evaluation Final Report.

centerline rumble strips. Crash data were generally available from 2005 to 2012; the team excluded from analysis crashes that occurred during the treatment installation year or years.

The researchers calculated the annual average daily traffic (AADT) for each site and year as the average of the AADTs of the segments within each site-year. The team then averaged these AADTs over the before and after years, respectively, for each site.

Comparing before-and-after crash data from 11 treatment sites and 8 nontreatment sites, along with Safety Analyst's safety performance functions for rural two-lane roads, the researchers applied the Empirical Bayes method to estimate the safety effectiveness of applying both centerline and shoulder rumble strips in reducing the target collision types. The target types included single vehicle run-off-road crashes (right or left side of the road), sideswipe-opposite direction crashes, and head-on crashes. The researchers performed separate analyses for total crashes, fatal and all injury crashes, and fatal and serious injury crashes.

Results. The safety effectiveness estimates, which showed a 35-percent reduction in total crashes and a 39.6-percent reduction in fatal and all injury crashes, were statistically significant at a 95-percent confidence level. The estimate for fatal and serious injury crashes, however, showed a 12.3-percent increase that was not statistically significant at a 90-percent confidence level and had a standard error of 39.4 percent. The high standard error of that treatment, which caused a statistically insignificant result for fatal and serious injury crashes, was due to the low number of fatal and serious injury crashes observed at the treatment sites: Only 13 fatal and serious injury crashes occurred in the years prior to the treatment, and 10 fatal and serious injury crashes occurred in the period after treatment.

Conclusions. The dual application of centerline and shoulder rumble strips on rural two-lane roads resulted in a decrease in single vehicle run-off-road, sideswipe-opposite direction, and head-on crashes. The treatment also resulted in a 35-percent reduction (standard error of 10.5 percent) in total target crashes and a nearly 40-percent reduction

Safety Effectiveness of Countermeasures in Mississippi

Crash* Type (Severity)	Number of Treatment Sites	Total Site Length (mi)	Safety Effectiveness (%)	Standard Error Of Treatment Effect (%)	Significance
Total	11	80.1	-35.0	10.5	Significant at 95% confidence level
Fatal and All Injury	11	80.1	-39.6	12.3	Significant at 95% confidence level
Fatal and Serious Injury	11	80.1	12.3	39.4	Not significant at 90% confidence level

**Crash types include only single vehicle run-off-road crashes (right or left), sideswipe-opposite direction crashes, and head-on crashes.*
Source: FHWA's Delta Region Transportation Development Program: Rural Safety Innovation Program Evaluation Final Report.

University of Missouri

Using funds from the Rural Safety Innovation Program, Missouri installed dynamic message signs like this one to provide realtime information to the traveling public.

(standard error of 12.3 percent) in fatal and all injury crashes.

Though these results seem promising, more quantifiable analysis is needed to determine the safety effectiveness of individual treatments installed in combination. Multiplying the crash modification factor (CMF)—a multiplicative factor used to compute the expected number of crashes that might occur after implementing a given countermeasure at a specific site—of individual countermeasures to estimate the combined CMF could overestimate the effectiveness of countermeasure combinations.

Missouri Uses Dynamic Message Signs and Closed-Circuit Video

In 2005, the Missouri Department of Transportation (MoDOT) began its Smooth Roads Initiative, which included improvements to many thousands of miles of the State's most heavily traveled roadways. To help manage the many construction projects, MoDOT used 40 portable changeable message signs to share information with motorists traveling along three rural highways, including rural interstates.

Recognizing the benefits of the signs, MoDOT decided to seek a more permanent solution for providing realtime information to the traveling public. The agency began a program of installing dynamic message signs and closed-circuit television cameras around the State. In case of an incident, MoDOT can use the cameras to verify the location and severity of the crash and help reduce emergency response times. The agency can employ the signs to warn motorists and direct them to bypass routes when incidents block major roads.

MoDOT received funding from the Rural Safety Innovation Program to install 6 dynamic message signs, upgrade fiber-optic connectivity between the signs, and install 13 closed-circuit TV cameras to relay information to the traffic management center in St. Louis. The agency installed the signs and cameras along I–57, I–55, and U.S. 60. Crews placed the signs upstream from key decision points so that drivers have ample time to change their travel plans based on the information.

The signs display messages 24 hours a day, 7 days a week. Messages may include information about crashes and other traffic-related incidents, work zones, detours, AMBER alerts, weather and pavement conditions, and other emergency information. When no such messages are needed, the signs display public service announcements related to highway safety, such as reminding motorists to buckle up or not to text and drive.

The cameras offer a continuous source of realtime surveillance of the transportation system, enabling MoDOT staff to monitor traffic and weather conditions, assess the impacts of crashes and construction on traffic flow, and manage incidents.

"The installation of closed-circuit TV cameras in rural parts of the State has significantly increased MoDOT's ability to quickly assess and respond to events as necessary," says Jon Nelson, a traffic management and operations engineer with MoDOT. "Benefits range from active monitoring of traffic backups to remote assessments of road conditions during inclement weather."

The rural dynamic message signs have improved the agency's communications with motorists too. Nelson continues, "The signs allow MoDOT to reach motorists with realtime, relevant traveler information. The signs can improve safety by providing advance warning of slowed or stopped traffic resulting from an incident or roadwork. They can also provide information that motorists may find helpful, such as detour routes or expected adverse weather conditions."

Results. MoDOT hired researchers at the University of Missouri in Columbia, MO, to conduct a formal evaluation of some of the signs deployed along the target roadways. Their evaluation drew from the results of three studies. The first surveyed motorists in person at two truck stops in the study region. Motorists were asked about sign visibility, message clarity and accuracy, the perceived effect of the signs on safety, and whether the driver took action (such as slowing down or changing his or her route) based on the sign's message. Overall, the surveyed motorists seemed to be very satisfied with MoDOT's use of dynamic message signs in rural areas, and 94 percent said they took the action suggested by the signs.

In the second study, MoDOT conducted field observations to assess the effectiveness of the dynamic message signs in alerting drivers of an upcoming work zone. MoDOT observed speed changes at two construction work zones on I–55. One site consisted of a permanent sign upstream of the work zone, and the other site consisted of a portable sign upstream of the work zone. The researchers observed average speed decreases of 3.64 miles per hour, mi/h (5.86 kilometers per hour, km/h) and 1.25 mi/h (2.01 km/h) at the first and second sites. The research team found the speed reductions to be statistically significant, indicating that the dynamic message signs had positive effects on safety.

The third study evaluated the effectiveness of the signs in detouring traffic around a full freeway closure. MoDOT surveyed motorists in the affected area to determine if they were aware of the closure and detour, and to what extent they relied on the dynamic message signs to obtain traveler information. Overall, motorists said they were satisfied with the information provided through the signs, trusted the accuracy and sufficiency of the detour information, and followed the recommendations the signs provided. About 41 percent (45 out of 109) of the respondents were aware of the bridge closure solely because they saw a dynamic message sign and

Messages may include information about crashes and other traffic-related incidents, work zones, detours, and other emergency information, as shown on this dynamic message sign on a rural road in Missouri.

University of Missouri

not through other means such as a radio or newspaper announcement. In addition, the researchers noted a significant increase in traffic flow on the detour route during closure days, along with a corresponding decrease in traffic on the normal route.

Conclusions. MoDOT generally found motorists to be very appreciative of information the agency is able to provide thanks to the dynamic message signs and closed-circuit TV cameras. Further, agency officials believe these safety measures are cost effective. To date, the maintenance costs have been minimal, while the range of benefits is substantial, including continued system surveillance, provision of valuable information to travelers, monitoring of traffic incidents and work zones in real time, and verifying weather and pavement conditions.

"The rural dynamic message signs allow us to communicate directly with motorists in the immediate vicinity of a work zone, incident, or other traffic condition," says Nelson. "Often . . . it is the most efficient and effective way for us to get critical traveler information to our customers so they can respond accordingly. If we're unable to provide customers with critical information about an event through traditional communication means, there's always that last opportunity to reach them via a dynamic message sign."

MoDOT also discovered that coordinating with the six electric cooperatives operating in the study region was crucial to the success of the project. Each had its own policies and procedures for providing power to the signs and cameras, and response times varied from one electric company to the next. Without the cooperation of these electric companies, project work was subject to snags.

MoDOT officials also reported that the agency has installed additional dynamic message signs and closed-circuit TV cameras since the completion of the project in order to fill gaps in its existing traffic monitoring system. Although these deployments were not a direct result of the Rural Safety Innovation Program, its success created additional support and justification for the subsequent installations.

Future Considerations In Evaluating Safety Effectiveness

Quantifying the safety effectiveness of specific countermeasures and presenting lessons learned offers benefits to other highway agencies by providing important information to help their States make funding decisions about future safety improvements.

Future research should focus on safety treatments that are not yet in widespread use or for which the information on safety effectiveness is limited. The lack of consistent, accurate data documenting the implementation of safety treatments, when and where they occurred, and before-and-after crash rates at those locations make this type of research challenging.

Highway agencies typically do not keep records identifying the locations of safety improvements and their installation dates. In many cases, maintenance crews install safety improvements without documenting them as such. Crews record the improvements in maintenance or construction documents without labeling them as safety improvements or formatting the information in a way that is conducive for safety-improvement evaluations. FHWA is working with States to improve their documentation of safety improvements.

In addition, data on traffic volumes showing exposure levels is critical in performing safety evaluations, along with accurately assigning crash data to specific locations as part of the electronic databases that link to roadway inventories and traffic volume data.

The Arkansas State Highway and Transportation Department installed this cable median barrier on a rural interstate, under the Rural Safety Innovation Program.

Arkansas State Highway and Transportation Department

To eliminate many of the challenges in performing evaluations of safety treatments, State and local highway agencies should consider improving the quality of data linking crashes to roadway inventory, traffic volume, and safety treatments. FHWA's Office of Safety is developing a program to assist State and local agencies in improving and expanding their inventories of roadway data. Known as the Roadway Data Extraction Technical Assistance Program, it will provide the agencies with better data for safety analysis and other purposes.

"The [program] will assist States in identifying, extracting, and recording model inventories of roadway elements from commonly available existing sources of data, such as State roadway photo logs and street view maps from Bing® and Google Earth™ mapping services," says Robert Pollack, a transportation specialist at FHWA. "A data extraction tool is in pilot testing and is expected to be available by summer 2015."

Darren Torbic, Ph.D., is a principal traffic engineer for MRIGlobal. He conducts research in highway safety, geometric design, traffic engineering, and bicycle and pedestrian transportation research. Torbic holds three degrees (B.S., M.Eng., and Ph.D.) in civil engineering from the Pennsylvania State University and a B.S. in physics from Westminster College.

John Campbell, Ph.D., is a research leader at Battelle Memorial Institute, where he leads a team that provides a human-centered approach to the development and evaluation of transportation programs, products, and systems. He has a master's degree in human factors and earned a Ph.D. in cognitive psychology from Claremont Graduate University.

Roya Amjadi is a civil engineer at FHWA's Turner-Fairbank Highway Research Center in McLean, VA. She manages the Development of Crash Modification Factors program. She has a bachelor's degree in mechanical engineering and a master's degree in civil engineering from Cleveland State University.

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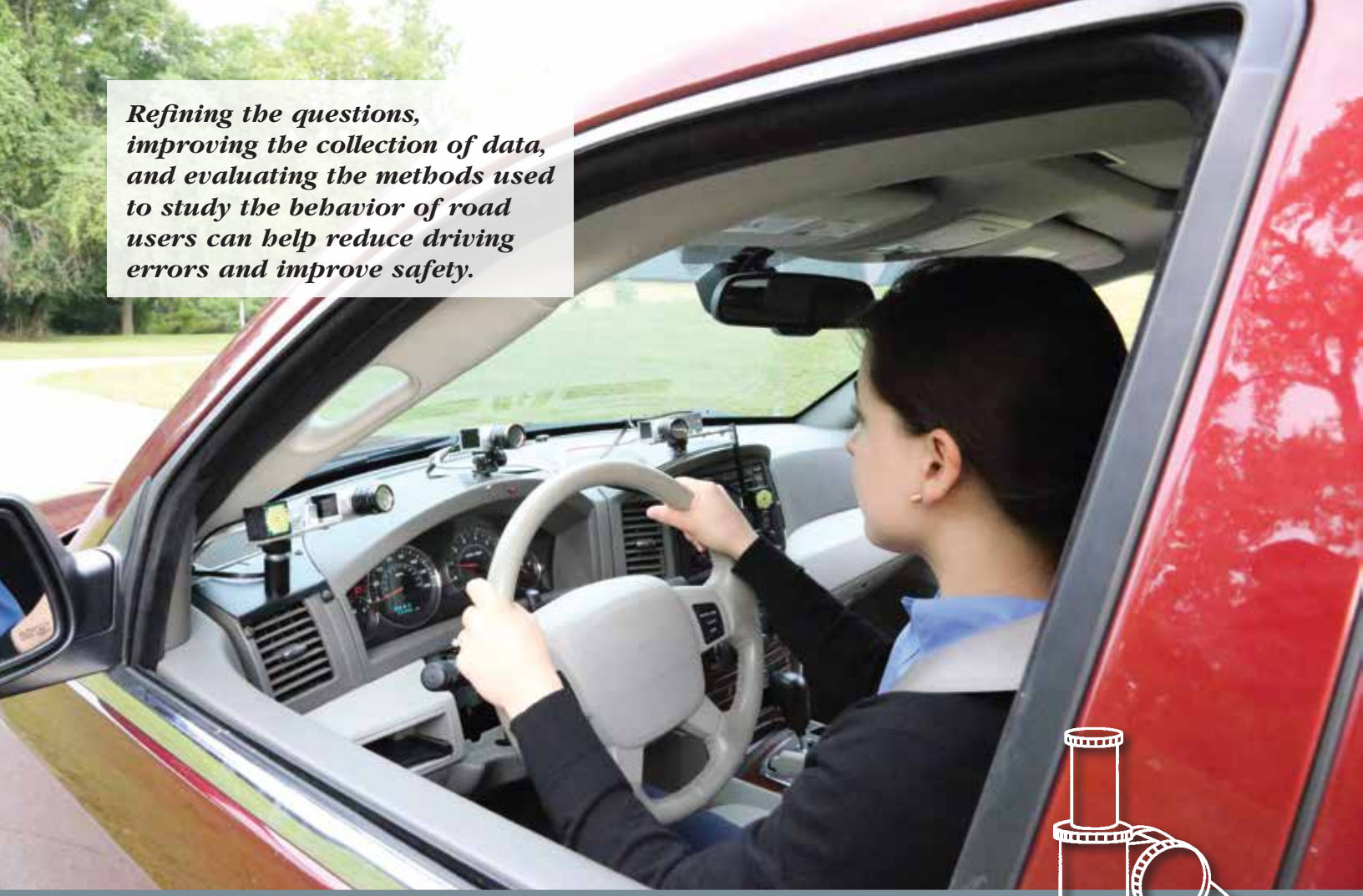
Refining the questions, improving the collection of data, and evaluating the methods used to study the behavior of road users can help reduce driving errors and improve safety.



The **Science** and **Art** of **Putting Drivers** under the **Microscope**

by Alicia Romo and C. Y. David Yang

(Above) Cameras on this vehicle's dashboard track a study participant's eye movements while she drives on an instrumented roadway. Identifying sources of driving distraction through eye fixation was the purpose of this experiment.

According to statistics from 2010 reported by the National Highway Traffic Safety Administration, the $871 billion economic loss and societal harm caused by vehicle crashes cost the average U.S. citizen $900 per year. Studies into the causation of crashes have concluded that approximately 90 percent of incidents can be attributed to driver error.

These statistics underscore the need for research to understand driver limitations, with the goal of

increasing roadway safety and reducing the cost of crashes. Associate Administrator Michael F. Trentacoste, head of the Office of Research, Development, and Technology at the Federal Highway Administration, says, "Understanding the behavior of road users is the key to designing effective countermeasures to improve transportation safety."

Significant research findings on driver behavior require selecting an appropriate research method to begin with and then ensuring credible interpretations of the results. To select a method and thus to provide solutions to problems and questions, researchers need to understand the types of data gathered under different methods. The usefulness of each method to performing analyses and obtaining valid findings has an impact on the quality of the research.

The question is: How should a researcher select a method to study a given driver behavior? More important, how do researchers determine whether their research approach is appropriate?

Researchers need to improve the selection of research tools to conduct studies, refine questions, collect relevant data, and find effective solutions to reduce driver errors and thus improve transportation safety. They need to examine the various methods to select those that can answer the research questions.

FHWA's Human Factors Team is working on identifying factors to evaluate a number of research methods and assist researchers in understanding the types of data needed for a given study. The following assessment of methods is essential to explaining the similarities and differences among the various approaches and communicating the value of research across disciplines.

Research Methods Used to Study Driver Behavior

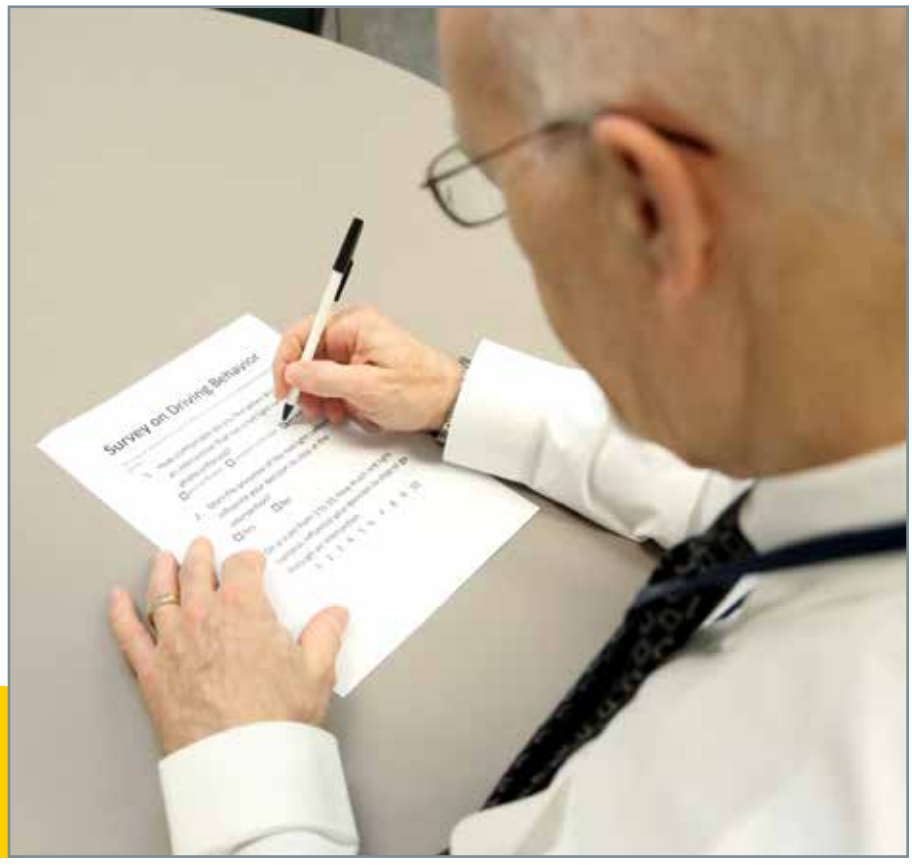
Safety researchers use various methods to generate and test new ideas, develop causal explanations of crashes, and understand the complex behavior and interactions of road users. The FHWA study explored the following six major methods that researchers use to collect data and investigate questions linked to driver behavior and transportation safety: surveys, crash data, driving simulators, test tracks or instrumented roadways, field operational tests, and naturalistic driving studies.

Surveys. A survey is a nonexperimental research method that is used in transportation research. The survey method involves using either self-reporting questionnaires or interviews with participants to collect information on their experiences. Researchers use surveys to understand driving attitudes and safety awareness, investigate travel behavior, rate driver acceptance of countermeasures and mitigations, and understand expectations for new technologies and preferences regarding them. Using predetermined questions enables researchers to understand and assess the reactions of road users to countermeasures of interest, such as a new traffic calming strategy or a new tolling policy. In addition, driving behavior questionnaires can be used to predict crash avoidance and crashes based on self-reported errors and violations.

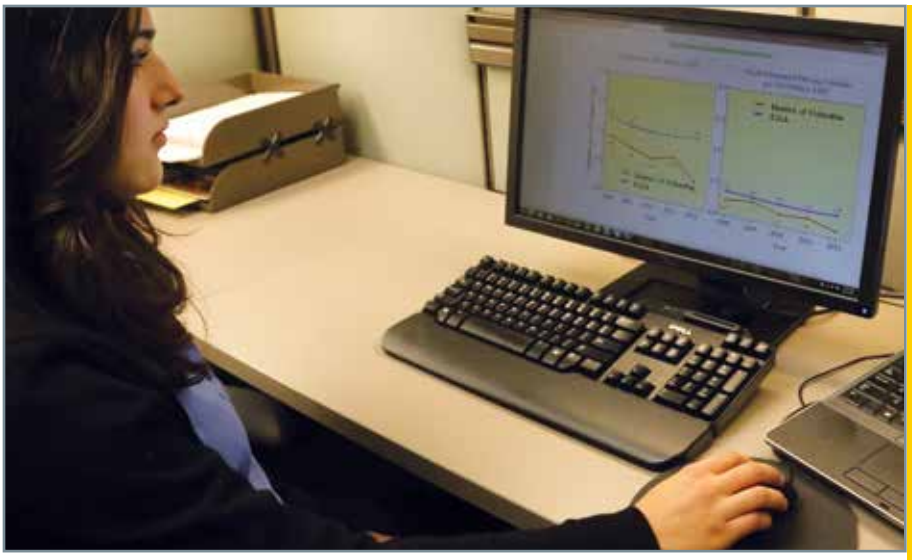
Crash databases. Crash databases are not considered experiments, but because of their significance to performing safety analysis, using crash data is considered a research method and therefore was reviewed in this study. Researchers collect most crash data by using documentation from police accident reports. The crash data from these reports provide statistics on high-crash locations and the frequency and severity of crashes. Researchers use crash data to investigate and predict when and where crashes will occur and identify roadway designs and road users vulnerable to crashes.

Driving simulators. By setting up studies in virtual driving environments, researchers can gather various kinds of behavioral data. They can use driving simulators to generate crash scenarios; investigate driver impairments; and test the limitations of vehicle designs, roadway configurations, and invehicle technologies. They can measure driving behavior and performance by controlling various factors in a study's experimental design.

Test tracks or instrumented roadways. A test track or instrumented roadway enables experimental



For research about driving behavior at intersections with red-light cameras, this study participant is filling out a hardcopy survey.



(Left) This researcher is performing data analysis to compare historical crash trends.

(Below) Sitting in a driving simulator, this research participant is using an automated adaptive cruise control technology in a virtual environment.

(Inset) Researchers in a control room are monitoring the driving performance of the participant in the simulator.

research to be performed on closed or open roads. Participants complete driving tasks in a research vehicle while researchers record their behaviors and interactions. Researchers can use test tracks to analyze dangerous and high-speed scenarios, last-second braking and steering performance, rear-end collisions, and alcohol impairment. Experiments on an open road permit interaction with other road users in real and controlled traffic settings.

Field operational tests. Often, these tests help researchers measure the effects of new technologies in the field while participants are being monitored as they drive on streets and highways. This kind of experiment uses a fleet of vehicles equipped with various systems and devices. Researchers view video and driving recordings to observe how participants adapt to technologies over a period of several weeks to a few months. In technology-based studies, researchers compare scenarios to analyze behavior changes, side effects, and usability issues. Some have used field operational tests to develop driving education and training programs. With data from field operational tests, researchers also can study risky behavior and driving performance of groups such as teen drivers, truck drivers, and motorcyclists.

Naturalistic driving studies. This kind of study offers an indepth investigation of everyday driving by observing the actual behavior of motorists going about their daily lives. Researchers collect large amounts of data, including nonnumeric (video recordings) and numeric information (such as speed, acceleration, and braking force). They provide the participants with devices or equip their vehicles or bicycles to record data in an unobtrusive manner.

Data involving participants' ordinary trips are collected for several days or months to as long as a few years. Measures of the outcomes help in tracking evidence on road users' behaviors and interactions, as well as drivers' cognitive and physiological states, which are investigated through multidisciplinary approaches. Some naturalistic driving studies focus on predicting risk exposure, estimating crash or near-crash count rates, and identifying critical events in crashes. Different from other research methods, the exploratory nature of naturalistic driving studies also permits researchers to investigate open-ended questions related to behavior, such as how do drivers interact with roadway features and how these interactions demonstrate the effectiveness of countermeasures.

Each of these six research methods offers different perspectives. For some studies, researchers may consider using multiple methods.

A motorist participating in a research study is driving a field research vehicle along a test track—an instrumented roadway—that in this case replicates an intersection.

Understanding the differences among the methods enables researchers to enhance the value of each dataset in providing crucial information without ignoring the limitations of each.

According to Sue Chrysler, former director of research at The University of Iowa's National Advanced Driving Simulator, "There is no perfect method that can account for every aspect of behavior research. There are various factors that can influence the type and quality of data being collected and, ultimately, the study findings."

Factors in Selecting Research Methods

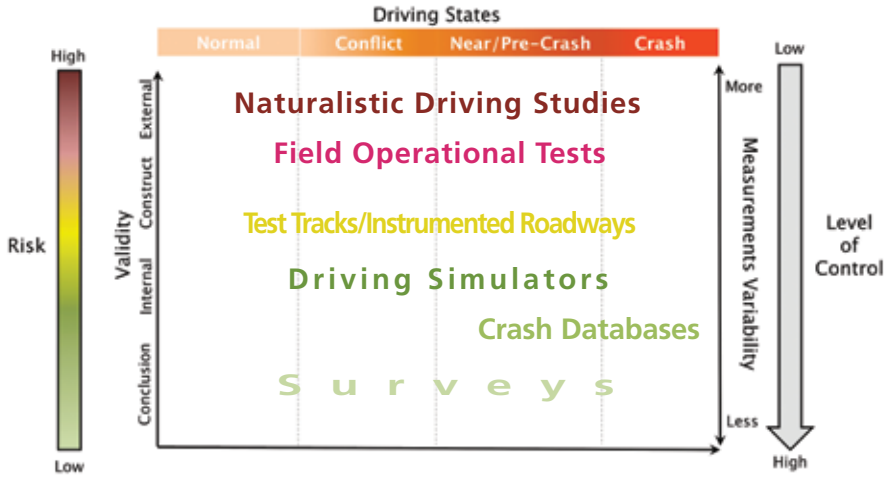
The FHWA study determined that five factors can explain the similarities, differences, advantages, and disadvantages among the six research methods. The five factors are driving states, risk, level of control, measurements, and validity.

Driving states. The FHWA Human Factors Team categorized driving phenomena into the following driving states: normal, conflict, near-crash/pre-crash, and crash. Normal driving represents driving tasks that are repeated as long as the motorist is on the road. The conflict state involves two or more vehicles with one of them performing an unusual action that jeopardizes the safety of others. This event may require an evasive maneuver by the other driver or drivers. Near-crash/pre-crash represents the last-second braking and steering maneuvers triggered by an imminent threat of a crash. Crashes are failed maneuvers that result in a collision of a vehicle with another vehicle or object.

Risk. A level of risk is inherent in every experiment that is performed for a research study. This factor includes exposures such as discomfort, simulation sickness, getting involved in an actual crash, and other risks associated with participating in an experiment. Of all the research methods discussed, survey has the lowest risk, whereas naturalistic driving studies and field operational tests are considered the riskiest. In those two research approaches, participants are exposed to real-life situations for a longer period than in the other methods, and actual crashes could therefore occur. Researchers who are performing behavioral studies must be aware of principles for protecting human subjects and comply with those principles. Knowing the risks of each experiment, the researchers can make the necessary preparations in advance to maximize the safety of participants.

Level of control. Researchers exert experimental control in manipulating the variables that are presumed to influence the occurrence of a crash or affect certain behavior (for example, roadway scenarios, speed of drivers, and distractions). The level-of-control factor demonstrates the efficacy of a research method in capturing what it is intended to capture and is inversely tied to the realism of the experiment. Researchers have a high level of control when using surveys

Relationship Between Research Methods and Impacting Factors



Six research methods are shown inside a framework according to the types of behavior captured by each method. The color of the vertical bar ranges from green to red to represent a low to high variation of risk to participants. Following this color code, Naturalistic Driving Studies and Field Operational Test are labeled in a red color to denote such methods as progressively riskier to participants. Test Tracks/Instrumented Roadways are coded as yellow to denote a medium risk. The green color expresses the lower risk of Driving Simulators, Crash Databases, and Surveys. *Source: FHWA.*

to collect data. This is because they can tailor questions to target specific driving behavior. However, there is no guarantee that participants' responses are a true reflection of their actual behavior. Experiments on test tracks and instrumented roadways permit the isolation of scenarios that create situations of interest. Those have a medium level of control. Naturalistic driving studies have a minimum level of control because they are designed to observe behavior "as is." Sometimes it is advantageous to use more than one experimental method due to the difference in the level of control.

Measurements. During experiments, researchers measure a behavior of interest and track their observations. According to the *International Organization for Standardization: Accuracy (trueness and precision) of measurement methods and results—Part 1: General principles and definitions*, published in 1994, the variation in the phenomena captured determines whether a study can be repeated under the same conditions so that other researchers can observe similar behavior or whether the phenomena change when reproduced in different settings. Minimum variability in observations enables researchers to track or explain behavior consistently.

An example of this is a survey, which can keep questions consistent and produce minimum variation in the responses. Otherwise, research outcomes vary if observations occur sporadically in different environments, such as data gathered from field operational tests or naturalistic driving studies. Driving simulators have both characteristics. Researchers using driving simulators can repeat the same experiment with different participants to observe cause-effect behavior. They also can reproduce experiments by testing the same behavior in different types of simulators.

Validity. The final factor describes the quality of the data and the credibility of the findings. This factor has four types: conclusion, internal, construct, and external validity. Conclusion validity refers to the appropriate statistical procedures to detect differences and correlations. Internal validity describes the degree to which alternative explanations can be ruled out. Construct validity evaluates whether the data consistently and accurately represent what they are assumed to capture. External validity measures the application of results across persons and places.

Surveys and crash data can control for factors not relevant to a study, such as personal information of participants, and set apart situations that establish a cause-effect relation of driving responses. Thus, they have the highest internal validity. Participants in driving simulation experiments may depict themselves as better drivers and alter their driving behavior, thus compromising the construct validity of the study. In the case of naturalistic driving studies, the validity of conclusions is threatened by the small sample size of events and limited number of participants who exhibit a specific behavior of interest. For example, searching for crash events caused by talking on a cell phone while distracted may result in few cases.

These five factors are empirical parameters that evaluate the quality of data and the research findings based on the analysis performed. Other considerations for researchers are the resources needed to conduct experiments and the time required for data collection. When comparing methods according to their cost, surveys have the lowest cost, simulator and observational methods involve medium-cost expenses, and onroad experiments are higher priced.

The time for a study depends on what the specific question is and the measure wanted. Surveys and crash data analyses are usually the fastest to conduct. Experiments that use driving simulations are usually medium in duration. Onroad studies, such as those involving test tracks or instrumented roadways, field operational tests, and naturalistic driving studies, require longer durations. Onroad studies are preceded by a lengthy process that involves activities such as obtaining permission to install devices, material facilitation and installation, and insurance coverage and liability for participants.

Selecting Research Methods: An Example

The following graphic example of selecting appropriate research methods is a hypothetic scenario in which the researchers want to understand driver behavior in work zones prior to crashes. The researchers must identify the number of methods available and their ability to measure certain variables of interest. The decision criteria summarize the characteristics of methods based on the factors previously described. Such criteria enable researchers to anticipate undesirable variables or unexpected results and select the best fit for their study.

In this hypothetical scenario, the researchers must collect data and measure behavior described by the questions under near-crash/pre-crash driving states. Based on the particular research questions assigned to this driving state, all methods are capable of identifying factors leading to crashes in work zones. At this point in the hypothetical scenario, it is unclear which method will yield the best quality results for the purpose of the study.

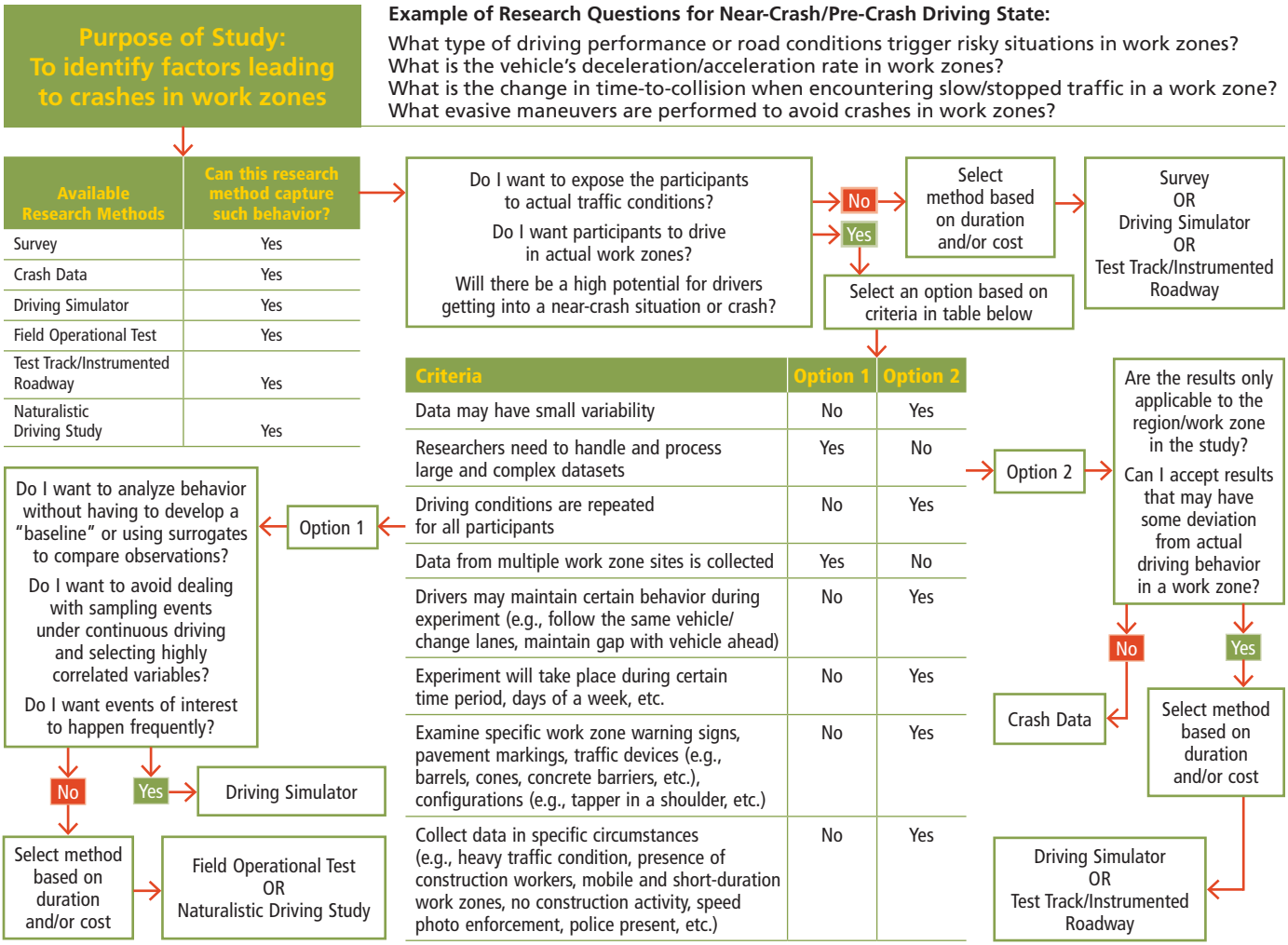
Researchers could make a straightforward selection based on the level of risk. For instance, avoiding congested traffic conditions and exposure to real situations will result in selecting surveys, a driving simulator, or a test track or instrumented roadway. If the researcher requires capturing road-user behavior in the field, other criteria must be considered, based on the preference to control an experiment and the consequent restriction in the variability of measurements.

Being able to reproduce the behavior of interest suggests collecting data without interruptions (option 1). A detailed study will be able to capture risky situations only applicable to certain conditions or situations (option 2). Based on the choice of the researchers, these options then will recommend a particular method or narrow it down to a couple of methods.

Concluding Remarks

The proper selection of research methods provides quantifiable solutions to improve transportation safety and eliminates wasteful spending of money, time, and effort. Research procedures must be adequate and need to address the research questions at hand. According to Monique Evans, director of FHWA's Office of Safety Research and Development (R&D), "Effective transportation strategies to reduce human error are

Decisionmaking Process for Selecting Research Methods



This flowchart illustrates a decisionmaking process for researchers to select a research method for a hypothetical study focusing on factors leading to crashes in work zones. *Source: FHWA.*

developed by solid research methods and reliable data. Selecting an appropriate method is a critical step in the earliest stage of a research project."

Using this systematic approach, researchers can make informed decisions on which method(s) will permit a targeted investigation of transportation issues and facilitate solutions.

Improving safety is a core mission of the U.S. Department of Transportation and FHWA. Examining and understanding behaviors of road users has a strong correlation to transportation safety. As the collection of behavior data becomes more sophisticated, researchers must employ proper methods to gather pertinent data about road users in order to implement effective transportation solutions.

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C. Y. David Yang, Ph.D., is the leader of the Human Factors Team in FHWA's Office of Safety R&D. He joined FHWA in 2008. Yang is the chair of the Transportation Research Board's User Information Systems Committee and serves on the editorial board of the *Journal of Intelligent Transportation Systems.* He received his B.S., M.S., and Ph.D. degrees in civil engineering from Purdue University. His doctoral dissertation used principles of human information processing and human factors to develop design recommendations for Advanced Traveler Information Systems.

For more information, contact Alicia Romo at 202-493-3369 or alicia.romo.ctr@dot.gov, or C.Y. David Yang at 202-493-3284 or david.yang@dot.gov.

Clearing Crashes On Arterials

by Dave Bergner and Kimberly C. Vásconez

(Above) Michigan DOT's Employee Memorial (shown here) is a permanent tribute to highway workers from across the State who lost their lives in the line of duty. Each figure represents a work activity conducted by DOT employees and is constructed of materials salvaged from highway jobs. The memorial, located at the Clare Welcome Center on U.S.127 in Clare County, MI, serves to educate the public about the human cost of building and maintaining Michigan's transportation system. *Photo: Michigan DOT.*

Local departments of public works and DOTs play a vital role in managing traffic incidents. But what exactly are they responsible for? And how can the TIM responder course help clarify their functions?

The roadway maintenance personnel of local departments of public works and transportation are often needed for major traffic incidents. The mix of public safety professionals who respond to an incident varies, depending on the complexity of the event, special conditions at the crash site, and the roles assigned by city and county chief executives to the pertinent public safety organizations.

Public works agencies, DOT maintenance crews, and safety service patrols play an important role in controlling the work areas around incidents. They establish temporary traffic control operations; clear debris and routine hazardous materials; alert oncoming motorists by setting up arrow boards, cones, flaggers, and portable message signs; provide alternate routes for the public; and conduct temporary

Traffic incidents like this one sometimes require quick repair of asphalt or other roadway infrastructure. Public works and transportation workers carry the right equipment to make rapid repairs to help get traffic moving again. *Photo: Chief Steve Carter and CVVFA Emergency Responder Safety Institute.*

repairs to the roadway infrastructure. All of these activities help mitigate congestion and reduce the likelihood of secondary crashes.

Recognizing the hazards that road maintenance workers face daily, the Michigan DOT manages a memorial and Web site for public works and DOT professionals who died in the line of duty. The New Hampshire DOT is fundraising to build a memorial for public works employees who died while performing their duties.

Sometimes, the role of public works and DOT maintenance crews in traffic incident management (TIM) may not be fully understood. The Web site of the American Public Works Association defines public works as "the combination of physical assets, management practices, policies, and personnel necessary for government to provide and sustain structures and services essential to the welfare and acceptable quality of life for its citizens."

The association also states that at present the structures and duties of public works departments are far from uniform: "In the real world there is no one, ideal structure for a public works operation. Even though some public works services are considered 'must haves' in every community, they may not be readily identified on a city organizational chart, or delivered in the same way, or to the same level, from one community to the next. In fact, some municipalities may not even have a department named public works."

The American Public Works Association, the Institute of Municipal Signal Association, and the Federal Emergency Management Agency (FEMA) hold the view that local public works and transportation maintenance workers are emergency responders. The 2007 version of the *I–95 Corridor Coalition Coordinated Incident Management Toolkit for Quick Clearance* states: "City and county [public works and traffic engineering] agencies have roles similar to the State DOTs. They are responsible for the highways not included under the State's highway system."

The division by jurisdiction, however, is clearer. For example, DOTs are generally responsible for interstates and State routes, even those within municipal corporate boundaries. Likewise, town, city, and county public works departments are limited to their jurisdictions' street and road systems, unless the departments specifically request assistance from their State DOTs.

Therefore, local and State maintenance crews do not work the same incidents unless the jurisdictional boundaries overlap. For instance, a DOT will respond to a major incident on an interstate in an urban area, while the local public works crew will handle the traffic detoured to adjacent surface arterial routes.

Police and fire often call upon local public works and DOT personnel to aid them in responding to incidents on local arterial roadways, particularly in complex situations such as hazardous materials spills, multivehicle crashes, fatalities, or damage to infrastructure. These professionals help make the scene safer for motorists and responders by deploying proper temporary traffic control, clearing debris from roadways, and quickly repairing damaged or defective infrastructure. A key performance measure of a successful TIM operation is rapid opening of traffic lanes with few or no secondary incidents.

Efficient Use of Resources

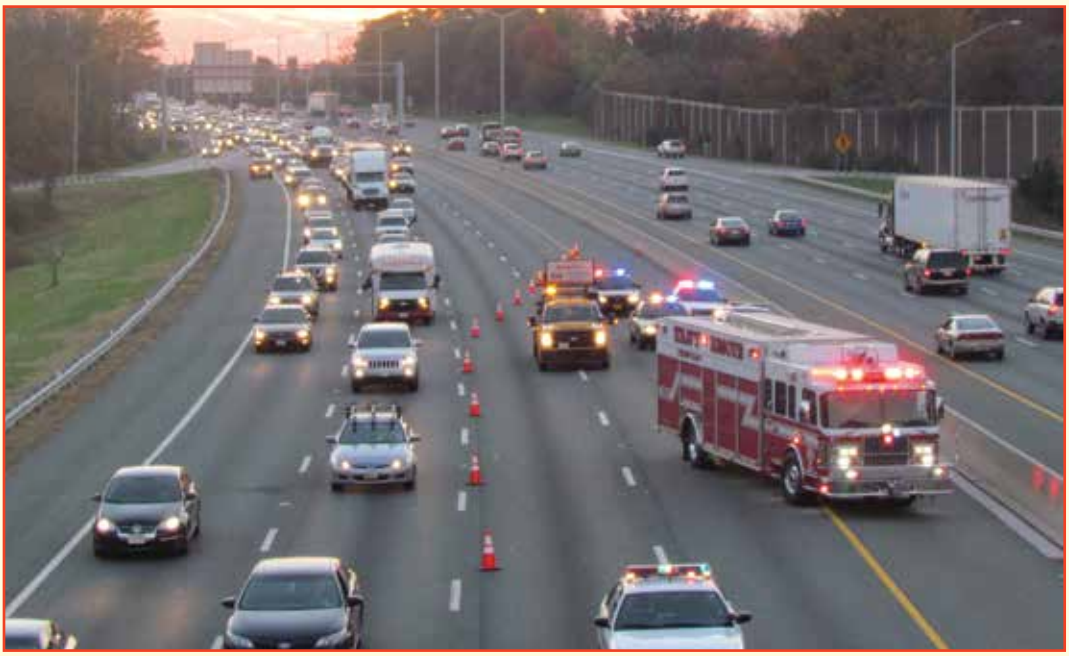
Public works and transportation maintenance workers and service patrol personnel may serve as the initial incident commanders if they are first on the scene. Typically, though, the operation transitions to an incident command system (ICS) structure directed by police or fire supervisors. At that point, the public works and transportation crews, if still needed, are integrated into the incident command operation.

Effective and efficient TIM resource management relies upon the use of appropriate personnel who are best qualified and equipped for the various tasks. As an example, public works and transportation personnel can take over directing traffic at incident scenes. The other responders then can redirect their attention to tasks, such as accident investigations and treatment of victims, that are specific to their roles.

In addition, using public works and transportation trucks to block lanes reduces the need to position expensive fire trucks. Should a public works truck or safety service patrol vehicle be struck, it would cost less to replace than a customized fire apparatus would. Some public works and DOT maintenance trucks have crash attenuators mounted on the rear that are used for routine road maintenance operations to protect workers. These same units are also valuable at traffic incident sites.

TIM Capabilities And Constraints

As noted in the FHWA publication, *Best Practices in Traffic Incident*



Michael Schwartzberg, Pikesville Volunteer Fire Company

Public works and transportation personnel can relieve police from directing traffic and blocking lanes at crash scenes like this one, where a Maryland State Highway Administration truck is helping block traffic. Police can then redirect their focus to other tasks more specific to their training and duty, such as crash investigations.

Management (FHWA-HOP-10-050): "Frequently, transportation personnel assigned to TIM duties have other full-time responsibilities in maintenance, traffic engineering, or ITS [intelligent transportation systems]. Further, transportation emergency management is often distinct from TIM in organizational and reporting terms although these activities are most often carried out by the same people at the field operational level."

Few DOTs are equipped for round-the-clock operations, unlike law enforcement, fire, emergency medical services (EMS), and private towing partners. Instead, most public works departments must call in off-duty personnel when emergencies occur outside normal working hours.

Calling up public works personnel can significantly affect their departments' budgets because of the unpredictable nature of overtime costs. Furthermore, usually the notified personnel have to go to a maintenance facility first to pick up a vehicle and other equipment before responding to the scene. This lag time may prove frustrating to other responding personnel. However, some agencies in southern Florida are experimenting with placing critical vehicles and equipment at designated locations for quicker access.

Even during normal work hours, personnel engaged in routine maintenance tasks might be unable to shift quickly from those activities to respond to traffic incidents. Agencies cannot afford to have personnel on constant stand-by just for emergencies. First responders typically understand these organizational, logistical, and financial constraints on local public works departments and DOTs that prevent them from around-the-clock operations. However, first responders recognize that these organizations often possess an on-call process that enables them to mobilize during urgent situations to clear roads, fill destructive potholes, aid utility restoration, and assist with critical needs on arterials to support traffic incident responses as needed to ensure public safety.

Temporary Traffic Control Devices and Skilled Personnel

As appreciation for the operational and safety benefits achieved by rapidly establishing proper traffic control at incidents continues to increase, local public works and transportation crews are likely to be more involved, particularly in addressing arterial roads. Police cars, fire trucks, and ambulances cannot carry all the temporary traffic control devices that may be needed for larger incidents. Although some State DOTs in larger urban areas have well-equipped service patrol vehicles, most public works departments and DOTs rely on the regular maintenance force to provide the requisite equipment, employees, and expertise. These employees must be fully prepared to provide this service, a major reason why TIM responder training is important.

The Need for TIM And ICS Training

Preparing workers to respond to traffic incidents involves more than providing equipment, such as trucks loaded with cones, barricades, and signs. Professional capacity building entails training all personnel—workers, operators, supervisors, technicians, and even dispatchers at traffic management centers—in the fundamental concepts, protocols, and practices of managing traffic incidents.

Significant operational and organizational differences exist among public works, transportation, and other emergency services disciplines such as law enforcement, firefighters, and rescue specialists. The core functions of the uniformed disciplines include reacting to emergencies, whereas public works and transportation departments are focused on designing, constructing, maintaining, and operating transportation infrastructure.

In recent years, awareness has grown of their critical role in all-hazards emergencies and managing traffic incidents, as indicated by Presidential Policy Directive 21, "Critical Infrastructure Security and Resilience." The Presidential directive identified public works and transportation disciplines as part of the emergency services sector.

Florida Department of Transportation

Traffic management centers, like this one in Broward County, FL, adjust the timing of traffic signals to mitigate congestion and delays from incidents. They also dispatch appropriate resources, such as public works and DOT maintenance crews.

As a basic requirement for their regular functions, all public works and transportation field maintenance personnel are trained in traffic control in work zones, per the *Manual on Uniform Traffic Control Devices*. Contractors and utilities working in the roadway also are required to take this training. The International Municipal Signal Association, American Traffic Safety Services Association, or each State's Local Technical Assistance Program provides training and certification. Some DOTs and public works departments conduct their own training and certification in work zone traffic control that complies with the MUTCD.

Public works and transportation employees are quite experienced with traffic control in work zones as they use it every day, whether they are patching potholes, repairing traffic signals and streetlights, installing pavement markings, fixing guardrails, or cleaning culverts. On the other hand, first responders may have had some training in temporary traffic control, a key element of traffic incident management. But, due to the increasing number of professional training requirements, first responders often do not reach the level of training in temporary traffic control possessed by city and county public works, DOTs, and safety service patrols.

Public works and transportation personnel also should be trained in the principles and practices of the national incident management system, as set forth by FEMA. FEMA has developed a guide to help State, territorial, tribal, and local leaders understand who on their staff needs to take what level of training offered through FEMA's Emergency Management Institute (www.fema.gov/pdf/emergency/nims/06_training.pdf).

The introductory training in the national incident management system, IS-700, is recommended for all personnel with a direct role in emergency preparedness, incident management, or response. The online course defines this training as needed for "emergency response providers and disaster workers, entry level to managerial level including [EMS] personnel, firefighters, medical personnel, police officers, public health personnel, *public works/utility personnel* [emphasis added], and other emergency management response personnel."

Public works and transportation employees also should be trained in the basic courses: ICS-100 Introduction to Incident Command System and ICS-200 Incident Command for Single Resources and Initial Action Incidents. Supervisors and managers should take the intermediate (ICS-300) and advanced (ICS-400) incident command courses.

After completion of the training, ICS practices need to be incorporated into routine operations. Unfortunately, this has not happened in many public works departments and DOTs, and the fundamental knowledge is lost over time. This can make integration of local public works and transportation personnel

Maryland's Coordinated Highways Action Response Team has specialized vehicles, shown here set up for temporary traffic control, which often help with incidents on larger interstates or arterials. Located at the start of the TIM area, where the responders cordon off their operational space, these personnel face higher risk of being struck by passing vehicles. *Photo: Scott Yinger, Maryland State Highway Administration.*

into an ICS structure more difficult, as they are not accustomed to using ICS organizations, language, and operating protocols. If a public works or transportation official is the first to arrive on the scene and does not know ICS protocols and procedures, then communications, control, and cooperation can be hindered.

TIM Responder Training

TIM represents a new facet of public safety. Certainly, law enforcement, fire, rescue, EMS, and others conducted traffic clearance processes ever since the first car took to the streets. But in recent years, a coordinated public safety approach has arisen based on those early TIM operations, plus locally developed policies, procedures, best practices, tools, and lessons learned.

In recent years, TIM stakeholders from across the Nation developed a new foundational training course through the second Strategic Highway Research Program (SHRP2). FHWA is responsible for deploying the 4-hour course, which is designed for responders from all disciplines. Participants learn best practices and "walk in others' shoes" through tabletop exercises in which individuals must perform the duties of responders from other disciplines.

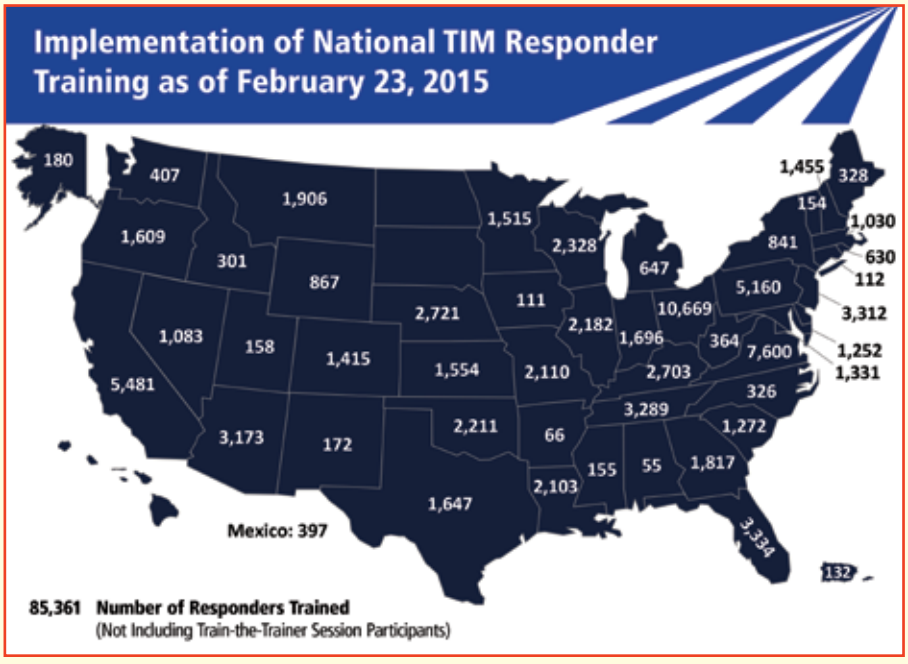
The TIM responder course teaches them to plan, train, and work together. The course provides responders with a common set of core competencies and assists them in achieving three key objectives: responder safety, quick clearance, and interoperable communications.

The course has been mostly provided through State law enforcement and transportation and local fire and rescue agencies. However, public works and transportation organizations that want to host the training, directly, for either the short 4-hour course or the train-the-trainer course, should contact FHWA's TIM responder course program manager, Jim Austrich, at james.austrich@dot.gov. The International Association of Fire Chiefs has a TIM Web site (www.safequickclearance.org) that also lists courses by location and date.

In 2012, FHWA introduced a TIM train-the-trainer course. Demand for the course has grown exponentially. FHWA trains instructors from various disciplines. And, in return, FHWA encourages the new instructors to conduct the free 4-hour TIM course and to include the course as part of the required curricula for public safety professionals, offering it through State and local public safety training academies.

Currently, FHWA is exploring opportunities to see if the training could be presented effectively using a virtual classroom format.

As of February 2015, 85,361 TIM professionals had received the training in a classroom format, and 5,663 more had qualified as instructors. FHWA expects that over a million responders will be trained over the next several years.



FHWA

Support for TIM Training

Although many public works and transportation personnel have participated in the TIM responder course, more still need training. To that goal, FHWA is working with the professional associations that represent the majority of public works and DOT employees. For example, the International Municipal Signal Association hosted the train-the-trainer course at its annual meeting in July 2014. The American Public Works Association also has expressed interest in conducting the TIM responder course at its regional chapter meetings. To date, about 10 chapters have asked to host the course.

In late 2014, FHWA held a meeting of senior leaders from those associations and others. (For a list of the participating organizations, see the sidebar on page 35.) The purpose was to gain their formal support and involvement in TIM training and other initiatives.

The leaders noted that public works and transportation practitioners are underrepresented in the TIM responder classroom sessions, especially in comparison with the other TIM disciplines. The group would like to come up with practical strategies to bring more TIM responder classroom sessions to this segment of the TIM community and to learn about the classroom sessions in advance so public works and transportation workers can participate with law enforcement, fire, rescue, EMS, towers, and others.

In addition to FHWA's responder course, the Cumberland Valley Volunteer Firemen's Association's Emergency Responder Safety Institute and the I–95 Corridor Coalition offer free online courses aimed at various responder disciplines. Also, the National Fire Protection Association in 2011 established a Technical Committee on Professional Qualifications for Traffic Control Incident Management. Although the primary audience is firefighters, the association expects that the final product will be applicable to all responder disciplines.

Traffic Planning For Special Events

Lastly, the same principles, concepts, and techniques used for handling traffic crashes are applicable to planned special events such as political conventions, major sports and entertainment events, demonstrations, county fairs, and so on. Jurisdictions must ensure security, safety, and access, and public works is often involved in some capacity.

As stated on the FHWA Web site on preparing for planned special events: "Unlike traffic incidents, natural disasters, and adverse weather, public agencies typically have access to information on the location, time, duration, and demand expected for a planned special event . . . [Planning for these events] also provides an opportunity for agencies to plan, coordinate, share resources, deploy intelligent transportation systems (ITS) technologies, and apply proven traffic management techniques to mitigate any possible adverse impacts."

As FHWA works with public safety officials in delivering TIM training around the country, agency officials continue to be encouraged that jurisdictions are accepting and more frequently applying advanced planning, proactive management, and traffic control in support of planned special events as a TIM mitigation strategy.

Planned special events provide opportunities for TIM partners to think through an operational plan and actually jump into operation if an incident occurs. These events also provide a chance to do a "hot wash"—an after-action discussion of resource sharing, roles, and responsibilities. The hot wash provides an opportunity to evaluate current TIM plans, break down administrative barriers, build relationships and trust that will benefit everyone when a traffic incident occurs, and practice information collection, analysis, and processing for consolidated situation reports on the watch.

A New Perspective And Attitude

"Call us if you need us" has been the prevailing attitude among many public works and transportation agencies. Several professional organizations are taking actions to change this perception so that public works and transportation workers begin to recognize that emergency management is an essential frontline function.

Incorporating TIM into their operations provides several benefits:

- Participating in TIM training and working with other disciplines on TIM helps to establish relationships that are vital during all-hazards emergencies.
- Training together helps the others become familiar with local public works and transportation capabilities and the benefits of including these agencies in planning, as they are involved in overall emergency management.
- TIM training contributes to improved morale and performance of public works and transportation employees by improving their understanding of their role in emergencies.
- The training broadens their experience with temporary traffic control.

As all incidents occur at the local level, it is incumbent on municipal, county, and tribal governments to plan accordingly. Police, fire and rescue, and EMS will serve as incident commanders on arterial roadways, but, as they integrate good practices taught through the SHRP2 TIM responder training, these organizations may elect to call upon public works and transportation departments for support. So, it is wise for TIM teams to bring local public works and transportation representatives into planning and operations now to be able to address the infrastructure and electrical needs of future roadway transportation.

Public Works and Local Transportation Senior Leader Meeting

On December 10, 2014, FHWA's Office of Transportation Operations hosted a meeting of professional associations representing the diverse local public works and highway operations and maintenance sectors. FHWA met independently with law enforcement, fire and rescue, and emergency medical services disciplines to discuss the importance of their members' participation in the TIM responder training course being deployed around the Nation. FHWA believed it important to meet with key groups vital to those often responsible for temporary traffic control and debris removal as a part of crash and incident response in local areas, particularly on arterial roadways. So, the agency invited key executive members of the public works and transportation operations and maintenance associations, including safety service patrols, to (1) better inform the associations of FHWA's TIM program; (2) help FHWA leadership understand the TIM capabilities of public works and DOTs; and (3) advance TIM knowledge, preparedness, and operational involvement among this large, diverse, and critically important segment of emergency responders. Meeting participants represented the American Association of State Highway and Transportation Officials; American Public Works Association; American Road & Transportation Builders Association; American Society of Civil Engineers; California Department of Transportation; U.S. Department of Defense Traffic Engineering Program; Intelligent Transportation Society of America; International Municipal Signal Association; International Bridge, Tunnel and Turnpike Association; Institute of Transportation Engineers; Maricopa County Department of Transportation; National Association of County Engineers; and the Transportation Research Board.

Dave Bergner is a retired public works superintendent/traffic operations manager. Currently, he is a traffic incident/emergency management specialist with Monte Vista Associates, LLC. Bergner has a master's degree in management from Webster University and is a Public Works Leadership Fellow.

Kimberly C. Vásconez serves as team leader of the Traffic Incident & Events Management Team and director of the TIM program in FHWA's Office of Operations. Vásconez has 28 years of disaster management experience with FHWA, the Department of Homeland Security, FEMA, and the U.S. Agency for International Development. She holds a bachelor's degree in journalism from Indiana University of Pennsylvania and a master's degree in public and international affairs from the University of Pittsburgh.

For more information, contact Kimberly C. Vásconez at 202-366-1559 or kimberly.vasconez@dot.gov. To learn more about FHWA's TIM program, please visit www.ops.fhwa.dot.gov/eto_tim_pse/about/tim.htm.

Along the Road

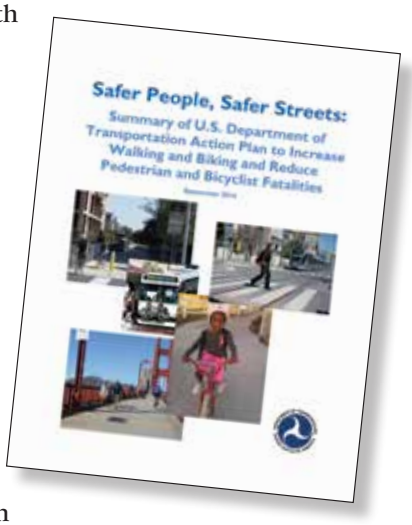
Along the Road is the place to look for information about current and upcoming activities, developments, trends, and items of general interest to the highway community. This information comes from U.S. Department of Transportation sources unless otherwise indicated. Your suggestions and input are welcome.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

Management and Administration

Secretary Foxx Announces Initiative To Enhance Pedestrian and Bicycle Safety

U.S. Secretary of Transportation Anthony Foxx recently announced a new initiative to reduce the growing number of pedestrian and bicyclist injuries and fatalities through a comprehensive approach. Since 2009, injuries and fatalities of pedestrians and bicyclists have steadily increased at a rate higher than motor vehicle fatalities. From 2011 to 2012, pedestrian deaths rose 6 percent and bicyclist fatalities went up almost 7 percent.

Dubbed "Safer People, Safer Streets," the 18-month campaign will begin with road safety assessments conducted by USDOT field offices in every State. The Federal Highway Administration, Federal Transit Administration, Federal Railroad Administration, Federal Motor Carrier Safety Administration, and National Highway Traffic Safety Administration field offices are working with local officials to conduct the assessments and have conducted pilots in Boston, MA; Dallas/Ft. Worth, TX; and Lansing, MI.



The new safety initiative will promote design improvements to ensure safe and efficient routes for pedestrians and bicycles, promote behavioral safety, and provide education to help individuals make safer travel choices. USDOT will work closely with State and local officials to support the implementation of new tools for pedestrian and bicycle safety.

An early product promoted by the initiative is FHWA's new guide to creating road diets, in which transportation agencies redesign roadways with lower traffic volumes to add space for bicyclists and pedestrians. Additional resources will help practitioners incorporate safety improvements into many road projects, address "last mile" safety for people taking buses and trains, and make it easier for jurisdictions to count and plan for people traveling by foot and bicycle.

For more information, visit www.dot.gov/office-policy/transportation-policy/secretary%E2%80%99s-action-plan-bike-and-pedestrian-safety.

Technical News

Caltrans Launches Interactive Game for Teen Drivers

In an effort to combat distracted driving among teen drivers and raise public awareness, the California Department of Transportation (Caltrans) developed an interactive, mobile and online game called Distraction Zone that helps educate teens about safe driving. Car crashes are the leading cause of death for 14- to 18-year-olds in the United States.

Caltrans

Caltrans' Distraction Zone game helps teens practice safe driving behaviors, such as when entering a highway work zone.

According to 2012 data from NHTSA, among drivers 15 to 19 years old who were distracted in fatal crashes, nearly 1 in 5 were distracted by their phones. Speeding is also a common contributing factor. In 2012, speeding was a factor in almost half (48 percent) of the crashes that killed 15- to 20-year-old drivers.

The Distraction Zone game is specifically designed to reinforce key safe driving behaviors like avoiding distractions, being alert, and slowing down when approaching highway work zones. Mobile versions of the game are available for download from Google Play and the App Store, and the online version is available at www.DistractionZone.com. As always, teens should not play the game or text while driving.

The campaign's media partner, iHeartMedia, is running a contest as an added incentive to entice teens to play the game. The contest invites teen players to submit their highest game score for a chance to win cash prizes. The top prize is $500. Players can play multiple times to achieve their best score and enter the contest until June 15, 2015.

For more information, visit BeWorkZoneAlert.com.

Caltrans

Public Information and Information Exchange

Technical Assistance Helps States Boost Data Quality

To support improvements in data quality among State departments of transportation, FHWA's Roadway Data Improvement Program (RDIP) has developed a data

Chris Armstrong, Leidos

Staff from the Rhode Island DOT and other stakeholders are shown here attending a workshop to review data on roadway safety.

review process for States' roadway inventory databases. A technical assistance team of subject matter experts reviews the data collected; its usage, management, and governance; and the interoperability of the data with other databases.

The RDIP review consists of a workshop addressing good practices for collecting, managing, and integrating roadway data; two technical transfer sessions; development of a summary report; and presentation of the assistance team's findings to the administrators and managers of the roadway inventory databases. In preparation for these activities, the assistance team reviews relevant materials, policies, practices, and procedures used by the State for its roadway database.

The workshop is open to both State DOT staff and external stakeholders invited by the host agency. The technical transfers are roundtable sessions to review and discuss the team's findings and recommendations. One session is devoted strictly to the internal practices of the State DOT. The second involves the State DOT and selected representatives from local agencies to examine information sharing practices.

As a final step, the RDIP team prepares a summary report on how the State is performing in collecting, using, governing, and sharing roadway data and makes recommendations for how these processes might be improved. The team presents these findings to the State DOT in a face-to-face meeting at the conclusion of the visit. The RDIP team develops a more complete narrative report of the findings for the State approximately 6 weeks after the site visit.

FHWA has completed reviews with seven States and has several more planned.

For more information, contact Robert Pollack at robert.pollack@dot.gov or 202-366-5019.

FHWA Releases Report on Effectiveness Of Dynamic Message Signs

The number of transportation agencies that use dynamic message signs to provide traffic information to motorists has increased dramatically over the past four decades. However, despite extensive research about traffic-related messages, policies regarding the display and type of messages that are unrelated to traffic vary greatly among States. It also remains unclear how effective these messages are at modifying behavior.

A recent FHWA study, *Effectiveness of Safety and Public Service Announcement Messages on Dynamic Message Signs* (FHWA-HOP-14-015), aims to help USDOT, transportation management centers, State agencies, and local transportation partners optimize the utility of safety and PSA messages on dynamic message signs.

USDOT selected four urban areas as study sites: Chicago, IL; Houston, TX; Orlando, FL; and Philadelphia, PA. The goal was to collect approximately 500 survey responses per city. In total, researchers received 2,088 responses.

Most respondents reported that they do see safety and PSA messages on dynamic message signs while driving, at least sometimes. The majority also noted that such messages are useful, with some even noting that those messages are more effective on dynamic message signs as compared to other media (such as television).

The survey results showed that messages were considered useful if the driver encountered them often. Respondents also thought that those messages could be effective in changing behavior.

Because drivers' stated preferences may differ from their actual preferences, researchers recommend an onroad impact assessment of safety and PSA messages on dynamic message signs to confirm the findings of this study.

For the full report, visit www.ops.fhwa.dot.gov /publications/fhwahop14015/fhwahop14028.pdf.

Now Available: *Guide for Effective Tribal Crash Reporting*

The Transportation Research Board recently released the National Cooperative Highway Research Program's *Report 788: Guide for Effective Tribal Crash Reporting*. The publication presents guidance for State agencies and tribal leaders for effective crash reporting. The guidebook also reviews the root causes of issues and deficiencies related to tribal crash reporting, highlighting best practices, success stories, lessons learned, published literature, and data from tribes and States involved in the data collection and analysis phase of the project.

The guidebook includes self-assessment tools for State agencies and tribes, and is accompanied by a CD with a supplemental report documenting the research approach

and findings. In addition, it includes flyers intended for use as handouts and reference materials at meetings, conferences, and events. The guidebook and contents of the CD are available to download at no cost, or hardcopies may be purchased from TRB.

The guidebook offers information on establishing, building, and maintaining communicative relationships between tribes and States, establishing effective methods for collecting crash data, creating a data-sharing system, and using the crash data to improve tribal traffic safety. Case studies are included to provide practical examples of implementing an effective system for reporting tribal crashes.

To download the guide or purchase a hardcopy, visit www.trb.org/Main/Blurbs/171540.aspx.

TRB

MassDOT to Redevelop Space Under Elevated Roadways

The Massachusetts Department of Transportation (MassDOT) recently announced its "Infra-Space" program to identify areas under elevated roads, bridges, or viaducts for possible opportunities for redevelopment. The Infra-Space program follows the successful ongoing development of a parking facility, a multimodal path, and adjustable ornamental light displays under a large elevated portion of the I–93 Southeast Expressway in Boston.

MassDOT

An artist's rendering of repurposed space below highway overpasses shows the type of project MassDOT is funding through its "Infra-Space" program.

The program requested input from municipalities, businesses, nonprofit institutions, property owners, developers, and community and arts organizations for nominations and proposals for redevelopment projects. MassDOT selected nine locations from those nominated from across the Commonwealth where elevated roadways, bridges, viaducts, or other transportation infrastructure are barriers to neighborhoods, pedestrians, bicyclists, multimodal travel, urban resources, and economic development. The agency is now reviewing redevelopment proposals for these locations.

The Infra-Space program asks for redevelopment ideas that would create a gateway between neighborhoods and urban resources, create better connections for multimodal travel, and support local economic development through commercial uses or parking. The projects could also create an arts or events space, add recreational amenities for adjacent communities, or increase safety and security through more active use and lighting. The selected projects would use public-private partnerships to fund and implement the improvements.

For more information, visit www.mass.gov/massdot/realestate.

MassDOT

California Creates Nation's Largest Active Transportation Program

The California Transportation Commission adopted 265 biking and walking projects—collectively valued at about $1 billion—in the State's 2014 Active Transportation Program, making it the Nation's largest such program.

California Governor Edmund G. Brown, Jr., created the program in 2013, replacing a patchwork of small grant programs with a comprehensive program. Projects selected for funding include improvements for Safe Routes to School programs, transit accessibility, multiuse trails, active transportation education and outreach programs, and bike and pedestrian infrastructure improvements. The full list of 265 adopted projects is available at www.catc.ca.gov/programs/ATP.htm.

Caltrans received hundreds of applications for projects located in cities and counties across the State. The adopted projects will receive a total of almost $368 million in program funds. The projects comprise three components: a Statewide Program ($183.8 million for 126 projects), a Small Urban & Rural Program ($37 million for 22 projects), and a Metropolitan Planning Organization Program ($147.1 million for 117 projects). Nearly 85 percent ($311.3 million) of the funds are directed at 220 projects that benefit disadvantaged communities.

For more information, visit www.dot.ca.gov/hq/LocalPrograms/atp/index.html.

Caltrans

TDOT Opens U.S. 41 Bridge in Marion County

Tennessee Department of Transportation (TDOT) Commissioner John Schroer joined State and local officials to celebrate the official opening of the recently completed bridge on U.S. 41 over the Tennessee River at Nickajack Lake in Marion County, TN. The new concrete and steel structure has two 12-foot (3.7-meter) lanes and full 10-foot (3-meter) shoulders, and replaces a nearby 1929 truss bridge. U.S. 41 is an important route, often used as an alternative to I–24.

Work began on the $21.5 million bridge replacement in March 2011. Unforeseen issues with rock near some of the new bridge piers added more than a year of additional work to the project and also forced the closure of the existing bridge, which project officials originally planned to keep open until they completed the replacement. TDOT permanently closed the old 1929 truss bridge to all traffic on January 9, 2012.

Joining Commissioner Schroer at the ribbon cutting was Madge Elizabeth Boggild. As a small child,

George Hornal, TDOT

A new concrete and steel bridge carries U.S. 41 over the Tennessee River in Marion County, TN. The bridge replaced a 1929 truss bridge that TDOT permanently closed to traffic in 2012. This image from August 2014 shows the new bridge nearing completion adjacent to the old truss bridge.

Boggild rode with her father in the first vehicle to cross the adjacent 1929 truss bridge. In January 2012, Boggild was in the last vehicle across the truss bridge before it was closed to traffic. At the recent opening ceremony, she rode in the first vehicle to officially cross the Tennessee River on the new bridge.

TDOT

MDOT Report Illustrates Economic Benefits of Bicycling

The Michigan Department of Transportation (MDOT) recently released a report, *Community and Economic Benefits of Bicycling in Michigan*, which details the economic benefits of bicycling on Michigan's local and statewide economies.

MDOT

Researchers found that pedestrians and bicyclists, such as the ones shown here riding in a bike lane, provided a significant boost to Michigan's economy.

The report finds that bicycling provides an estimated $668 million per year in employment, retail revenues, in-State tourism expenditures, and increased health and productivity. Statewide, 39 percent of households reported using a bicycle for transportation in 2013, and nearly 800 people are employed by bicycle-related industry in the State.

Using both quantitative and qualitative data, MDOT identified five communities across the State to measure the annual impacts of bicycling on a local economy. All of the case studies occurred within city limits and did not include the broader metro areas. The study found that bicycling provides a $5.5 million economic boost in Traverse City, $6.4 million in Holland, $20.7 million in Detroit (defined as southwest Detroit and the Conner Creek Greenway area), $25.4 million in Ann Arbor, and $39.1 million in Grand Rapids.

The second phase of the project is underway and will include specific data on the economic impact of cross-State bicycle touring, Michigan as a bicycle destination, and cycling events including races like the Iceman Cometh Challenge and multiday fundraising rides. That phase is scheduled to be complete in late spring 2015.

To view the full report, visit www.michigan.gov/mdot/0,4616,7-151-9615_11223_64797_69435---,00.html.

MDOT

MassDOT Displays #DOTspeak Safety Messages

In the summer and fall of 2014, MassDOT displayed the winning messages from a #DOTspeak Highway Message Board Contest on hundreds of message boards across the State. The winning messages from the social media contest were displayed throughout the State during some of the busiest travel periods of the year.

MassDOT launched the contest in June 2014 to collect ideas from the public for creative ways to remind drivers about proper driving behavior and to improve safety for all roadway users. The agency received more than 500 entries in three categories from Twitter, Facebook, Instagram, and email.

The winner in the road rage category, "Keep Calm and Drive On," submitted by Patrick Casey of Allston, MA, ran August 15–18, 2014 (a top 10 travel weekend based on 2013 toll data). Labor Day weekend drivers were reminded, "Put down the phone! Your LOLs and OMGs can wait." Submitted by Justin Lovell of Whitman, MA, the message won in the distracted driving category. The Parent's Supervised Driving Program team of Safe Roads Alliance submitted the winner for seatbelt use with "Make yah Ma proud, wear yah seatbelt," which MassDOT displayed over Columbus Day weekend.

"With the 'Use Yah Blinkah' sign, we got people's attention," says Massachusetts Acting Secretary of Transportation Frank DePaola, referencing a tongue-in-cheek message displayed earlier in 2014. The viral popularity of that message inspired the contest. "By changing the routine messages, we hope to bring a new light to important public safety messages that sometimes may be overlooked."

MassDOT

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Lisa A. Shuler, Editor-in-Chief
December 19, 2014

Internet Watch

by Carrie Boris

Office of Safety Refreshes Web Site And Launches Video Series

In 2012, highway crashes resulted in more than 33,500 fatalities in the United States. The Office of Safety is the lead champion within the Federal Highway Administration advocating for the integration of safety into the entire life cycle of roadways—from planning and design to operations and maintenance. As part of its mission to reduce the number and severity of crashes, the office manages a variety of Web-based resources for the highway community and the public.

Recent updates to the office's primary Web site at www.safety.fhwa.dot.gov make it easier for site users to find resources. In addition, the office released a new video series to educate transportation professionals and the public about how alternative intersections can help improve safety.

A New Look

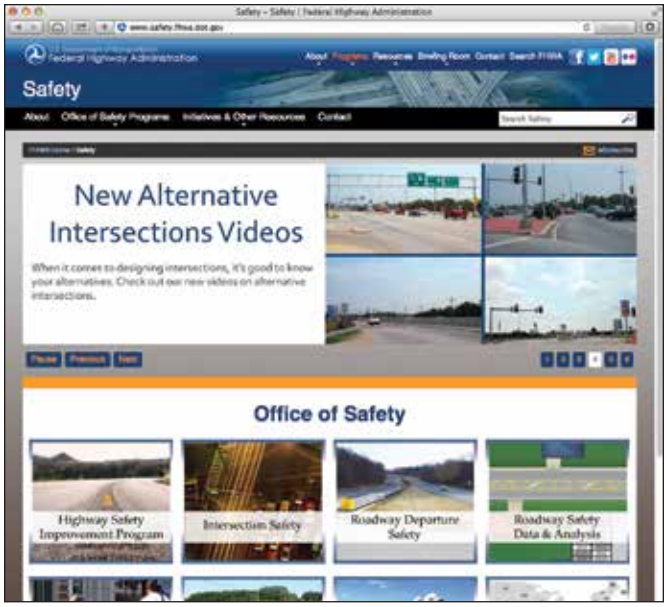
In fall 2014, the Office of Safety redesigned its Web site to improve access for visitors. The streamlined, graphically oriented look features new programs more prominently and makes it easier for users to find the information they need more quickly.

The site's home page received key updates including a rotating "slider" feature to promote new, time-sensitive, and frequently used content. Eight boxes below the slider highlight the office's primary programs and subject areas: the Highway Safety Improvement Program, intersection safety, roadway departure safety, roadway safety data and analysis, pedestrian and bicycle safety, local and rural road safety, capacity building, and the Roadway Safety Data Dashboard.

Drop-down menus at the top of the page provide a cross-listing of programs as well as an extensive list of initiatives and other relevant resources. These include links for topics such as geometric design and road safety audits, and information for specific concerns like older road users and nighttime visibility. The list also provides links to resources including newsletters, statistics, and proven safety countermeasures.

The workgroup for the project included members from each team in the Office of Safety. The group worked closely with Web designers to ensure that the new look met best practices for Web design and organization, and achieved the office's goals for ease of use and visual appeal. "The design update was truly a collaborative effort," says Tara McLoughlin, a communications and marketing specialist with the Office of Safety. "We received input throughout the process from four focus groups conducted with staff from across the office."

The updated look, which also includes visual revamps of several key subpages, launched on October 15, 2014. The response has been overwhelmingly positive, says McLoughlin. "The home page slider has been particularly popular with program managers as a dynamic way to promote new publications and upcoming webinars."



The updated design is a first step in a major undertaking to reorganize the Office of Safety's entire 6,000-plus page Web site. The overhaul is a long-term effort that includes archiving out-of-date materials, adhering to plain language style, and refreshing content.

Videos on Alternative Intersections

Alternative intersections and interchanges offer the potential to improve safety and reduce delay at a lower construction cost, and with fewer impacts on the local environment and adjacent property than comparable traditional solutions. As part of the Every Day Counts initiative's focus on alternative intersections, the Office of Safety produced a series of videos providing overviews of four types of alternative intersections, as well as a dozen video case studies.

The four overview videos run about 8 minutes each and describe in detail the diverging diamond interchange, the median U-turn, the displaced left turn, and the restricted crossing U-turn. The case study videos, which run 3 to 4 minutes, feature implementation of these designs in Michigan, Missouri, North Carolina, and Utah. According to Jeff Shaw, a safety design engineer in FHWA's Office of Safety, "the four informational overviews are more for nontechnical viewers, and the 12 video case studies are geared toward transportation professionals."

Production of the videos began in fall 2013, and the completed videos became available on FHWA's official YouTube channel by summer 2014. The video on diverging diamond intersections is the most popular so far, with more than 4,500 views as of December 2014. The full playlist of videos, titled "Alternative Intersections," is accessible on FHWA's channel at www.youtube.com/user/USDOTFHWA/playlists.

Carrie Boris is a contributing editor for PUBLIC ROADS.

by Kimberly Williams

Integrated Response Training Moves Online

Three injury crashes occur every minute in the United States, putting thousands of incident responders potentially in harm's way every day. Congestion from these incidents often generates secondary crashes, further increasing traveler delay, frustration, and risk. Clearing traffic incidents effectively is critical to improving safety and reducing congestion delays on the Nation's roadways.

To assist with this goal, the Federal Highway Administration, under the second Strategic Highway Research Program (SHRP2), developed a National Traffic Incident Management (TIM) Responder Training Program. This multidisciplinary curriculum helps ensure a well-coordinated response to traffic incidents that achieves faster clearance and improves safety for both responders and motorists. To supplement the training program, the National Highway Institute launched a Web-based course that can offer immediate training until a classroom course is available, or serve as a refresher. (For more information, see the TIM series in PUBLIC ROADS, which includes "Clearing Crashes on Arterials" on page 30 in this issue as well as articles in the July/August 2013, November/December 2013, and July/August 2014 issues.)

Improving Incident Response

The national TIM responder training brings together police, firefighters, towing operators, medical personnel, and other incident responders to engage in interactive, hands-on exercises in incident resolution. Learning to coordinate response activities and optimize operations in the classroom is vital to responding effectively in the field and to building a unified national practice on incident management.

The online course provides first responders with a shared understanding of the requirements for safe, quick clearance of traffic incident scenes; prompt, reliable, and open communication; and motorist and responder safeguards. First responders learn how to operate more efficiently and how to better coordinate across disciplines.

"All TIM responders should take a classroom session if possible," says Kimberly C. Vásconez, team leader for the Traffic Incident and Events Management team and director of the TIM program in FHWA's Office of Operations. "However, many responders are located in remote or rural areas, or small to medium urban areas without easy access to on-location classes. The online course provides a valuable tool to train responders."

Segmented into 10 modules, the training covers the national TIM program's recommended procedures and techniques, including fundamentals and terminology, notification and sizing up the scene, safe vehicle positioning, command responsibilities, traffic management, telecommunicators, and special circumstances, such as crashes with fatalities or hazmat spills.

FHWA recommends that interested responders complete the following courses, offered by the Federal Emergency Management Agency, as prerequisites to the TIM training: IS 700 – National Incident Management System (NIMS), An Introduction; ICS 100 – Introduction to Incident Command System (ICS); and ICS 200 – ICS for Single Resources and Initial Action Incidents.

Reaching More Responders

The SHRP2 national TIM training program strengthens the incident management programs currently offered by response agencies and provides a common platform for training the responder community. The Web-based training does not replace the on-location training, explains James Austrich, TIM training program manager with FHWA's Office of Operations. "This free, online training supplements the in-person experience," he says, "by providing immediate training until a course is available in your area or by serving as refresher training after you attend an in-person event."

Although NHI has begun charging for some Web-based courses, the TIM trainings—Web-based and classroom—remain free to all participants.

For more information, visit NHI's Web site at www.nhi.fhwa.dot.gov.

Kimberly Williams is a contractor for NHI.

Changes Underway to Web-based Training

On January 1, 2015, NHI began charging a small fee for select Web-based training courses. NHI continues to offer Web-based prerequisite courses and those supported by other organizations, such as the Transportation Curriculum Coordination Council and some program offices, at no cost. Courses will be free or cost $25 or $50. To see how much a specific Web-based training will cost, view the course details on the NHI Web site.

Participants who enroll in Web-based training will have access to the course for 6 months. After that time, a participant will need to register for the course again to access or complete the training.

Additional information, including frequently asked questions about the cost of Web-based training, is available on the NHI Web site at www.nhi.fhwa.dot.gov.

Communication Product Updates

Compiled by Lisa Jackson 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 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).

The Use of Recycled Tire Rubber to Modify Asphalt Binder and Mixtures (TechBrief) Publication Number: FHWA-HIF-14-015

The paving industry has used recycled rubber from waste tires in asphalt since the 1960s. Recycled rubber can be used as an asphalt binder modifier and asphalt mixture additive in gap-graded and open-graded asphalt mixtures and surface treatments.

This technical brief provides an overview of the processes for tire rubber used as a modifier for asphalt binders and as an additive for asphalt mixtures. It includes considerations for laboratory and field testing as well as performance. As some aspects of the technology are still evolving, it covers best practices and areas of caution. The document also includes information on how to incorporate recycled tire rubber into the Superpave (SUperior PERforming Asphalt PAVEment) design system.

Until recently, the routine use of recycled tire rubber in pavements was limited to a few States. While performance is generally good, the cost of recycled tire rubber is generally higher than conventional practices. However, asphalt binder costs have increased over recent years because of the rising cost of crude oil. Polymers also have seen an increase in cost due to other market demands and fluctuations in availability. In contrast, over this same time period, recycled rubber from car and truck tires has experienced a relatively stable market price.

Local, State, and Federal regulations, such as FHWA's 2006 recycled materials policy, have increased the availability of recycled tire rubber, driving a renewed interest in the material as an asphalt binder modifier and mixture additive to provide a long-lasting, cost-competitive, and environmentally responsible pavement system.

This technical brief includes information about mix design challenges, tires and tire processing, various processes for creating binders and mixtures using tire rubber, performance challenges, and industry resources on tire rubber.

The document is available to download at www.fhwa.dot.gov/pavement/pubs/hif14015.pdf.

Fatigue Testing of Galvanized and Ungalvanized Socket Connections (Report) Publication Number: FHWA-HRT-14-066

Fatigue of structural supports for overhead signs, traffic signals, and high mast light poles has received focused attention from researchers in the last 25 years because of failures reported in welded details. These lightweight, flexible structures are often susceptible to vibration from wind, which may lead to fatigue cracking at welded details in the structure.

Researchers hypothesized that cracking in the zinc metal bath during galvanizing caused some premature failures. This report describes how researchers tested specimens from two pole

manufacturers and presents the results showing the difference in fatigue life between galvanized and ungalvanized structures. Generally, the galvanized specimens showed a one-category reduction in fatigue life, meaning they would have a shorter expected life compared to identical specimens that were not galvanized.

The report assists stakeholders, including State transportation departments, researchers, consultants, and industry representatives, with the design and review of ancillary sign structures. It is available to download at www.fhwa.dot.gov/publications/research/infrastructure/bridge/14066/index.cfm. Printed copies are available from the PDC.

Wind Tunnel Investigations of an Inclined Stay Cable with a Helical Fillet (Report)
Publication Number: FHWA-HRT-14-070

In recent decades, engineers have recognized cable-stayed bridges as the most efficient and cost-effective structural form for medium- to long-span bridges. Though widely used, some of these bridges have experienced serviceability problems associated with large-amplitude vibration of the stay cables. This report discusses a study to supplement the existing knowledge base on some of the outstanding issues of stay cable vibrations and to develop technical recommendations that may be incorporated into design guidelines.

Because stay cables are laterally flexible with very low inherent damping, they are highly susceptible to environmental conditions such as wind and combinations of rain and wind. To counter this susceptibility, engineers use various mitigation measures on many cable-stayed bridges around the world. These measures include surface modifications, cable crossties, and external dampers.

This study examined wind and cable interaction, with particular focus on airflow close to the cable as well as forces on the cable surface. Researchers attached a helical fillet, a commonly used surface modification, to an existing cable model to evaluate the influence of this mitigation feature. To represent field orientations, they varied the cable inclination angle during testing. They conducted tests at various levels of damping, with and without the fillet, and in turbulent as well as smooth flow conditions.

The researchers found that a stay cable with a representative surface roughness, cross-sectional shape, and helical fillet inclined at 60 degrees can experience wind-induced vibrations with large amplitudes in smooth or turbulent flow. For a stay cable inclined at 45 degrees with a helical fillet, researchers did not observe large vibrations for the range of wind speed they investigated.

This report assists bridge engineers, wind engineers, and consultants involved in the design of cable-stayed bridges. It is available to download at www.fhwa.dot.gov/publications/research/infrastructure/structures/bridge/14070/index.cfm.

Slip and Creep of Thermal Spray Coatings (TechBrief)
Publication Number: FHWA-HRT-14-083

When used in high-strength bolted connections, coating systems to protect steel bridge systems and components from corrosion must meet required levels of slip and creep performance. The American Association of State Highway and Transportation Officials' specifications for load and resistance factor design of bridges require bolted connections to be designed as slip critical under certain circumstances, including heavy impact loads or severe vibration. Slip-critical connections rely on the clamping force from bolts to develop frictional shear stresses to transfer force from one bridge element to the next.

In severe environments, thermal spray coatings offer better long-term corrosion protection for steel bridge systems and their components than zinc-bearing paint systems. Yet these coatings have not been mainstreamed into practice, in part because of the unknown frictional resistance they provide for slip resistance within high-strength bolted connections. This technical brief discusses research aimed at understanding key variables that influence the slip and creep performance of thermal spray coatings in high-strength bolted connections. It introduces limited data on slip coefficients developed by sealed and unsealed coatings.

Researchers found that because of rough textures, unsealed zinc and zinc/aluminum alloy thermal spray coatings had no problems passing slip performance requirements. However, once the surface was sealed, neither coating system could meet slip performance criteria. Until further research can demonstrate slip-critical performance of sealed thermal spray coatings, the researchers recommend that slip-critical surfaces be either masked off during manufacturing to prevent sealing or assembled before coating sealers are applied.

This document is available to download at www.fhwa.dot.gov/publications/research/infrastructure/structures/bridge/14083/index.cfm. Printed copies are available from the PDC.

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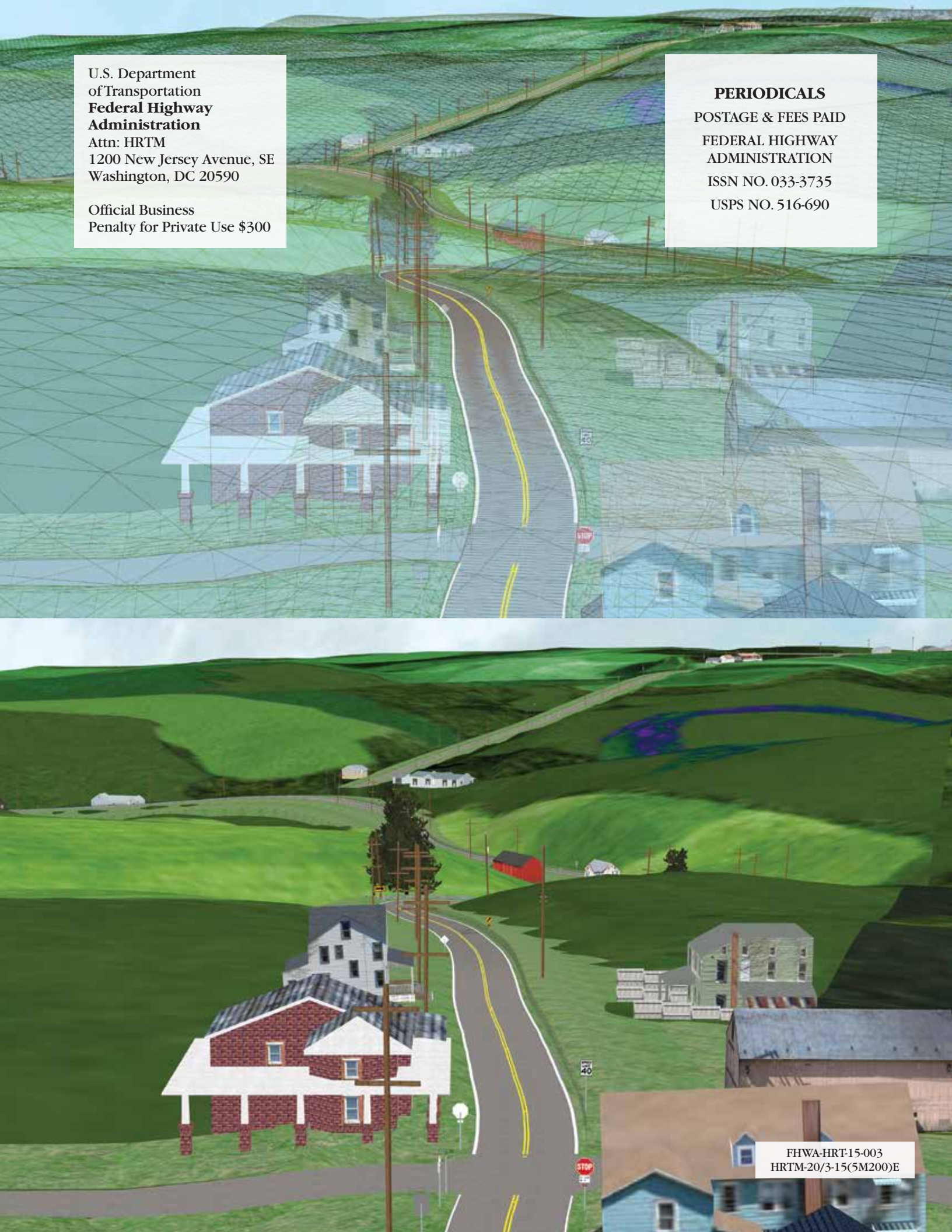

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