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Michigan DOT's Unmanned Surface Vehicles for Monitoring Bridge Scour

U.S. Department of Transportation
Federal Highway Administration

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DEPARTMENTS

COVERS and ABOVE–Michigan DOT is using an unmanned surface vessel to supplement its scour inspections on bridges.

U.S. Department of Transportation
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The Road to Technology Transfer

Source: FHWA.

We've been in the innovation and technology transfer game for more than 70 years at the Turner-Fairbank Highway Research Center. Over that time, we've turned scientific discoveries and technological breakthroughs into products that transform entire industries. One example of technology transfer (T2) success is how the Dynamic Angle Validation (DAV) kit improved Superpave™ design. The gyratory compactor dynamic angle measuring device was developed by the Federal Highway Administration in partnership with its equipment partners.

The creation of the angle measuring device spurred competitors to develop similar devices. The invention of the dynamic angle measuring device has dramatically changed the practice of asphalt testing by producing more consistent test results between laboratories. Most transportation departments and asphalt suppliers are now using gyratory compactors to verify the volumetric data and compaction consistency. For more information, see "Tech Transfer Success: How the DAV Improved Superpave Design" on page 4 of this issue of *Public Roads*.

FHWA's T2 activities include direct technical and financial assistance, training, peer exchanges, collaboration with industry groups to disseminate knowledge and information, and evaluation of deployment methods to determine effectiveness, assess needed improvements, and document outcomes. FHWA uses a series of successful T2 venues including Every Day Counts (EDC), the Accelerated Innovation Deployment Demonstration program, the Accelerating Market Readiness program, and the State Transportation Innovation Councils, a State-based innovation deployment approach. EDC is a State-based model that identifies and rapidly deploys proven, yet underutilized innovations to shorten the project delivery process, enhance roadway safety, reduce traffic congestion, and integrate automation. The EDC program has made a significant positive impact in accelerating the deployment of innovations and in building a culture of innovation within the transportation community.

Key T2 stakeholders include State departments of transportation and local agencies, Federal land management agencies, Tribal governments, and industry groups. These stakeholders are often the intended audiences for the research deployment outputs. The Local and Tribal Technical Assistance Program centers and other deployment programs play a critical role in T2 activities with these stakeholders. FHWA markets products and demonstrates to these stakeholders that the FHWA research products (such as ultra-high performance concrete and diverging diamond interchanges) are valuable, practical, and constitute best practices. For example, the FHWA-patented in-situ scour testing device (ISTD) was piloted in 19 States and is now being improved based on the lessons learned from the pilots. The ISTD is a field testing device used to determine the scour-depth potential of soils relied upon to support structural foundations placed in flowing water.

As I mentioned, we've been in the business of innovation and T2 for a long time, and we're still at it today. To paraphrase Acting Administrator Stephanie Pollack's statement in the Spring issue of *Public Roads*, FHWA has some of the world's most innovative road and bridge engineering and planning expertise, and access to important and actionable data. It is the perfect place to lead in solving some of the most difficult transportation challenges. Thus, the mission of FHWA's T2 program is to ensure that innovations developed for the U.S. transportation system are broadly available to all levels of the government and the general public—maximizing the benefit to the Nation.

Dr. Kelly Regal
Associate Administrator for Research, Development, and Technology
Director, Turner-Fairbank Highway Research Center
Federal Highway Administration

The New FHWA Office Is a HIT!

by **AMY LUCERO**

It is my great pleasure to introduce you to the new Office of Transportation Workforce Development and Technology Deployment. If you're wondering what this has to do with innovation, the answer is A LOT!

The Office of Transportation Workforce Development and Technology Deployment will be the Federal Highway Administration's conduit to a broad network of external partners. It provides the highway transportation community with world-class subject matter experts, resources, and innovative technologies and practices all under one organization. It leverages external relationships with other government agencies, industry, foreign partners, and academia to provide FHWA partners access to innovative transportation solutions.

While the new office name is a mouthful, we refer to the new team internally as HIT—a nod to Innovation and Technology. This new organization brings together two offices that have traditionally been leaders in workforce development, innovation, and technology deployment: the Office of Technical Services and the Office of Innovative Program Delivery. Together, this team will achieve several outcomes: (1) create efficiencies and enhance innovation and collaboration; (2) centralize formal technical assistance, training, workforce development, and implementation support for transportation practitioners; and (3) develop and manage workforce opportunities for the practitioners of the future.

Creating efficiencies. In HIT, the development and delivery of training courses will happen under one roof, fostering closer collaboration across the training and delivery aspects. The new structure adds efficiency and cohesiveness and ensures that the needs of all audiences—States, localities, Tribes, Federal lands management agencies, and industry partners—are met. HIT also brings together the two key teams behind the Every Day Counts program and other innovation initiatives, so that innovation program development and implementation are more closely linked. The new structure centralizes all primary innovation and technology deployment functions and maximizes the opportunity for collaboration and better coordination. Internally, HIT supports the FHWA workforce with training and technical assistance on essential collaboration tools and techniques, technical topics, and key FHWA initiatives.

The lobby of the EDC Virtual Summit gave attendees access to a range of content, including panel presentations, online posters, and office hours sessions.

Source: FHWA.

Source: FHWA.

Centralizing support. The new office merges all training, workforce development, technical assistance, and implementation support, regardless of the customer. This is particularly supportive when a transportation partner needs a solution that incorporates several of these activities. An initial call for technical assistance on a safety issue may evolve into assistance with deploying a proven safety countermeasure, and then lead to training on Road Safety Fundamentals. Now, customers can access their needed technical assistance, technology deployment, and training with one phone call. Within HIT, staff are well-positioned to respond to iterative and evolving partner requests.

Developing and managing workforce opportunities. The new structure facilitates closer connections and shared goals. Programs such as the Highway Construction Workforce Program can be developed in parallel with State and local partners (through the Local Technical Assistance Program) who provide essential input into future skillset needs. And these activities will be enhanced through their tie to the National Highway Institute. This connectivity results in programs that can best address the needs of the future highway workforce.

I'm excited about our new organization, and I hope you are too. We're better together, and our customers will see the fruits of this great collaboration. All of us in the new FHWA Office of Transportation Workforce Development and Technology Deployment (the HIT Team) look forward to partnering with you on your workforce development, technology deployment, and innovation needs. You'll still find the same great staff that you've worked with before, and now our combined resources are positioned to serve you even more effectively. Please reach out to us and let us know how we can support you.

AMY LUCERO is FHWA's Associate Administrator for the Office of Transportation Workforce Development and Technology Deployment.

Managing Curbside Productivity

by **JEFF A. PRICE**

Increasing use of curb space offers challenges in considering accessibility for all users, accommodating increased delivery access, and optimizing curb productivity.

The Nation's roadways now serve an ever-growing set of users: vehicular traffic, pedestrians, public transportation riders, transportation network services, freight and delivery drivers, and various micromobility riders, including cyclists. Many areas require mixed usage of curb space for both motorized and nonmotorized traffic and must adapt to unanticipated uses such as outdoor restaurant space, temporary shelter for homeless populations, and emergencies. Local jurisdictions are constantly challenged to develop creative ways to manage the demand from the various functions of the street.

The Federal Highway Administration recognizes the need for strategic curbside management approaches to the street network. State and metropolitan partners need tools and knowledge to understand and react to this developing practice. Curbside management project goals and objectives need to support the overall efficiency of the surface transportation system. It will take a continuing, cooperative, and comprehensive transportation planning process to foster and improve a systems-based approach to making the street network deliver benefits to all users.

In partnership with State and local governments, public transportation agencies, and other interested parties, FHWA has undertaken research to identify challenges faced by the growing demands for curb space and infrastructure. There is a consensus that research needs to include: (1) a summary of best practices, (2) a report on curb data to understand what is happening, and (3) an exploration of the co-benefits of curbside management.

In collaboration with the Institute of Transportation Engineers, FHWA has developed a new resource on curbside management that will support communities in managing curb space considerations for accessibility, delivery access, and mobility innovations such as emerging micromobility options and autonomous vehicle technology.

FHWA has explored potential solutions to optimize curb productivity for the transportation network that address challenges in the following main areas: increased freight traffic and deliveries, transit priority, shared mobility and micromobility, pedestrians, accessibility and compliance with the Americans with Disabilities Act, parking management, electric and autonomous vehicles, and curbside retail.

In 2020, some towns and cities expanded outdoor dining onto sidewalks or along the curb on the roadway.

Source: FHWA.

Curbside management can include considerations for pedestrians, micromobility (like this bikeshare dock), parking, and access to businesses.

Source: FHWA.

FHWA is preparing the *Curbside Implementation Report* to convey current practices and emerging specifications in the area of curbside management. The study aims to provide practitioners of all levels of experience with information on how to assess, gather, and analyze data to understand available information on curbside management inventories. The research provides practitioners with suggested criteria to weigh tradeoffs to better assess, prioritize, and optimize curb uses and to synthesize data to create a strategic, data-driven approach to curbside management projects.

The *Curbside Implementation Report* will provide an indepth technical study pertaining to the collection, inventories, and processing of information relevant to existing conditions, curbside activity, and performance measurement. The analysis will provide the practitioner with the tools needed to establish modal priorities within a jurisdiction, paving the way for the pursuit of new projects and strategies. The study will cover identifying appropriate measures of effectiveness to understand project needs, selecting appropriate data to evaluate the measures and project alternatives, and obtaining selected data. It will include a discussion of methodologies for collecting new data relevant to curbside management projects through both manual, in-person observations and automated data collection equipment.

For more information on FHWA's curbside management program, visit *www.fhwa.dot.gov/livability/fact_sheets/curbside_fact_sheet.cfm*.

JEFF A. PRICE is a transportation specialist in FHWA's Office of Planning, Environment, and Realty.

TECH TRANSFER SUCCESS: How the DAV Improved Superpave™ Design

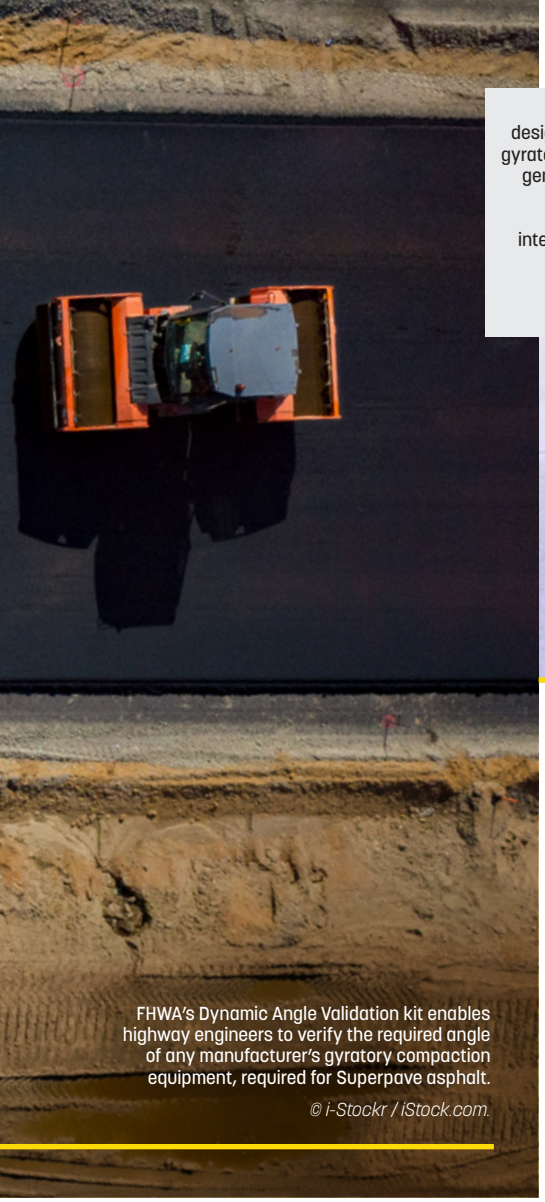
The Dynamic Angle Validation (DAV) kit ensures uniformity and consistency between gyratory compactors in asphalt testing. Here's how it came about.

by **MARY HUIE**, **THOMAS HARMAN**, and **EILEEN S. NELSON**

Mixing asphalt can be tricky business. To use the analogy of baking chocolate chip cookies, it is essential to balance the ingredients to get the desired taste. To make the cookie analogy work, think of a recipe as having three components: the fine (flour, baking soda, salt, sugar), the coarse (chocolate chips, brown sugar), and the sticky stuff (egg, vanilla, butter). Similarly, in asphalt mixes, there is the fine (sand or aggregate typically less than 2.36 millimeters, or that can pass through a number 8 sieve), the coarse (typically rocks or aggregate retained on a number 8 sieve), and the sticky stuff (asphalt binder, which can include modifiers and additives). In asphalt, the desired taste is a long-life pavement.

How these ingredients are proportioned together requires a meticulous baker and state-of-the-art utensils. In an asphalt laboratory, ingredients are combined, mixed, and then compacted using a Superpave™ (SUperior PERforming asphalt PAVEment) gyratory compactor. The gyratory presses the mix into its cookie shape, which is a cylindrical specimen 115 millimeters high with a diameter of 150 millimeters. During mix design, where the baker develops the recipe for production, the asphalt cookies are evaluated volumetrically and undergo additional performance testing. Dry "cookie" recipes can lead to cracking on the roadway and recipes that are too soft can lead to rutting.

The Superpave asphalt mixture design system requires gyratory compactors to provide a uniform compaction effort. This effort is based on the downward pressure inside the compaction mold, the speed and number of rotations, and the tilt or angle of the model. The most important component is the angle, which creates the shearing action. Today, the angle of gyration is set and verified internally to 1.16 °±0.02° under American Association of State Highway and Transportation Officials specifications. However, there was a time when internal angles could not be measured, and there was no way to ensure uniformity from machine to machine or manufacturer to manufacturer. The issue became a major hurdle in



FHWA's Dynamic Angle Validation kit enables highway engineers to verify the required angle of any manufacturer's gyratory compaction equipment, required for Superpave asphalt.

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The Dynamic Angle Validation Kit is designed to ensure uniformity between gyratory compactors. This second-generation DAV 2.0 includes an added eccentric ring to create an internal movement to simulate asphalt mix.

Source: FHWA.

the 1990s during the national implementation of the Superpave system.

Enter the Dynamic Angle Validation kits, or DAVs. DAVs are used for ensuring consistency and volumetric quality between gyratory compactors. Asphalt "cookie" specimens from gyratory compactors are not only used for developing tasty recipes, but are also used during field production in quality assurance testing.

Initial Development

The original prototype gyratory compactor, developed during the Strategic Highway Research Program (SHRP), called for an external angle of gyration set to 1.25°. An external angle does not account for something called "machine compliance." As a gyratory compactor presses an asphalt specimen into shape, the asphalt specimen pushes back on the load frame, which causes it to comply (deform slightly). This issue of machine compliance was not realized during the initial technology transfer effort for the Superpave system in the early 1990s.

Under a pooled fund procurement, the Federal Highway Administration solicited manufacturers to produce a gyratory compactor that could meet an external angle of 1.25°. FHWA selected two companies as successful bidders for this procurement and asked them to provide "first article" units to FHWA for evaluation. Upon receipt of these units, FHWA, along with the Asphalt Institute, performed extensive evaluations on each unit and conducted extensive discussions with SHRP researchers and the manufacturers. After a slight redesign of one of the units, FHWA ultimately approved both units, enabling a pooled fund purchase to proceed for all State highway agencies.

As time went on, more equipment manufacturers became involved with producing Superpave gyratory compactors. However, each production model employed a unique method of setting, inducing, and maintaining the angle of gyration. Unfortunately, this meant that no single manufacturer's calibration system could be universally applied to all the different models that were commercially available.

Creating a Universal Angle Validator

Recognizing the need for a way to validate the angle of gyration on any device, a team of three researchers at FHWA began to brainstorm. Tom Harman, then the lead for the Asphalt Pavement Team at FHWA's Turner-Fairbank Highway Research Center; Tom Brovold, who, at the time, sold his own version of a portable gyratory compactor; and Paul Fuchs, who had been an onsite contractor under FHWA's Nondestructive Evaluation Validation Center, sketched out a rough idea of what a universal fixture might look like that could dynamically measure the angle of gyration internally and work with any device.

Using this idea to produce a single, small conceptual device, the team worked to demonstrate consistent calibration with the same uniformity of compaction between two different devices. As with all eventual successful technologies, the first few attempts failed, and there were many design iterations. However, over the course of several years, the team developed and validated a functional internal device, which is now known as the DAV.

The team realized it had something novel, and they had the added advantage of using Brovold's private gyratory company to fully realize the technology. At the time, FHWA's device was the only proven technology. The creation of the DAV spurred competitors to develop similar devices. Other companies designed at least two devices—and even produced the same results—but their approaches were different.

FHWA aimed to get the internal calibration technology into the hands of State departments of transportation and asphalt suppliers. To do so, the DAV kits needed to be commercially available. In addition, the inventors wanted to secure the intellectual property rights. The next step was to file for a patent, which was successfully awarded in 2002.

The successful patent led to an exclusive license agreement between FHWA and Brovold, who already owned a company that manufactured and sold gyratory compactors. A royalty arrangement for the use of the

technology was established, with a nominal licensing fee with the intent of giving recognition back to the laboratory and researchers while also making the use of the technology affordable and attractive at all levels of industry.

Improving Asphalt Testing

The invention of the dynamic angle measuring device has dramatically changed the practice of asphalt testing. Most transportation departments and asphalt suppliers are now using gyratory compactors to verify the volumetric data and compaction consistency. A version of the DAV, or a similar device, is used to calibrate gyratory compactors used in the United States.

The Nebraska Department of Transportation (NDOT) has been using the DAV technology for more than a decade. Two of the main advantages are convenience and consistency. Because the DAV acts as a mix inside the mold, it does not need existing hot mix. In other words, no mix has to be continually hauled to various branch labs. Further, says Jody Paul, the highway quality assurance manager at NDOT's Bituminous Aggregate Laboratory, "The DAV gives you your true angle reading. Consistently. From my gyratory to the branch lab to the next branch lab, it is all consistent."

Robert Rea, NDOT's assistant materials and research engineer, says, "The DAV allows contractors and Nebraska labs to tighten up their verification testing tolerance and precision between laboratories, which means producing more consistent test results. Therefore, it reduces the amount of test variability on a paving project."

FHWA's Technology Transfer program played an important role in the process of getting the DAV kits patented, licensed, and commercialized. The Technology Transfer program is designed to provide support services in moving research from laboratory to market and ensures that the technologies produced are developed and disseminated with the user and adopter needs guiding the process. In addition, the program seeks to market products and demonstrate to State and local highway agencies that the FHWA research products are valuable, practical, and constitute best practices.

"The overall impact of the DAV technology and its successful adoption by the industry are a Technology Transfer success story," says Jack Jernigan, the director of FHWA's Research and Technology Program Development and Partnership Team.

The DAV, shown here, is a Technology Transfer program success story.

MARY HUIE is the manager of the Technology Transfer program at FHWA's Turner-Fairbank Highway Research Center. She holds a B.S. in civil engineering from the Catholic University of America in Washington, D.C.

THOMAS HARMAN serves as the director of FHWA's National Highway Institute and was the Director of the Center for Accelerating Innovation. He has a bachelor's degree in civil engineering from the University of Maryland and a master's in civil engineering from the University of Illinois.

EILEEN S. NELSON is a program manager working as a contractor with FHWA's Technology Transfer program. She holds a B.A. in history and curricular studies, as well as a minor in women's studies, from the former Randolph-Macon Woman's College in Lynchburg, VA.

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Monitoring Scour Using Unmanned Vehicle Technology

The Michigan Department of Transportation tested unmanned surface vehicles (USV) to aid in inspections of bridges and other assets. The selected USV is shown here with the associated running gear.

Michigan DOT researched the use of unmanned surface vehicles for bridge scour observation to improve the safety of inspectors and transportation systems users during and after flood events.

by **RALPH PAULY** and **CHAD SKROCKI**

During and after flood events, inspectors monitor scour at bridges to ensure that public safety is not compromised. The effect of scour on structure stability is difficult to assess during events as the extent of scour is not visible and cannot be easily verified by probing. Thus, inspectors make stability determinations based on experience, visual cues, flow rates, and other factors that hint at potentially unsafe conditions.

To help, the Michigan Department of Transportation (MDOT) researched several platforms for collecting scour-related data during and after flood events. To meet MDOT's needs, the platforms needed to be stable in swift-moving water, able to collect data using sonar technology, and easily and safely deployable throughout the State.

The platforms researched included monohull and catamaran (multihull) unmanned surface vessels (tethered and untethered) as well as stationary and fixed-position systems. MDOT evaluated both multibeam and single beam sonars for use with the platforms.

Assessing Vessel Design

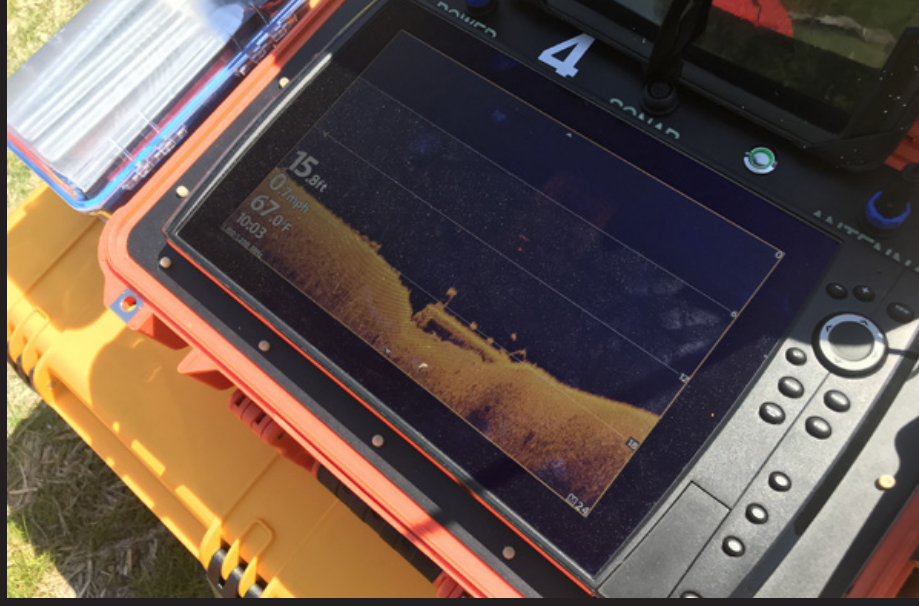
Early on, the research team dismissed tethered and stationary or fixed-position systems as viable alternatives because of their inherent limitations. Tethered systems prove hard to deploy when there is limited clearance, or freeboard, between the waterline and a structure's low chord—the lowest portion of the superstructure (bottom of the lowest beam or girder)—which hinders the inspector's ability to collect scour-related data. Stationary or fixed-position systems are difficult to use when flood events create unsteady or irregular flows and are unable to collect data rapidly at multiple locations (such as structures and substructure units).

A catamaran hull design provides a stable platform; however, keeping the vessel as small as possible means limited internal hull storage, requiring more of the instrumentation and equipment to be mounted on the exterior of the hull. Exterior mounting exposes the equipment to environmental hazards and snagging by trees or debris within the waterway or channel.

MDOT chose a monohull design because it offers protection for instrumentation and equipment within the enclosed

MDOT's USV performs a scour inspection.

© Chad Skrocki, Michigan Department of Transportation.



Sonar imagery showing a pier footing displays in real time on the USV operator's equipment in the field.

© Chad Skrocki, Michigan Department of Transportation.

hull, reduces the potential for hooking obstructions within the waterway or channel, and is durable enough to be deployed from riverbanks during flood events. The untethered vessel may be safely operated from shore, ensuring that the inspector is out of harm's way.

MDOT selected a vessel 50 inches (130 centimeters) in length, weighing 37 pounds (17 kilograms), and capable of achieving speeds of 18 miles (29 kilometers) per hour.

Selecting Sonar

The research for appropriate sonar equipment focused on an inspector's ability to collect, interpret, and evaluate the sonar data to aid the decisionmaking process while on site.

Multibeam sonar provided more accurate data than single beam sonar; however, the multibeam sonar equipment was cost prohibitive and required extensive knowledge to obtain and process the data. Researchers also expressed concern about maintaining the GPS signal lock adjacent to or below structures to provide correct spatial orientation.

Single beam sonar has its own limitations. Sonar imagery is collected and displayed relative to the position of the vessel and the fixed markers (such as piers and abutments), requiring the operator to maintain a relatively straight parallel path to the fixed marker to ensure data quality. The heaving, swaying, or surging motion caused by whirlpools and eddies formed during an event also affects data quality. As translational motion increases, data quality is reduced, and images may become distorted.

Despite these limitations, by testing the capabilities of single beam sonar, the research team found it to be advantageous for field use during flood events. Data can be collected and interpreted quickly by inspectors with varying levels of experience, ensuring that safety-related decisions are sound and data driven.

Proof of Principle

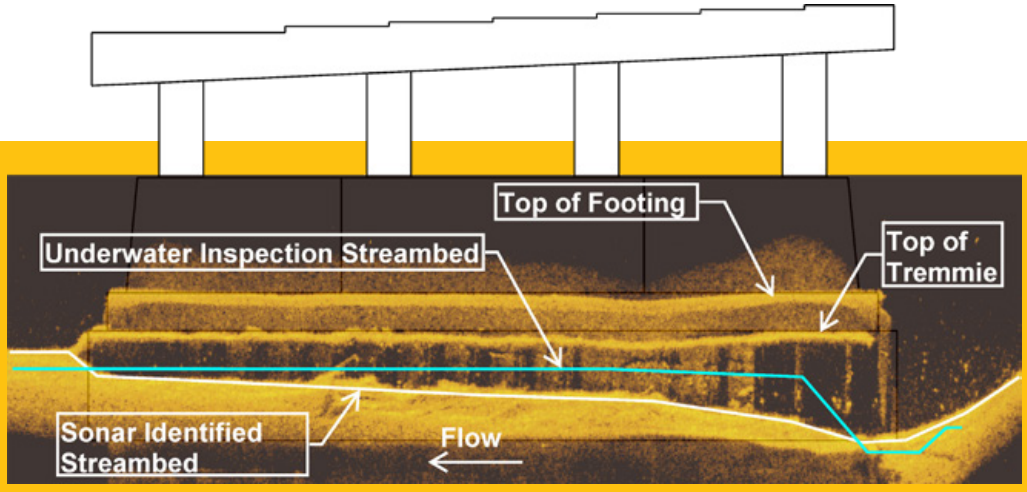
MDOT verified the sonar capabilities of the recommended unmanned surface vehicle (USV) platform (monohull vessel with single beam sonar) using underwater diver inspection data collected during a scour inspection on Michigan's Upper Peninsula. The researchers first plotted the inspection data on a drawing of the plan and the elevation of the submerged pier, then overlaid sonar imagery on the drawing using known points of reference. The results from sonar imagery proved comparable to inspection findings.

During and after the spring storms experienced throughout mid-Michigan in 2020, MDOT used the platform to monitor and assess conditions at scour-susceptible structures. The results further confirmed the capabilities of the selected platform.

"MDOT's USV platforms are an excellent tool for bridge inspectors to safely assess the condition of underwater elements and monitor scour sensitive issues safely, without putting inspectors at risk in the waterway itself," says Matt Chynoweth, the director of MDOT's Bureau of Bridges and Structures. "The platform was used extensively immediately following the flooding from the dam breaches along the Tittabawassee and Tobacco Rivers in May 2020 on many trunkline and local agency-owned structures to ensure safety and stability prior to reopening."

Additional Value

Rising water levels throughout Michigan have reduced the available distance between the waterline and a structure's low chord, limiting inspector access to the underside



The research team compared sonar imagery collected using MDOT's USV to the underwater inspection streambed performed by divers, overlaid on a drawing of the elevation of the pier.

© Chad Skrocki, Michigan Department of Transportation.

of the structures. USVs, when outfitted with video cameras and advanced imaging equipment, can gather photos and data to supplement routine visual inspections when access may be difficult or unsafe.

USVs can also be used to verify probing (wade and probe or boat and probe) and waterway information gathered during routine and construction inspection, which is crucial for managing long-term risks associated with scour. Information gathered before, during, and after construction of scour countermeasures ensures that measures are installed in accordance with design specifications and plans and will provide adequate protection during the design flood event.

The USV platform has also proven to be a valuable tool when performing underwater inspections. The detailed imagery can be used to identify underwater hazards and to verify inspection findings when underwater visibility is limited.

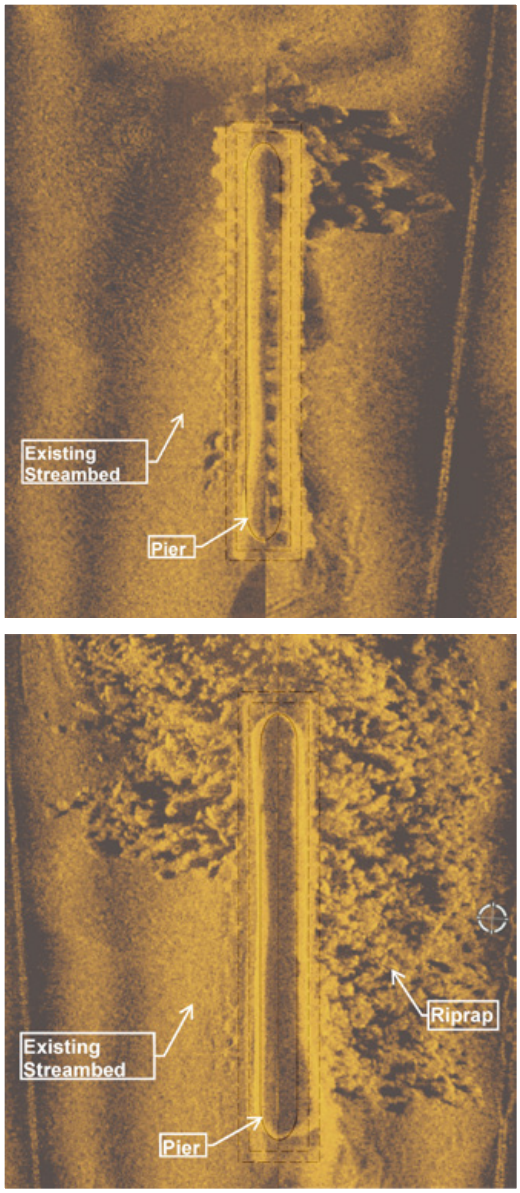
"We have integrated the use of this USV platform into our routine and high-risk dive operations to identify hazards, to monitor and assist divers during the dives, and for additional data that are not attainable during the dive," says Casey Collings, a project manager with a private engineering group. "The platform has made our higher risk dives safer."

Use of the USV platform for scour monitoring is crucial to improving inspector safety and ensuring that the transportation systems remain safe for all users during and after flood events. Information gathered by USVs during flood events or during routine inspections will assist owner agencies with managing these assets in a more effective and efficient manner.

RALPH PAULY, P.E., is the assistant structures engineer for FHWA's Michigan Division. He provides oversight of State compliance with the National Bridge Inspection Standards; technical guidance to ensure that regulatory mandated requirements are met; leadership on Federal-aid eligibility; structural asset management and structural preservation; and technical support as requested to Division staff on structural, geotechnical, and hydraulic issues. He earned both a B.S. and an M.S. in civil engineering from Michigan State University.

CHAD SKROCKI, P.E., is the assistant region bridge engineer for MDOT's North Region. He serves as a regionwide resource and is involved in the routine bridge inspection program, annual bridge call for projects, bridge maintenance and construction, and many other tasks associated with managing the North Region's bridge inventory. He served as the project manager for the recent research project titled Unmanned Surface Vessels for Bridge Scour Monitoring. He earned a B.S. in civil engineering from Michigan Technological University.

For more information, see *www.michigan.gov/mdot/0,4616,7-151-9622_11045_24249-487023--,00.html* or contact Chad Skrocki at *skrockic@michigan.gov* or Ralph Pauly at *ralph.pauly@dot.gov*.



Before (top) and after (bottom) sonar imagery collected as part of a construction inspection for placing riprap.

© Chad Skrocki, Michigan Department of Transportation.

Here, MDOT's USV is being used to aid visual inspections of bridges and culverts with reduced freeboard both with (left) and without (right) the canvas boat cover.

© Chad Skrocki, Michigan Department of Transportation.

CARMA℠: MARITIME ADMINISTRATION CDA DEVELOPMENT AND TESTING

Can applying cooperative driving automation (CDA) systems increase efficiency and safety and decrease emissions in a port environment? The CARMA Program's testing aims to find out.

by **HYUNGJUN PARK**, **KIRK CLAUSSEN**, **LINDSEY GROOMS**, **KATIE BLIZZARD PISKAI**, and **ED LESLIE**

Urban streets, commuter corridors, work zones—all of these environments can benefit from the implementation of cooperative driving automation (CDA) technologies. But the benefits of CDA are not only for passenger travel. The Maritime Administration, the Federal Motor Carrier Safety Administration (FMCSA), and the Intelligent Transportation Systems Joint Program Office (ITS JPO) have partnered with the Federal Highway Administration's Saxton Lab to explore CDA applications to port drayage and commercial motor vehicle operations.

This multifaceted project began in 2019 and will be completed in 2022. Its primary goal is to use CDA to improve the performance of maritime ports and terminals along with the larger freight network. The project aims to develop and test use cases for port drayage and commercial motor vehicle operations that leverage CDA-equipped commercial vehicles to increase efficiency and safety and decrease emissions.

This port drayage testing has two primary objectives: (1) to support the adoption of connected automated vehicle and CDA technologies in U.S. ports, and (2) to study the costs and benefits of automated truck movement in queues at ports and staging areas. By building on past research, the testing should provide some indication of possible benefits to port authorities and stakeholders.

"CDA technology offers the potential to significantly improve port operations," says Kevin Dopart, the program manager for vehicle and safety automation with the ITS JPO. "However, further use case development is necessary to demonstrate the concept to stakeholders, and data-driven analyses are needed to refine the technology to operate in the most beneficial way."

This project aims to fill these gaps by developing and testing proof-of-concept use cases for a test track, initially with a real CDA-enabled Class 8 tractor and trailer and later with CDA-enabled, automated, small-scale model trucks.

FHWA and its partners are developing the CDA-enabled model trucks as part of the CARMA 1Tenth program. The program is inspired by the F1TENTH program, an effort founded by the University of Pennsylvania that now partners with dozens of universities and organizations worldwide. F1TENTH holds regular racing competitions focused on advancing automated driving system education on scaled-down autonomous vehicles. CARMA 1Tenth works to incorporate CDA into F1TENTH's efforts.

This research builds on FHWA's CARMA Platform℠, which provides open-source software for the research and development of CDA capabilities. The port

Researchers are using a test fleet of four CARMA-equipped commercial motor vehicles to explore CDA technology for freight, including at maritime ports.

Source: FHWA.

drayage use cases will extend the CARMA ecosystem to explore the benefits of CDA for the Nation's ports and their stakeholders.

Proof-of-Concept Testing

The team developed a high-level concept of operations for using CDA to improve drayage operations at ports, as well as a proof-of-concept test plan for demonstrating this concept using CDA-equipped commercial motor vehicles. In the demonstration, the trucks will self-navigate around a loop, starting and ending in a mock staging area lot for the loading and unloading of containers. Along this loop, each vehicle will enter a mock port (on a test track), get a container loaded onto its chassis, and stop at a virtual inspection point where vehicles "passing" inspection will continue onward and vehicles "failing" inspection will navigate to a holding area for further inspection. Passing vehicles will then traverse gate passage and emulate a short-haul drayage before returning to the starting location. The CARMA ecosystem's cloud capabilities (CARMA Cloud℠) will be used to manage the rules of this fleet as it drives through each of the activities.

The project will use commercial motor vehicles equipped with automation technologies, including CARMA, for this testing. The U.S. Department of Transportation currently maintains a fleet of four CDA-enabled commercial vehicles—three from FMCSA's Automated Commercial Motor Vehicle Evaluation (ACE) program and one from the FHWA CARMA Program. The FMCSA ACE program supports this project and several related efforts to promote the safe deployment of commercial vehicles with connected and automated vehicle technology.

CARMA-equipped vehicles like this truck are helping FHWA, MARAD, and FMCSA discover how CDA technologies can improve safety and efficiency for commercial freight.

Source: FMCSA.

The demonstration will use FMCSA and FHWA's combined fleet of CDA- and CARMA-equipped Class 8 tractor trailers at a test track. Researchers are considering the Aberdeen Test Center in Aberdeen, MD, and SunTrax in Auburndale, FL, for the testing.

Key trends indicate the need for greater operational efficiencies in ports where port drayage automation could help offset or overcome some limitations. The current atmosphere includes increased costs because of increasing port traffic, fluctuation in demand, larger vessels deployed by ocean carriers, rigid capacity limitations, and diverging needs of truck and marine terminal operators.

This map shows a proposed use case test route for port drayage at a test track. The commercial motor vehicle enters, is directed to one of three loading points (1, 2, 3), goes through a virtual inspection point (4), and then exits if it passes inspection or proceeds to a holding area (5) if it does not.

Original image © Google Earth. Overlay source: FHWA.

Looking Ahead

The next step after the proof-of-concept demonstration will be to develop and test a more enhanced port drayage automation use case customized for an actual port. The team is in the process of selecting a port by identifying and reaching out to candidate ports that show an interest in collaborating on this testing and meet the use case requirements. Once a port is selected, the team will develop a customized port drayage automation use case, and two demonstrations will take place sequentially. The first demonstration will use CARMA 1Tenth trucks and a model of the configuration of the selected real port. The second demonstration will use real CDA-enabled commercial motor vehicles at the selected port.

"This project is an exciting part of our multiyear research program that addresses critical freight movement and ITS infrastructure gaps," says Travis Black, the team lead for Port Development and Intermodal Planning for the Maritime Administration's Office of Ports & Waterways Planning.

For more information, see "CARMA℠: Enabling Collaboration and Ensuring Safety in Freight Operations" in the Summer 2020 issue of *Public Roads*. The CARMA open-source software is available on GitHub at *https://github.com/usdot-fhwa-stol*.

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FMCSA's ACE program uses CARMA-equipped freight trucks.

Source: FMCSA.

How 10 States Use, Evaluate, and Implement Nondestructive Evaluation Technology

State DOTs are adopting NDE techniques to manage pavement and bridge deck maintenance and repairs.

A bridge inspector uses the chain dragging technique to help identify delamination. While some States continue to prefer traditional methods like chain dragging, others are beginning to employ advanced nondestructive evaluation (NDE) technologies instead or in addition to these methods. FHWA spoke with 10 States about their use of NDE methods for assessing bridges and tunnels.

by **HODA AZARI**

Historically, State departments of transportation have relied primarily upon visual inspections to evaluate the condition of bridge decks. For suspect areas identified during the visual inspection, engineers use hammer sounding or "chain dragging" to further evaluate potential subsurface damage, such as delamination. Delamination occurs when deicing materials and water penetrate the concrete bridge deck down to the steel reinforcing bar. The steel corrodes until the force from the buildup of corrosion product cracks the concrete along the rebar mat, resulting in spalls and similar damage.

Advances in nondestructive evaluation (NDE) technology have enabled States to save inspection time and better assess the actual condition of bridge decks. The Federal Highway Administration NDE Program, in collaboration with the U.S. Department of Transportation's Technology Transfer program, recently conducted a comprehensive review of current practices and policies of those States that are using NDE technologies to complement visual inspections. FHWA researched published papers and conference presentations and also conducted interviews with key State asset owners.

The FHWA review primarily addressed bridge deck inspection and presented highlights of how bridge owners use NDE technologies to assist in managing bridges more effectively. The most common NDE methods used by States, primarily on bridge decks, pavement, and tunnels, are ground-penetrating radar (GPR), infrared thermography (IR), and impact echo. As part of the research process, each State also answered the question: "How can FHWA help with NDE knowledge and implementation?"

NDE Method	Description of Physical Principle
Ground-Penetrating Radar (GPR)	Ground-penetrating radar uses electromagnetic wave pulses in the microwave band of the radio spectrum to image the subsurface features in bridge decks or pavement. Radar reflections from inside the material are then imaged for evaluation. GPR can be deployed by hand or on push carts ("ground coupled") for a slow, more detailed inspection, or attached to a vehicle at traffic speeds ("air coupled"), but with some lost resolution in exchange for speed.
Infrared Thermography (IR)	Infrared thermography uses a camera that images the temperature of an object in lieu of inspecting the visual appearance of the object. Flaws in the bridge deck, pavement, or tunnel liner heat and cool at a different rate, providing a surface image of the location of the flaw.
Impact Echo	Impact echo is an acoustic or stress wave-based method in which stress waves are transmitted into the material and then reflected from features and flaws in the material.

Common NDE Methods.

The States discussed in this article also participated in at least one of the second Strategic Highway Research Program (SHRP2) projects by the American Association of State Highway and Transportation Officials (AASHTO): Nondestructive Testing for Concrete Bridge Decks and Nondestructive Testing for Tunnel Linings. Details of each State's participation, results, and reports can be found on the AASHTO SHRP2 program website at *http://shrp2.transportation.org/Pages/R06_NondestructiveTesting.aspx*.

While it is difficult to call any one State a lead NDE adopter because different States have different needs, examples of successful applications and case studies are provided in the following summaries and tables.

CALIFORNIA

While the California Department of Transportation (Caltrans) is researching and starting to implement newer NDE technologies, the agency's bridge deck inspections remain primarily visual. Like most State DOTs, Caltrans supplements and enhances its visual inspections with spotting scopes and similar visual aids. As a followup to the visual bridge deck inspections, hammer sounding and chain dragging continue to be the primary methods to further evaluate suspect areas.

Caltrans has some high-speed inspection programs in place for pavement inspection and crack detection. Cameras collect images of pavement and bridge decks and apply artificial intelligence technology to identify and determine details like crack locations, widths, and density. The program has proved highly effective, especially in urban areas where it is difficult to close lanes for conventional visual inspection.

As a result of its participation in the SHRP2 program, Caltrans is deploying some NDE techniques such as IR cameras and GPR.

Caltrans reported that air-coupled GPR enables an increased data acquisition speed of up to 50 miles (80 kilometers) per hour; however, this rate is not appropriate for every investigation. The agency also investigated automated hammer sounding. This technique can be done faster than walking speed and is yielding similar results to chain dragging. The main advantage of this technique is that it uses a rolling closure at about 20 miles (30 kilometers) per hour in lieu of complete lane closures.

In terms of barriers to additional implementation of advanced NDE techniques, Caltrans indicated that the primary limiting factor is resources. With the number of bridge decks in California, current applications of advanced NDE technologies are better focused on specific project-level investigations responding to known or anticipated problems. Caltrans is not yet routinely using GPR, IR, or any other common NDE technologies for bridge deck evaluations.

The agency indicated that GPR is a good tool, but it requires significant training and experience to use it effectively. It is not clear how to make GPR simpler or more accessible, but it is a valuable tool, and Caltrans says it should be pushed forward to become a more routine, turnkey-type inspection. Similarly, IR is also helpful and complementary to GPR, but it needs some continued internal development to deploy. Other NDE techniques, such as impact echo, are waiting in the wings but not quite ready for broad implementation. These techniques should continue to be researched and moved ahead as a complement to GPR and IR.

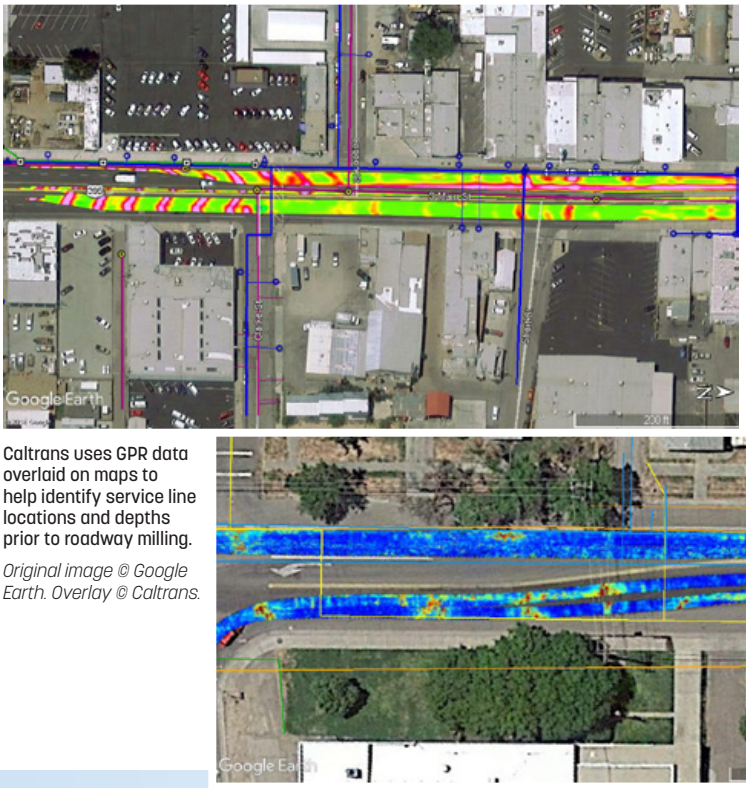
"Caltrans would like to see improvements and enhancements in existing NDE techniques," says Erol Kaslan, the State bridge maintenance engineer in the Division of Maintenance at Caltrans. "More research is required to make NDE methods more economical to use and less subjective, so that the advanced NDE methods can be routinely used. Cheaper versions of technology with little or simplified postprocessing of data would be the goal in that alternative."

Caltrans performs return-on-investment calculations to decide when and where to use NDE and to determine if it is worth implementing additional NDE technologies.

How Can FHWA Help?

When asked how FHWA can help Caltrans with NDE knowledge transfer and implementation in California, the agency noted that there seems to be a core group of States implementing these technologies. On a Federal level, it would be good to bring States together and share results so that they can hear about lessons learned, develop core experiences, apply certain best practices, transfer knowledge, and implement group training. Improved dissemination of information among the States would be beneficial so that they can keep in touch with each other to share experiences.

Caltrans also feels more work needs to be done in validating and evaluating the effectiveness of the various NDE methods. An unbiased assessment of the advantages and limitations of the methods would be more useful than relying on assessments from consultants and equipment manufacturers.



Caltrans uses GPR data overlaid on maps to help identify service line locations and depths prior to roadway milling.

Original image © Google Earth. Overlay © Caltrans.

COLORADO

The Colorado Department of Transportation (CDOT) applied NDE techniques as part of its SHRP2 tunnel inspection program. CDOT employed both IR and LiDAR (light detection and ranging) methods in the initial scans of some tunnels.

"CDOT ran the IR and LiDAR system at traffic speed (up to 35 miles per hour, or 56 kilometers per hour) so that the tunnel could initially be inspected much faster

State	Chain Dragging	Ground-Penetrating Radar (GPR)	Infrared Thermography (IR)	Impact Echo
California	• Evaluating suspect areas on bridge decks • Investigating automated sounding	• Inspecting pavement • Estimating recycled volumes for asphalt milling • Determining asphalt thicknesses for concrete overlay • Detecting delamination in suspect areas on bridge decks and in tunnel liners • Locating subsurface utilities • Measuring cover depth prior to milling operations to avoid equipment damage • Identifying clear areas for coring	• Using in conjunction with GPR • Detecting moisture in tunnel liner	• Detecting delamination in suspect areas on bridge decks and tunnel liners
Colorado	• Evaluating suspect areas on bridge decks • Hammer sounding tunnel liners	• Evaluating suspect areas on bridge decks	• Inspecting tunnel liners	• Using in trial evaluations of suspect areas in tunnels

Summary of NDE Technology Applications in California and Colorado.

than through manual inspections," says Tyler Weldon, a maintenance engineer with CDOT. "Where IR identified potential problems, CDOT manually investigated the areas with the conventional tunnel lining inspection techniques of visual inspection and tapping."

The agency found that the time required to collect, correlate, and analyze the data was not necessarily cost-effective relative to the information obtained from the inspections, and noted some data analysis repeatability issues. Correlating the images to the correct locations proved to be particularly cumbersome and time-consuming.

For bridge deck inspections, CDOT starts with a visual inspection and uses chain dragging to further investigate any suspect areas. Because NDE inspections provide the bridge inspectors with more detailed information about the condition of a bridge, CDOT looks at the NDE results when rating the bridge. For bridge decks with overlays, the agency brings in maintenance personnel for more examination and repair if the visual inspection identifies any suspected membrane problems. For inspections prior to a bridge deck rehabilitation, CDOT employs chain dragging and GPR to help with rehab quantity estimates.

In addition, CDOT applies various monitoring technologies, including accelerometers, tilt meters, and water flow meters, when the agency has particular concerns about a bridge or wall—often because of scour impacts.

While CDOT does not have any new NDE technology investigations in its plans, it keeps up with the latest NDE developments through vendors, other States, and the Transportation Research Board to help identify potential applications. The agency has investigated drone use, but because of

CDOT used this truck-mounted high-speed IR and LiDAR system in tunnel inspections.

State	Chain Dragging	Ground-Penetrating Radar (GPR)	Infrared Thermography (IR)	Impact Echo
Indiana	• Detecting debonding in overlays	• Detecting where chlorides have migrated into bridge deck using high-speed GPR • Predicting when and where problems can occur	• Evaluated to identify suspect areas, but not currently implemented	• Detecting debonding in overlays
Iowa	• Using manual and automated sounding on bridge decks to evaluate suspect areas	• Not applicable (high salt buildup in concrete, due to Iowa's climate, precludes the use of GPR)	• Evaluated, but found polished rock aggregate causes reflection problems	• Uses cart-based system on bridge deck overlays
Louisiana	• Evaluating automated sounding to better plan hydro demolition	• Inspecting decks and deck joints using high-speed GPR	• Inspecting bridge decks and deck joints	• Assessing fire damage to bridge decks • Measuring pile depths for scour evaluations

Summary of NDE Technology Applications in Indiana, Iowa, and Louisiana.

the involvement required (such as trained pilots) and high costs, CDOT does not anticipate a broad implementation of drones for its inspections.

How Can FHWA Help?

When asked about what else FHWA can do to help CDOT with NDE knowledge and implementation in Colorado, the agency responded that it always seeks to keep up to date on new NDE technology. Peer exchanges are particularly valuable for this effort. CDOT noted that the Western Bridge Preservation Partnership may be a group to further investigate for partnership or information exchange opportunities because NDE fits into part of its objectives.

CDOT cautioned that while new NDE technology offers some useful applications, it is not always a cost-effective solution, and forcing new technology on the States should be avoided. While FHWA guidance helps, States should determine if and when new NDE technology would be useful and cost-effective for a particular project or program.

INDIANA

The Indiana Department of Transportation (INDOT) participated in the SHRP2 study and scanned over 200 decks using air-coupled GPR. The agency used the results to assist engineers with programming decisions. INDOT viewed the SHRP2 meetings as helpful to better learn what other States have been doing with their evaluations and implementations of NDE technology.

"Bridge NDE inspection is becoming a larger part of INDOT's program to manage bridges. The NDE data are used to predict when and where problems can occur and to define deteriorated areas, including delamination," says Anne Rearick, the director of bridge management at INDOT.

While INDOT does have the ability to conduct NDE itself, it has found that consultants bring much more experience and sometimes apply proprietary software that does a good job. The agency enters the results into a database, and bridge inspectors may then use that information as part of their condition rating process. While INDOT does not perform return-on-investment calculations for NDE technologies, it does use the NDE data to develop bridge degradation curves and to make decisions about whether to repair or replace a bridge deck.

For future plans, INDOT came away from the SHRP2 study with questions about when and how to use GPR. As a result, the State is conducting further studies with IR, aerial IR, pole-mounted IR, and impact echo technologies with the intention of developing both project- and network-level NDE programs.

How Can FHWA Help?

When asked how FHWA can help further NDE knowledge and implementation in Indiana, INDOT noted that more emphasis should be given to support practitioners on how to best apply the various NDE technologies, including the collection, interpretation, and management of the data produced. Different recommendations are needed to address variables such as State geographies, weather, road treatments, and aggregates. INDOT is always looking to keep abreast of what is new in NDE technology and how it may help Indiana.

IOWA

For bridge deck inspections, the Iowa Department of Transportation (Iowa DOT) employs sounding as their most widely used and trusted technique, with repeatable and readily understood results. While almost all inspections are done manually, Iowa DOT has also investigated some automated hammer sounding systems to speed up the

A bridge inspector uses a cart-based impact echo system on a bridge deck in Iowa.

inspections. The agency concluded that while it does not necessarily save money performing automated inspections, inspections are completed much faster. Iowa DOT carried out validation tests and found that automated system results reasonably match the manual sounding results. In addition, the agency found the impact echo method—typically a cart-based system—to be the most reliable to inspect through concrete overlay bridge decks.

"The agency found that validation testing is the key to determine if an NDE technique does what consultants and equipment manufacturers claim," says Mike Todsen, a special projects engineer for Iowa DOT.

In one study, Iowa DOT compared the results from an automated system scan to their manual sounding results, with almost no correlation. "Without physical validation of the actual condition when using methods such as coring, the NDE results cannot be relied on," says Todsen.

Iowa DOT believes NDE can help in planning and decisionmaking, but has not done formal return-on-investment calculations to quantify the added value of NDE.

How Can FHWA Help?

Iowa DOT reported that it would like to see more work done by FHWA to evaluate the effectiveness and validation of the various NDE methods. An unbiased assessment of the advantages and limitations of the methods would be more useful than relying on consultants and equipment manufacturers. The agency would also welcome having advice available to pick the best NDE system and solution for a particular inspection problem.

LOUISIANA

The Louisiana Department of Transportation and Development (LADOTD) has experienced a culture shift toward the use of NDE technology. The agency believes chain dragging to be an aging technology, and typically only the more experienced inspectors still use it. The new generation of inspectors does not view chain dragging as the best technique.

The agency has employed high-speed GPR and IR to minimize or eliminate the need for lane closures, and as a way to prioritize which bridge decks need work.

"LADOTD has the third-highest bridge deck area in the country, and with such long bridges—some more than 17 miles [27 kilometers] long—it is not practical to chain drag all the decks," says Haylye Brown, an assistant bridge maintenance engineer for LADOTD Section 51. "LADOTD is proactive in the use of NDE and relies heavily on NDE techniques to help identify potential problems areas."

LADOTD noted that its NDE applications are working well. Program managers use the NDE data to plan repairs to bridge decks. Currently, LADOTD does not use NDE results as part of the bridge condition rating; however, it would like to pursue this capability and is investigating the possibility.

Regarding the use of other advanced NDE technology in the State, LADOTD is evaluating unmanned aerial vehicle (drone) technology and plans to provide a drone to every district for bridge inspection. The agency also noted that NDE technology is improving. High-speed GPR deck inspection used to be limited to around 34 miles (55 kilometers) per hour, and now, inspections are performed at up to 60 miles (96 kilometers) per hour.

How Can FHWA Help?

LADOTD indicated that FHWA could increase NDE knowledge and implementation in Louisiana by working to define what NDE personnel requirements should be specified and how to correlate NDE data to bridge element conditions. The agency would also appreciate ways to keep abreast of advances in NDE technology, including knowledge sharing about what is new and where best to use it.

LADOTD used this truck-mounted, high-speed impact echo system as part of its SHRP2 project.

The Nebraska Department of Transportation uses a truck-mounted, air-coupled GPR system to evaluate bridge decks.

© Nebraska DOT.

NEBRASKA

The Nebraska Department of Transportation (NDOT) reported that it conducted university-level research in NDE and completed some field implementations. NDOT inspectors routinely use visual inspection. If visual inspections indicate a concern, NDOT performs chain dragging or a more indepth inspection.

NDOT performs advanced NDE only at the project level and does not own its equipment for advanced NDE methods. The agency hires outside consultants for all advanced NDE. Under SHRP2, the consultants, along with a team from the University of Nebraska and Brigham Young University, carried out GPR and IR imaging on a variety of bridge decks. Because NDOT uses asphalt overlays extensively when rehabilitating bridge decks, it primarily wanted to determine how the NDE methods worked on overlaid decks.

"NDOT wants to apply NDE to help with estimating quantities for its rehabilitations," says Fouad Jaber, an assistant State bridge engineer for NDOT. "Overall, NDOT was satisfied with the technology's performance at estimating quantities on asphalt overlays."

While no specific return-on-investment calculations have been performed, NDOT believes these scoping inspections will save money by more accurately estimating the range of work.

"NDOT now has 2 years of preconstruction deck evaluation data that could be analyzed to see if 1) they correlate with lower unit cost for repairs, 2) they have been accurate when compared to paid quantities, and 3) there have been cases when repairs were not cost-effective because they were too extensive," says Kent Miller, a data management engineer at NDOT.

NDOT's university partners are also working on a traffic speed platform with several NDE methods.

How Can FHWA Help?

When asked how FHWA can help with NDE knowledge and implementation in Nebraska, NDOT noted that some NDE methods are easy to comprehend and interpret and some are more challenging. The agency does not have the training to interpret NDE data, so assistance in that area would be helpful. The agency must rely on the consultant and cannot, as the owner, do a good job on the quality control of the inspection process.

"The top NDE need for NDOT would be a way to determine when membranes are breached," says Miller.

The implementation of the SHRP2 project went well because NDOT received funding to apply new technologies, rather than having to fund the work internally. NDOT would like to see more of these kinds of projects to try new or proven technologies. It would be helpful if competitive funding were available that could be requested to evaluate and enable new NDE research, similar to the programs for evaluating ultra-high performance concrete. An FHWA program would enable the States to implement some of the new ideas they would like to see to fruition.

NDOT indicated that the Midwest Bridge Preservation Partnership would be a good forum to help spread any NDE news. There are also annual bridge preservation partnership meetings at which NDE news could be shared.

NEW MEXICO

The New Mexico Department of Transportation (NMDOT) primarily uses NDE to follow up on suspected areas identified in visual inspections. NMDOT reported that it employs NDE methods to help manage bridges on a project level, as well as to find problems that need repair, and then to establish projects to fix the problems. The agency also uses NDE results to help guide

A student researcher performs a GPR evaluation of a bridge deck in New Mexico.

© New Mexico DOT.

decisions on whether to preserve, repair, or replace bridge sections.

NMDOT identified a number of factors as barriers to implementing more advanced NDE techniques, including: 1) difficulty accessing all areas on elements other than bridge decks, 2) traffic control, 3) resistance from users because of the uncertainty of the data's usefulness, and 4) variability of results between inspectors. However, NMDOT indicated some successful NDE applications, in which NDE resulted in more precise results than chain dragging. For instance, the agency used ultrasonic testing to detect voids on bridge diaphragms and to inspect steel bridge pins to ensure that they were free of cracks.

"GPR is not a magic bullet, but it offers value when applied appropriately," says Kathy Crowell, a bridge design section manager for NMDOT's Bridge Bureau. "GPR can help determine whether a deck is a candidate for preservation versus replacement."

NMDOT found that GPR works well as a first pass, but a second, more indepth scan is necessary to produce the more detailed results critical to decisionmaking. For overlay inspections, NMDOT indicated that chain dragging is the most reliable technique it has used to detect debonded overlays. GPR seems to work in seeing through asphalt and epoxy overlay, but does not appear to work with some overlay materials such as latex-modified concrete.

How Can FHWA Help?

NMDOT indicated that FHWA could contribute to NDE training and education opportunities—particularly because of turnover in NMDOT staff. FHWA could also assist with a better way to keep apprised of advances in NDE technology, including webinars, NDE-focused videos, and peer exchange meetings. NMDOT indicated that it will be important to keep expectations reasonable when comparing NDE lab performance and real-world NDE performance.

OREGON

The Oregon Department of Transportation (ODOT) reported that it extensively employs chain dragging on concrete decks, and regularly uses magnetic particle inspection and ultrasonic inspection on steel bridge elements.

After performing some experimental projects using advanced NDE methods on concrete, the agency concluded that chain dragging will perform the same inspection as the more advanced NDE methods—and do it faster and cheaper. ODOT also felt that manufacturers oversold the capabilities of some of the advanced NDE technology, and the techniques did not necessarily do a good job at detecting delamination.

ODOT noted that it has had some successes in the area of structural health monitoring. "The agency monitored 13 bridges because of known, existing problems," says Steven Lovejoy, a senior mechanical engineer with ODOT. "ODOT monitored some bridges for just a few months and others for approximately 20 years, generally using strain gages or displacement transducers."

ODOT also noted that NDE results do not directly tie into the condition rating of bridges because the NDE results were difficult to correlate to an actual bridge condition, primarily because of issues in interpreting NDE data.

ODOT did not present any recent examples of the value of NDE being quantified for any projects. The agency discussed future plans to assess the cost of hiring an NDE consultant to scan a bridge deck to help estimate the extent of required repairs. This cost would then be compared to the cost of material overruns.

How Can FHWA Help?

When asked to highlight gaps between NDE technology that is available and potential future implementations in Oregon, ODOT responded that the procedure to take large amounts of raw NDE data and process these data to a point where they could be used to manage an asset (such as a bridge) is too difficult and inconsistent between operators. Despite ASTM standards to help regulate the process and make it more consistent than chain dragging, the data post-processing seems to add inconsistency. ODOT feels that it would be valuable if universal references and standards could be created to make the tests more repeatable.

PENNSYLVANIA

The Pennsylvania Department of Transportation (PennDOT) reported that it primarily uses visual inspection on bridge decks. However, it has used NDE data, such as GPR and IR, to manage bridges and tunnels on a limited basis on specific projects to help with decisionmaking.

Pennsylvania also participated in the SHRP2 program for bridge decks and considered it a success. The program familiarized the State with some of the advanced NDE equipment and technology. PennDOT has used the GPR unit it purchased as part of the SHRP2 project to scan bridge decks and help plan the type and amount of needed rehabilitation or repair work.

PennDOT concluded that GPR can be effective, but only on certain bridge decks and in certain circumstances, because getting bridge deck deterioration information takes a lot of analysis after the scanning.

"Uncertain accuracy in the NDE results and the time and cost involved to get the

State	Chain Dragging	Ground-Penetrating Radar (GPR)	Infrared Thermography (IR)	Impact Echo
Nebraska	• Evaluating suspect areas on bridge decks • Developing automated system with local universities	• Evaluating bridge decks to help estimate repair work	• Evaluating bridge decks	• Used infrequently
New Mexico	• Detecting debonding in overlay	• Checking for correct rebar placement when unexpected cracking occurs • Detecting delamination in bridge decks (used infrequently)	• Used infrequently	• Used infrequently
Oregon	• Evaluating bridge decks with high-speed automated sounding	• Inspecting bridge decks at higher speeds • Checking for correct rebar location and depth • Supporting identification of coring locations for concrete chloride testing • Locating subsurface utilities	• Evaluating bridge decks	• Performing experimental projects using high-speed impact echo system • Assessing bridge deck condition

Summary of NDE Technology Applications in Nebraska, New Mexico, and Oregon.

State	Chain Dragging	Ground-Penetrating Radar (GPR)	Infrared Thermography (IR)	Impact Echo
Pennsylvania	• Evaluating bridge decks and tunnel liners using hammer sounding	• Evaluating bridge decks to estimate repair work • Detecting deterioration under asphalt • Measuring asphalt thickness • Measuring rebar cover depth • Performing quality assurance inspections of the rebar cover depth on new bridge decks • Evaluating tunnel liners	• Evaluating bridge decks • Detecting moisture in tunnel liners	• Used infrequently
Virginia	• Detecting delamination and overlay debonding in concrete decks	• Evaluating bridge decks • Checking rebar placement on new decks • Evaluating suspect tunnel liner areas • Evaluating tunnel roadway	• Evaluating bridge decks • Inspecting tunnel liners using combination of IR and high-resolution videos • Checking for water intrusion in tunnel liners and culverts	• Evaluating suspect areas in tunnel liners

Summary of NDE Technology Applications in Pennsylvania and Virginia.

final NDE results are the main barriers to implementing NDE on bridge decks," says Tom Macioce, the chief bridge engineer in the Bridge Design and Technology Division of PennDOT's Bureau of Project Delivery. "PennDOT would like to see a standard GPR procedure or solution for data analysis and reporting, including detailed settings of equipment, better accuracy in the rebar identification aspect of the software and process, and more cooperation between academia and NDE equipment manufacturers."

PennDOT also performed some tunnel inspections as part of the SHRP2 program. The goal was to demonstrate and evaluate the ability of hand-held NDE methods and high-speed mobile scanning NDE methods, such as air-coupled GPR and vehicle-mounted IR, to detect deterioration and defects in concrete tunnel linings. The agency also tested traditional physical inspection techniques, including hammer sounding and coring, in some limited areas to evaluate the high-speed NDE results.

PennDOT concluded that no single technology by itself can provide all information needed to ascertain the condition of the tunnel lining. The agency believes that the best application for the NDE technology is to use one or two NDE methods in combination with traditional hammer soundings. PennDOT determined that while GPR correlated reasonably well with hammer soundings, GPR does not seem to be a practical solution over traditional physical methods for biennial inspections because of the cost and time required for data processing. However, cost and time may be reduced significantly during subsequent NDE inspections because test procedures would already be established.

PennDOT used this van-mounted GPR system to inspect tunnel walls.

© PennDOT.

In the tunnel IR testing, PennDOT found it difficult to obtain reliable and useful results for tunnel liners because the surface of the liner is not directly exposed to the sun for more active heating and cooling cycles. IR may be better suited to detect moisture-related anomalies in which the evaporative cooling is detectable.

PennDOT indicated several obstacles to greater highway application of NDE technologies. The cost and uncertain accuracy of NDE results are concerns, and sounding is still required. The software used to process and analyze the large amounts of collected data is not user-friendly and an experienced operator is required to run the software. For example, PennDOT received an estimate of 2,500 man-hours to convert digital photogrammetry data to drawings. Typically, the agency receives final NDE results within about a month of an inspection. In one case, it took 7 months to get a final NDE report.

How Can FHWA Help?

When asked how FHWA might better contribute to PennDOT's applications, the agency indicated that it would like to receive more updates about the general state of infrastructure NDE and to learn what NDE technologies and vendors have been evaluated by FHWA. FHWA could also help by continuing to share through the SHRP2 program what other States are doing. PennDOT would be interested in obtaining FHWA sponsorship every few years to participate in the updates.

VIRGINIA

The Virginia Department of Transportation's (VDOT's) bridge deck inspections are primarily visual and tactile in nature. When preliminary inspections indicate significant corrosion deterioration, the agency deploys more indepth methods such as chain dragging, sounding, and half-cell potentials. VDOT has used advanced NDE techniques like GPR, IR, impact echo, and ultrasonic tomography if the need arises.

VDOT's work on evaluating advanced NDE techniques concentrates on two areas. The first area of interest is the rapid screening of a bridge deck to quickly assess its condition without the need to close lanes. Lane closures not only interfere with normal traffic flow, but also are hazardous for highway workers on the bridge deck. The second area of interest is in using NDE methods to help determine the extent of damage to a bridge deck. This information becomes valuable in making repair decisions, estimating damage progression rates, and better estimating and planning repair material quantities.

"Virginia's bridge deck NDE research under the SHRP2 program evaluated GPR, IR, and high-resolution digital imaging NDE technologies on 25 bridges," says Soundar Balakumaran, the associate director at the Virginia Transportation Research Council, which is part of VDOT. "The inspections did not yield any significant new information when compared to conventional manual inspections. The tunnel lining interfered with IR, which did not appear to provide enough image contrast."

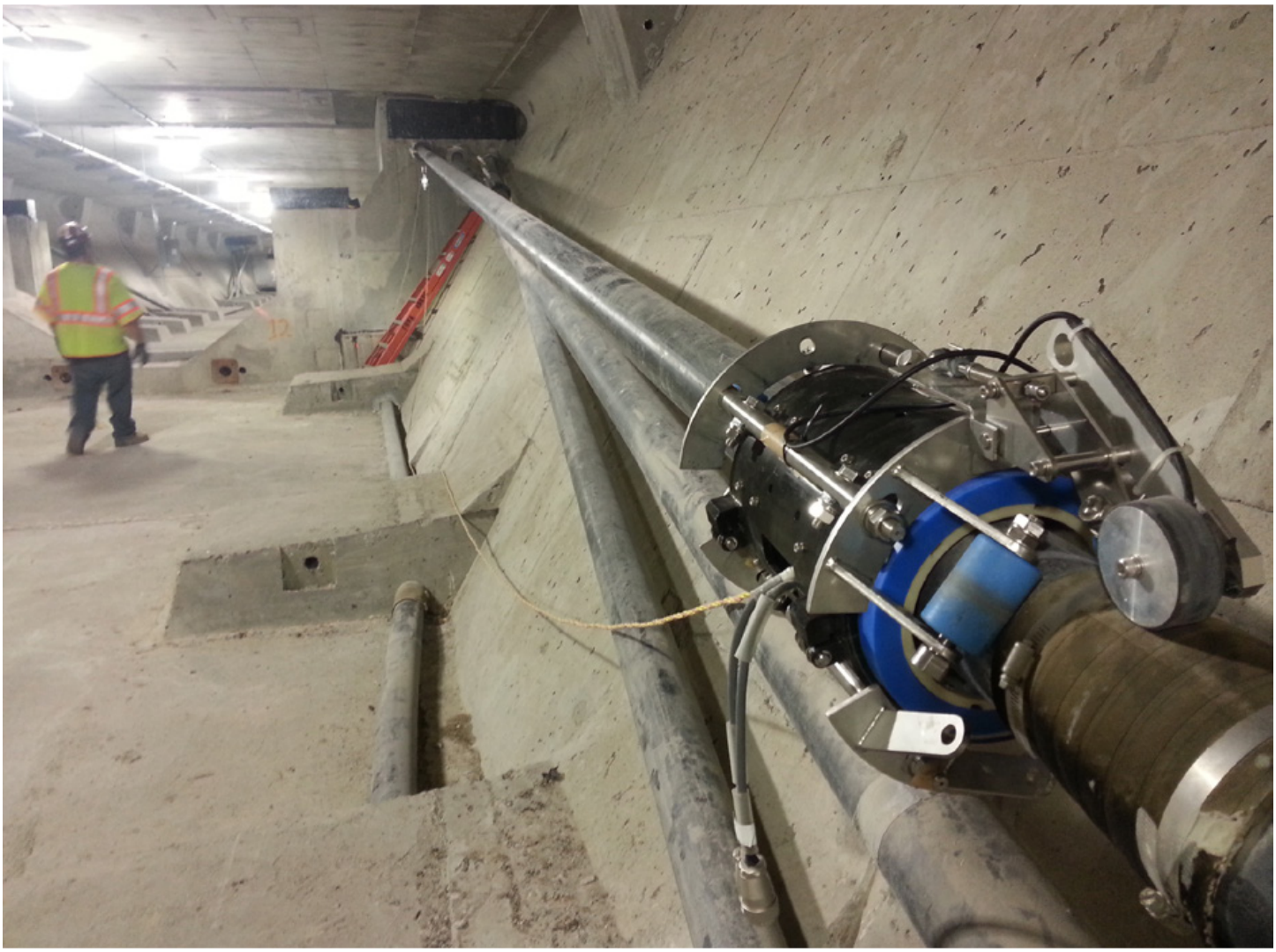
VDOT inspected a few of the suspect areas with a more thorough hand-held GPR scan and with impact echo. Those results correlated well with routine inspections.

VDOT also performed NDE research in several other areas such as time-lapse thermography and magnetic flux leakage inspections. Magnetic flux leakage is a method where a magnetic field is introduced in a steel cable or tendon and then magnetic field sensors are used to look for leakage fields that identify potential underlying damage. These are not routine inspections, and were used only for a few special investigations. VDOT employed a magnetic flux leakage NDE system to inspect some post-tensioned tendons with good results and verified the technology in the lab on a few mock-up tendons with prebuilt defects and found excellent correlation.

VDOT reported that its approach is to conduct research first, perform some trial projects on the more promising technologies, and then look for the best potential applications of the technology. The agency usually performs the initial implementation of new technologies with consulting companies. VDOT wants to implement the new

VDOT used this magnetic flux leakage NDE technique to scan a post-tensioned tendon inside a segmental box girder of a Virginia bridge.

© Virginia DOT.



technologies to reduce lane closures and save money, but first needs to validate each technology's performance.

There were many cases in which NDE methods saved VDOT money. In one example, initial tests showed that there may have been an issue with the cover depth of the reinforcing bar on a new bridge deck. A more detailed scan with GPR revealed that the entire top rebar mat had sunk due to misplacement and left a thick, unreinforced layer of concrete at the surface. The contractor replaced the entire deck before the bridge was put in service, avoiding the problems and resulting repairs that the issue would have caused.

How Can FHWA Help?

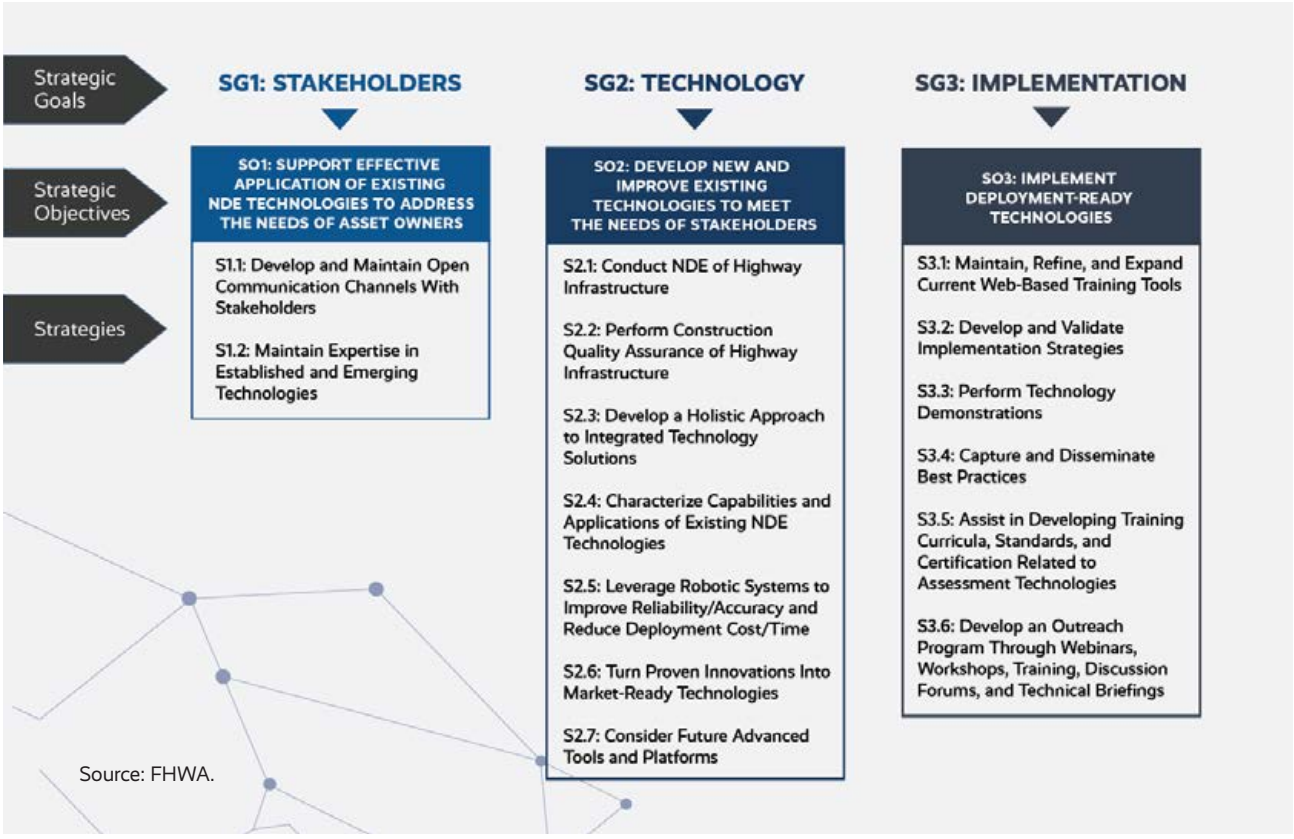
When asked how FHWA could better support VDOT's NDE applications, the agency stated that open communication, such as the discussions and demonstrations in the SHRP2 meetings, helps States to keep up with which NDE technologies are being used and which new ones are emerging for potential future applications.

SUMMARY

The FHWA review provides a snapshot of how 10 States use, evaluate, and implement both basic and advanced NDE methods as part of their bridge deck inspection and management programs. All States have applied NDE techniques at some level. Several of the sample States have successfully established advanced NDE technology. For example, Indiana and Louisiana have both improved their ability to efficiently manage bridge deck maintenance and repair through new NDE processes. While traditional chain dragging techniques remain the choice of some States, NDE technologies such as at-traffic speed GPR and IR have enabled some States to dramatically improve the value of their NDE information and inspection efficiency.

FHWA provided States with an opportunity to identify where they saw gaps between NDE knowledge and NDE implementation, and where FHWA can focus its support to close those gaps. FHWA is thoroughly evaluating and prioritizing these recommendations to ensure that the goals of the FHWA NDE program are addressing the needs of the States. The latest FHWA NDE Program Strategic Plan has incorporated these States' needs as the primary focus.

HODA AZARI is the manager of the NDE Research Program and FAST NDE Laboratory at FHWA's Turner-Fairbank Highway Research Center. She holds a Ph.D. in civil engineering from the University of Texas at El Paso.



The strategic plan for FHWA's NDE Program includes strategic goals and objectives for stakeholders, technologies, and implementation.

Source: FHWA.

The Research Associateship Program at FHWA provides mentorship and career-building opportunities for participants in facilities like the Structures Lab at Turner-Fairbank Highway Research Center and sometimes results in talented new hires for FHWA.

Source: FHWA.

FORMER RESEARCH ASSOCIATES FIND SUCCESS

FHWA's Research Associateship Program helps participants launch their careers—sometimes with FHWA itself.

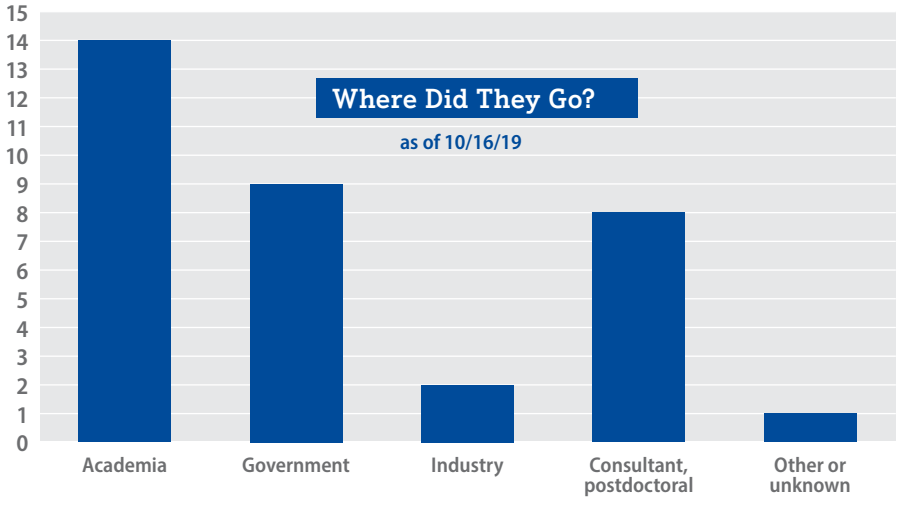
by **JIM SHURBUTT**

Postdoctoral candidates who apply for positions as research associates with the Federal Highway Administration do so to continue their research, make connections in their fields, and launch their careers. For some, career success is found right at the facility where they started as associates.

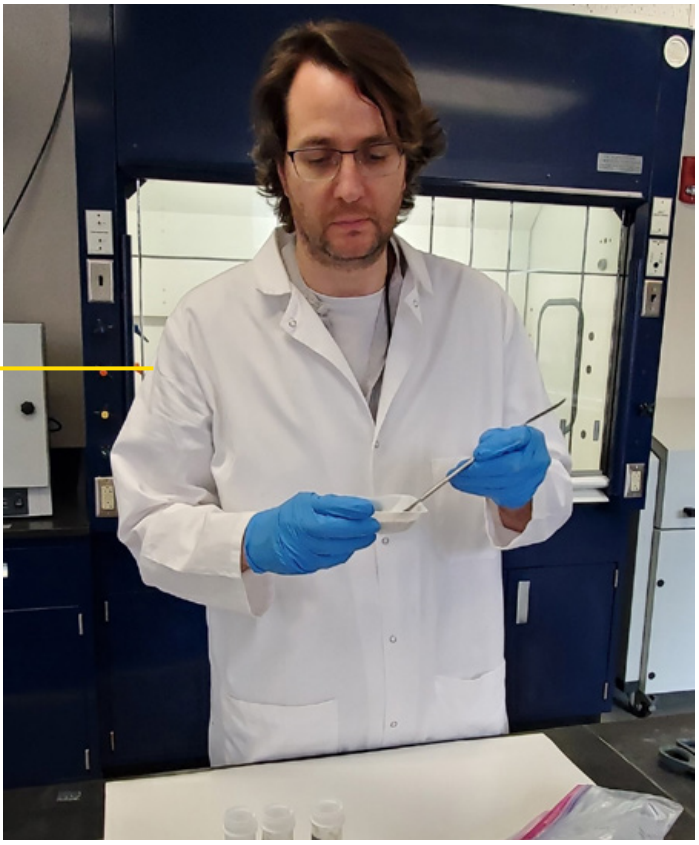
FHWA's Exploratory Advanced Research (EAR) Program funds research associates through the Research Associateship Program of the National Academy of Sciences. The EAR Program seeks qualified candidates to work on real-world transportation problems largely of their own choosing, provided the topics are compatible with FHWA's research interests. Associates work with FHWA advisers who mentor them throughout their tenure, which usually lasts for 2 or 3 years.

From 1992 through 2019, FHWA hosted 50 research associates at its Turner-Fairbank Highway Research Center (TFHRC) and its Headquarters office. Former associates have gone on to work in academia, government, and industry, as well as to work as consultants.

Four former research associates currently work at TFHRC, either as FHWA staff or as contractors. They have each gone directly from the program to positions that have enabled them to continue their research while expanding their professional expertise and developing their careers.



Former Research Associateship Program participants go on to work in a variety of fields.



Jose Munoz prepares fine aggregates for chemical analysis in the Chemistry Lab at TFHRC.
© Jose Munoz, SES & Associates.

Jose Munoz, Ph.D.

As an associate, Jose Munoz focused on the development of specific nanoadditives to improve the mechanical performance of the cement paste-aggregate interface in concrete—specifically, the fundamental aspects of the interaction between nanosilica coatings and concrete-based materials. Munoz worked under the guidance of Jack Youtcheff in the Office of Infrastructure Research and Development from April 2010 to April 2013.

Munoz then was hired to work as a contract researcher in the TFHRC Chemistry Laboratory, where today he is the contracted laboratory manager.

"My main motivation to accept the job offer at TFHRC was my passion for research. TFHRC is probably one of the few places in the United States that offers such a unique opportunity to do research on concrete-related materials," says Munoz. "Another important factor was the balance between fundamental and applied research that could be done at TFHRC."

Munoz currently works on two projects. One is to develop a new screening test to assess the alkali-silica reactivity of aggregates used in concrete. The other is a collaboration between the Chemistry Laboratory and the Structure Laboratory at TFHRC, which is a continuation of the work he did as an associate. It is a project to develop nanosilica-based thin films to improve the bond in prefabricated bridge element connections.

Munoz cites several benefits he received from his participation in the Research Associateship Program, including strengthening his resume because of the prestige of the program, conducting research and publishing manuscripts, and networking with colleagues at TFHRC and other institutions.

"Thanks to the program, I had the unique opportunity to join the TFHRC team as a contractor and pursue both fundamental and applied research," he says.

David Mensching, Ph.D., P.E.

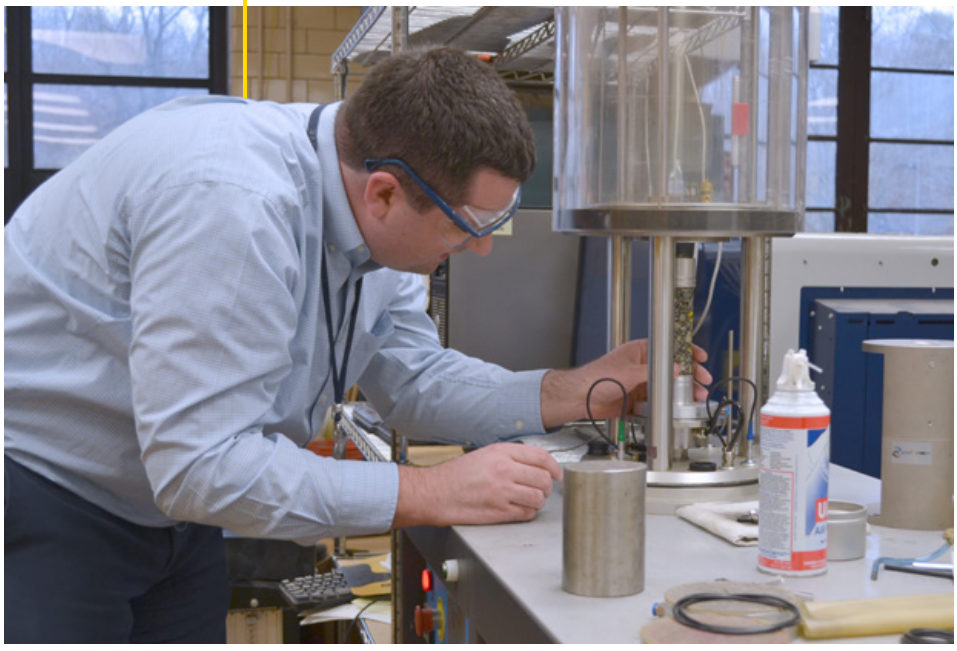
David Mensching served as a research associate from May 2015 to August 2016, working with former FHWA employee Nelson Gibson in the Office of Infrastructure Research and Development. As an associate, Mensching researched performance-based mixture design and rheological parameters for asphalt mixture and binder characterization. After his tenure as an associate, he was hired as an asphalt pavement engineer at TFHRC. Today, he is FHWA's asphalt materials research program manager and serves as an adviser to current associates.

"My time as an associate was for exploration and network building," says Mensching. "The associateship was my first chance to lead research from conception to completion. That's invaluable experience that can't be had in many places and in many postdoctoral positions."

As an associate, Mensching published extensively, which he says built national expertise. He also took advantage of the travel budget he was given to present on his research and improve his work.

Given the opportunity to stay on at TFHRC, he took it. "You have so many possibilities for cross-cutting transportation research, and the people here are welcoming, bright, and motivated. TFHRC's leaders have research backgrounds and expertise themselves, which allows for deeper cultivation of thought and creativity," he says. "It's really an unparalleled location for intellectual growth."

Mensching's career path has taken him from his associateship to managing a program of 11 other researchers, including one associate. He has gone from narrowly focusing on one project as an associate to managing a program with a broad portfolio of original research covering topic areas such as reclaimed asphalt pavement, performance specifications, long-life wearing courses, asphalt binder specifications, artificial intelligence, connected pavements, and resilience.



David Mensching sets up a dynamic modulus test in the Asphalt Mixture Performance Tester.
Source: FHWA.

Rafic El-Helou installs sensors to measure the deformation of a UHPC beam in FHWA's Structures Laboratory.

Source: FHWA.

Pavle Bujanović, Ph.D.

Pavle Bujanović spent 2 years at TFHRC as a graduate research fellow under FHWA's Eisenhower Transportation Fellowship Program before serving as a research associate from August 2018 to August 2019. Under the guidance of his adviser, Taylor Lochrane in FHWA's Office of Operations Research and Development, Bujanović worked on developing cooperative driving automation (CDA) algorithms, specifically localization and platooning algorithms. He also worked on adding the CARMA Platform℠ to one of the vehicles in FHWA's CARMA fleet.

FHWA hired Bujanović to join the staff of the Office of Operations Research and Development as a highway research engineer at the end of his associateship.

"I work to increase the safety and efficiency of our Nation's infrastructure through CDA strategies that are designed and tested in the CARMA ecosystem," says Bujanović. "I also help promote CARMA and invest in relationships with different people and organizations that are interested in CDA research. I'm still involved in technical design, as I was before, but now I'm also contributing to the direction of the entire CARMA Program."

Bujanović praised the Research Associateship Program as a valuable research experience with excellent resources and opportunities to help recent doctoral graduates pursue their research, in part because of the freedom and flexibility the FHWA mentors provide associates in their choice of projects.

As a staff member with FHWA's CARMA Program, Pavle Bujanović has continued and expanded the work he started as an associate.

Source: FHWA.

Rafic El-Helou, Ph.D.

As a research associate, Rafic El-Helou worked on the structural behavior of prestressed ultra-high performance concrete (UHPC) girders and on the development of structural design guidance for UHPC bridge components. He worked with adviser Benjamin Graybeal in FHWA's Office of Infrastructure Research and Development from December 2016 to October 2019.

A private firm hired El-Helou directly out of the program to work as a contracted structural research engineer at TFHRC.

"I am passionate about the research I started during my tenure as an associate and wanted to continue the work after my tenure ended," says El-Helou. "I also enjoy the work environment and the collaborative research experience at TFHRC."

El-Helou's current research is a continuation of his work as an associate. "I am part of the TFHRC team that supports FHWA's efforts to develop structural design guidance for UHPC," he says. "I also research various UHPC applications in the highway sector."

Like other alumni of the associateship program, El-Helou would recommend it to others. "The program connected me with experts in my field and provided me with mentorship to kick off my career. It also provided the means for numerous professional development opportunities," he says. "It's a great start to your career in a reputable laboratory."

Become a Research Associate

The EAR Program actively seeks qualified postdoctoral candidates to participate in the Research Associateship Program, where they will work with leading researchers, have access to state-of-the-art laboratories and equipment, and expand their career possibilities. To learn more about RAP opportunities through the EAR Program, visit *https://highways.dot.gov/research/research-programs/exploratory-advanced-research/nrc-research-associates-help-ear-program-solve-transportation-issues* and click on the Apply link to view the list of current opportunities available at FHWA.

JIM SHURBUTT is the program coordinator for FHWA's EAR Program. One of his primary responsibilities is the management of the Research Associateship Program. He holds a Ph.D. in applied behavior analysis from Western Michigan University, where his research focused on both pedestrian safety and organizational management.

FHWA and its partners are aiming to make the use of aggregates in pavement more sustainable. Here, crushed stone is processed and shipped from a plant at a granite quarry in Virginia.

Source: FHWA.

Looking to AGGREGATES to Improve Pavement Sustainability

FHWA is conducting research, developing tools, and gathering data to improve how aggregate materials are sourced, planned, and used in sustainable pavement construction and maintenance.

by **RICHARD MEININGER**, **HEATHER DYLLA**, and **JACK YOUTCHEFF**

Aggregate is a critical element in the construction, maintenance, and repair of roadways and concrete structures. However, the aggregate resources needed for the construction and maintenance of highways, local roads, and streets, as well as for basic materials for concrete structures and drainage applications, often are not given sufficient consideration early in the planning and design process. Planners and engineers need to consider: What are the local natural and recycled aggregate resources and are they of the quality needed for anticipated pavement layer construction, overlays, and preservation treatments?

Natural aggregate availability depends on the regional geologic resources and whether those resources can be mined and transported in a long-term, sustainable way to the major construction markets. There are significant challenges to managing resources for the reuse or recycling of reclaimed asphalt pavement (RAP) and recycled concrete aggregate (RCA). In rural areas, the reclaiming and recycling of aggregates can be done on a project-by-project basis, ensuring more consistent quality, but it is expensive and inefficient to move these low-value materials long distances to other projects. Combined RAP stockpiles and

urban rubble recycling of concrete, brick, and stone are common in many metropolitan areas, but create more variable quality for these resources.

To help address these challenges, researchers at the Federal Highway Administration's Turner-Fairbank Highway Research Center (TFHRC), along with other partners, have been researching the physical and chemical factors necessary to effectively deploy both natural aggregates and recycled materials in the major components of pavement construction and maintenance. These components include aggregate base courses for pavement foundation layers, compacted asphalt mixtures for bases and surface courses, and concrete pavements used extensively for heavy traffic and mainline highway pavements.

In addition to this research, FHWA has expanded its Sustainable Pavements Program, offering educational resources and tools to help project planners and highway engineers consider the impacts and costs of choosing pavement options in a holistic way. The program's vision is to increase the knowledge and practice of designing, constructing, and maintaining more sustainable pavements. To accomplish this vision, the Sustainable Pavements Program strives to educate and support stakeholder needs by producing technical resources, creating training opportunities, developing tools, and facilitating conversations through stakeholder meetings.

In particular, over the past 20 years, FHWA has partnered with the International Center for Aggregates Research and committees of the Transportation Research Board and the American Association of State Highway and Transportation Officials in shaping research and engaging with stakeholders to gather information and ideas on technical priorities and needed research approaches to improve the performance of pavements and materials, resulting in the Aggregate Research Roadmap. The roadmap is revisited and updated regularly to keep it current and match priorities to research needs.

Sustainability and the Triple Bottom Line

Sustainability is a quality that reflects the balance of three primary components: economic, environmental, and social impacts, which are often collectively referred to as the triple bottom line. Considering sustainability during the transportation decisionmaking process is not new. Typically, the environmental and social impacts are quantified during the conceptual design phases as part of the environmental review process, while cost-effectiveness is a consideration in pavement design. However, there is growing recognition in the industry that the pavement design, material selection, and construction phases, including aggregate mine sources, transportation, and aggregate recycling, contribute significantly to all three pillars, and thus opportunities for improvement exist.

Source: FHWA.

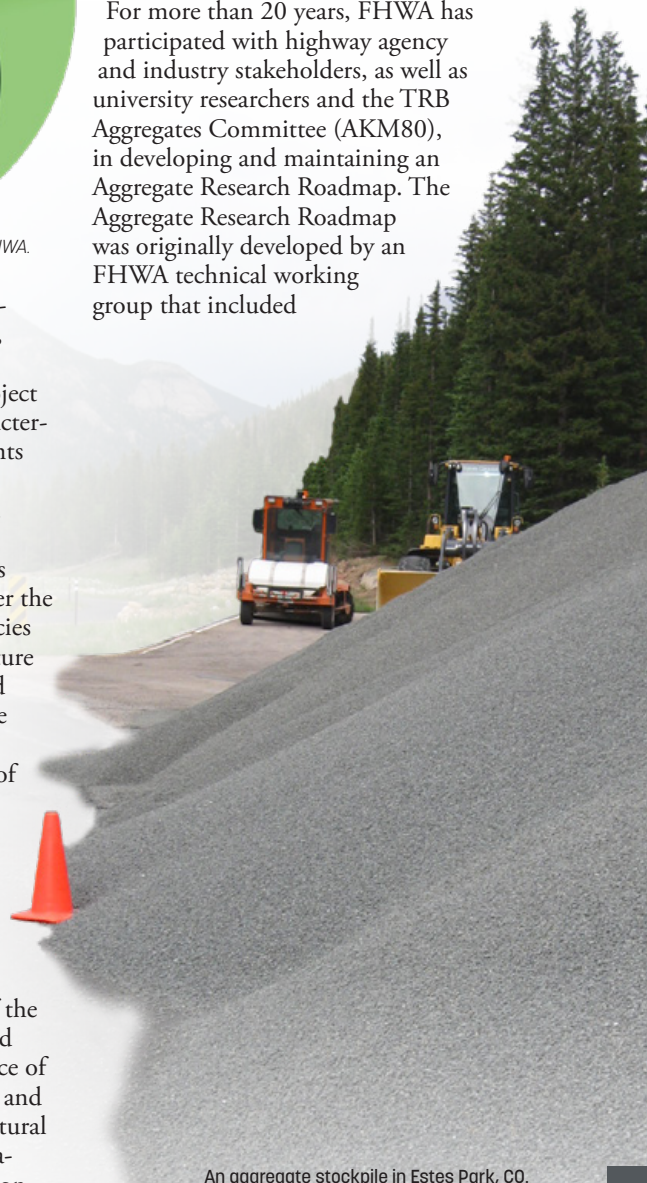
The relative importance and consideration of each of the economic, social, and environmental impacts factors are context-sensitive and driven by the project goals and performance demands, characteristics, location, materials, and constraints of a given project, as well as the overarching goals of the sponsoring agency. By designing, constructing, restoring, preserving, and maintaining pavements that consider the triple bottom line over the project's life cycle, transportation agencies can develop a more resilient infrastructure system with increased performance and a high return on investment despite the growing constraints on economic and material resources, such as availability of local crushed stone, sand, and gravel.

"Aggregates are the most predominant material in highway and other transportation applications," says Matthew Beeson, Director of Materials and Tests, Indiana Department of Transportation and Chair of the Aggregates Technical Subcommittee of the AASHTO Committee on Materials and Pavements. "Improving the performance of aggregates used in current applications and expanding the use of and sources of natural and recycled aggregates for new applications will make a significant contribution toward creating a sustainable society and extending the performance of infrastructure containing aggregates."

Some areas and regions of the country have experienced aggregate shortages for certain highway pavement applications that have necessitated longer transportation distances for aggregates that meet project requirements. Some of these inefficient and unsustainable practices have been prompted by method (rather than performance) specifications or pavement design practices that have not considered the best uses of certain local natural aggregate characteristics, nor considered whether local recycled or reclaimed aggregate products can be used instead to construct or rehabilitate quality, long-lasting pavement layers.

A Roadmap to Research Success

For more than 20 years, FHWA has participated with highway agency and industry stakeholders, as well as university researchers and the TRB Aggregates Committee (AKM80), in developing and maintaining an Aggregate Research Roadmap. The Aggregate Research Roadmap was originally developed by an FHWA technical working group that included


An aggregate stockpile in Estes Park, CO.
Source: FHWA.

Source: FHWA.

university researchers, State departments of transportation, and aggregate industry representatives. In cooperation with the International Center for Aggregates Research, and later, in collaboration with TRB and AASHTO aggregate committees and subcommittees, these stakeholders helped shape aggregate research conducted over the past two decades.

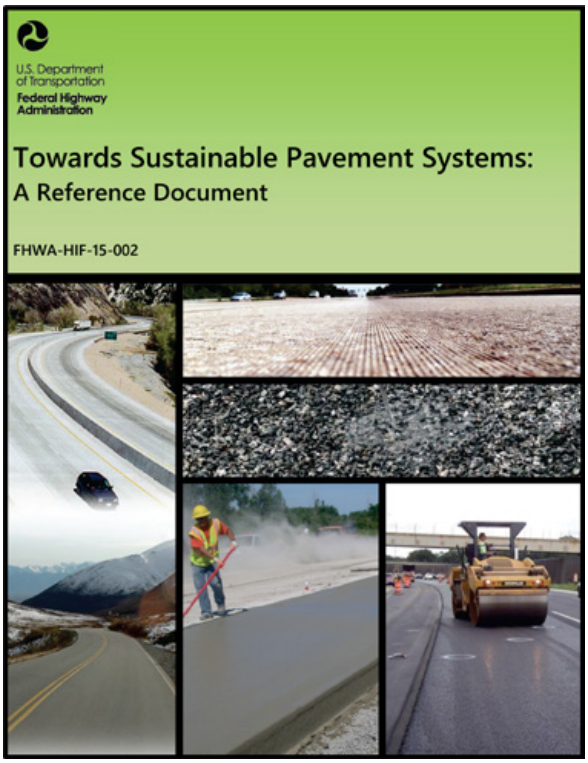
Discussions about the needs for pavement technology research and the periodic review of the roadmap have resulted in many research needs statements, such as those vetted by TRB and AASHTO, and aggregate research projects funded by the States, industry, and FHWA. Roadmap priorities have led to completed research projects and syntheses recommended through TRB and conducted by the National Cooperative Highway Research Program, universities, and agencies. These include completed projects on compacted aggregate base course properties and aggregate-specific gravity research, and syntheses on granular base course construction and on aggregate quality criteria.

Resources for Sustainable Pavement Systems

FHWA's Sustainable Pavements Program provides webinars, tools, and resources developed and presented to the pavement community that consider the elements of the triple bottom line of sustainability that are impacted by pavement design, aggregate choices, and pavement life cycle performance. Through the program, FHWA has developed tools to aid in choosing sustainable options for aggregate sources, transportation, and recycling, as well as showing how better performance and timely preservation are significant inputs into life-cycle analysis and pavement management concepts.

In 2015, the Sustainable Pavements Program published *Towards Sustainable Pavement Systems: A Reference Document* (FHWA-HIF-15-002), which walks through the pavement life cycle and highlights potential strategies for improvement. The publication identifies context-specific, potential strategies for sustainability improvements, including strategies for aggregate production and use. Strategies for aggregates include reducing virgin aggregate use by using recycled waste materials, using more durable aggregates to maximize pavement life, reducing hauling distances by selecting local materials, and improving aggregate acquisition and processing. Building on the publication, FHWA offered a 10-part webinar series in 2019 and 2020 on the key concepts and practices related to pavement sustainability to help engineers begin identifying potential environmental, economic, and social impacts of decisions. The webinar recordings are available at *www.fhwa.dot.gov/pavement/sustainability/webinars.cfm*.

Tools exist to quantify and assess the sustainability performance and to help agencies review sustainability strategies and take a holistic life cycle approach to balance tradeoffs. For example, FHWA's RealCost tool, available at *www.fhwa.dot.gov/infrastructure/asstmgmt/lccasoft.cfm*, can help with life-cycle cost analysis. For pavements, life-cycle cost analysis provides a way of measuring the economic consequences of choices in design, materials, construction techniques, construction windows, maintenance schemes, and end-of-life treatments over a prescribed analysis period. Many State agencies have life-cycle cost analysis policies and procedures in place.



Source: FHWA.

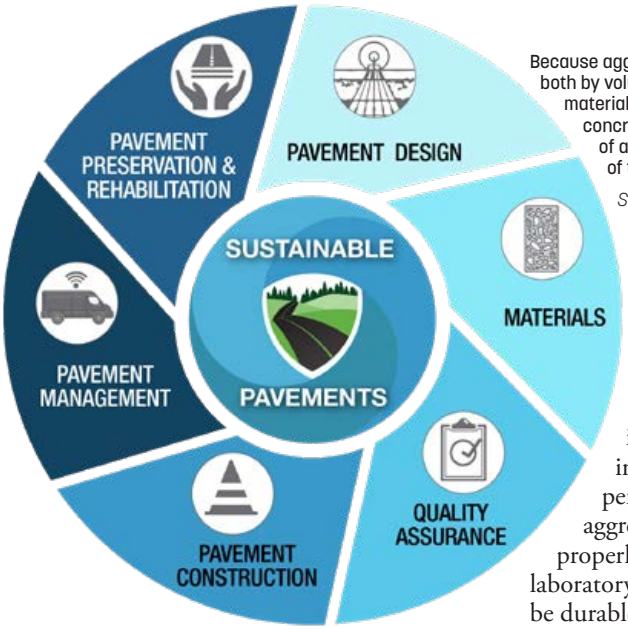
Life-cycle assessment (LCA) is a methodology used to evaluate a range of environmental impacts, such as potential for climate change, ozone depletion, acidification, eutrophication, and smog formation. Over the last decade, FHWA, along with its partners from transportation agencies and industry, have conducted substantial work to incorporate LCA into the pavement investment decisionmaking process. One resource is FHWA's LCAPave, a new tool that is currently going through FHWA's publication process after a successful beta test, which can help agencies understand the environmental impacts of material and design choices. LCAPave can incorporate aggregate producers' specific data, via environmental product declarations, or can help make generic assessments of different mixture and pavement designs, such as inverted pavements compared to conventional designs. FHWA has a pooled fund project for States interested in trying LCAPave in a demonstration project; for more information, visit *www.pooledfund.org/Details/Solicitation/1542*.

Social indicators are an important pillar of sustainability, but harder to assess. Social impacts from pavement and material decisions can include both short-term construction and long-term operations factors, such as noise, traffic, safety, materials hauling, resource conservation, and ride quality. To stay abreast on the latest topics of pavement sustainability, join the FHWA Sustainable Pavements Friends list by signing up at *https://public.govdelivery.com/accounts/USDOTFHWA/subscriber/new?topic_id=USDOTFHWA_146*.

Pavement Sustainability Sectors

Recently, FHWA refined and restated the core objectives of the pavement program to emphasize the importance of constructing and managing quality pavements through the full life cycle, while also meeting community objectives. These objectives and categories were developed through the collaboration of the pavement and materials team leaders within FHWA's Office of Infrastructure, Office of Infrastructure Research and Development, and Resource Center.

All phases of the life cycle are important in meeting the core sustainability mission, and since aggregates are the predominant constituent both by volume and mass in



Because aggregates are the predominant constituent, both by volume and mass in the various pavement materials and layers (bases, asphalt, and concrete), the selection and quality assurance of aggregates play a major role in all segments of the pavement life cycle wheel.

Source: FHWA.

the various pavement materials and layers (bases, asphalt, and concrete), the selection and quality assurance of aggregates play a major role in all segments of the pavement life cycle. These sustainability sectors are pavement design, materials, quality assurance, pavement construction, pavement management, and pavement preservation and rehabilitation.

Pavement design and pavement type are often influenced by local and regional aggregate sources and quality, as well as by the properties of the subgrade soil.

Materials used in pavements and structures can be much more successful and durable when specifications and test methods for the individual aggregates, and for the performance of mixtures containing aggregates, have been developed to properly characterize materials in the laboratory and in mixture designs that will be durable in service, and to facilitate efficient production and placement in the field.

Quality assurance is the backbone for durable, long-lasting highways and pavements. Owners and engineers have the responsibility to provide inspection, sampling, testing, and verification that construction using aggregates is in conformance with the plans, specifications, and materials designs. This includes ensuring that laboratory and field quality assurance personnel are qualified in the specialized sampling techniques for aggregate from stockpiles, bins, and roadway placements.

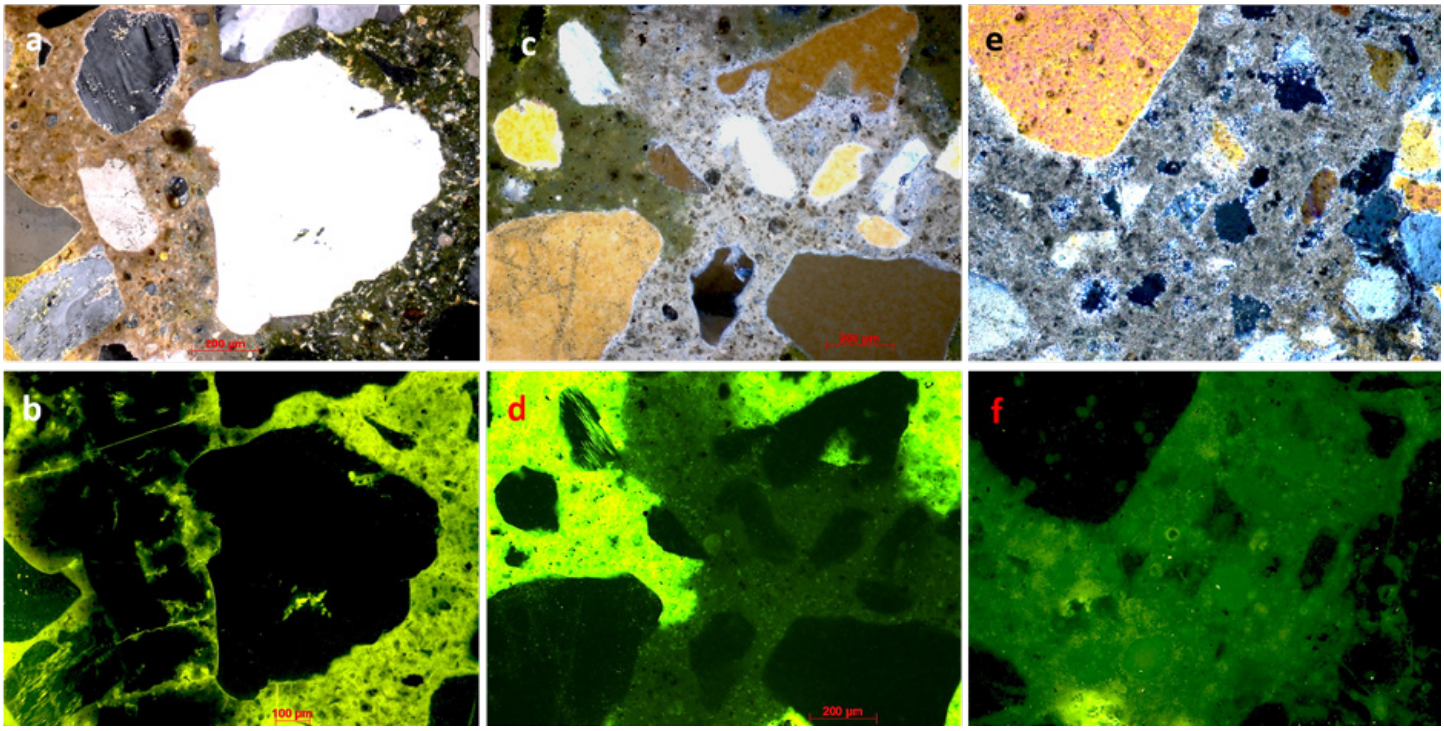
Pavement construction involving the placement and optimum compaction of granular aggregate bases can be challenging in that segregation needs to be avoided in all phases of recovery from stockpiles and bins, truck delivery, and spreading aggregate on the grade.

Pavement management depends on the acquisition of periodic data on rideability, friction, rutting, cracking, and profile and drainage issues. Aggregates exposed at the wearing surface contribute to the duration of sufficient macro- and micro-texture to provide needed traction in wet weather. Aggregate selection and performance can also contribute to the likelihood of rutting, drainage, and durability problems causing spalling, raveling, and water accumulation.

Pavement preservation and rehabilitation treatments and methods often require special attention to aggregate grading and quality. Even for pavements that have deteriorated, the aggregate bases can often be considered a valuable asset that can be reshaped, rehabilitated, or stabilized through processes such as full-depth reclamation and drainage improvements to provide a quality foundation for new pavement layers, overlays, and wearing course treatments.

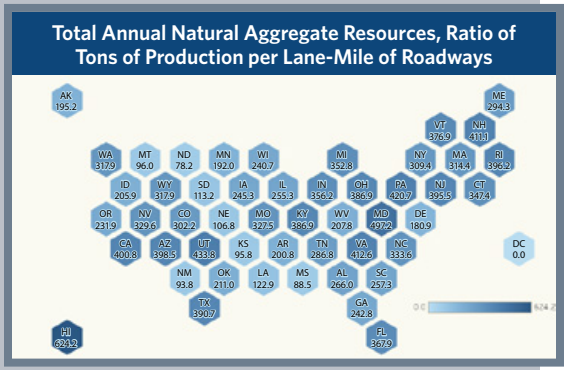
Relative Supplies of Natural Aggregates by State

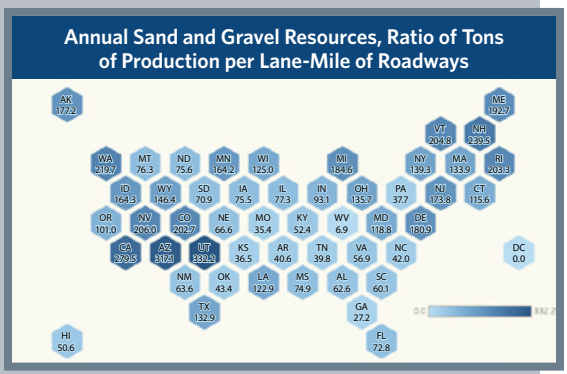
To help highway agencies understand the

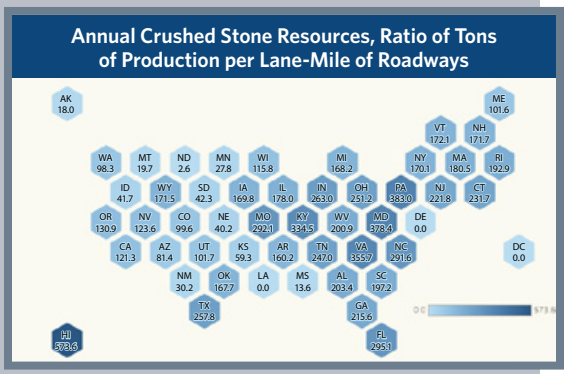


Photomicrograph of thin sections of recycled concrete aggregate particles for analysis, viewed through a petrographic microscope. The top images use cross-polarized light for mineral identification. The bottom images use fluorescent light to study porosity.

Source: FHWA.



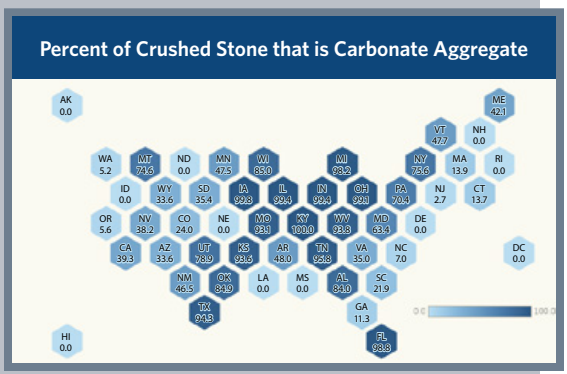




ABOVE: Amounts of annual aggregate resources expressed as a ratio of tons of production per lane-mile of roadways in each State, including total natural construction aggregates, sand and gravel, and crushed stone.

BELOW: This chart shows the percent of annual crushed stone production that is carbonate aggregates (limestone, dolomite, and marble) in each State. Carbonate aggregates are relatively soft, limiting use in pavement surfaces because they can polish under traffic, creating slippery-when-wet conditions.

Source: FHWA.



available supply of natural aggregates (crushed stone, sand, and gravel) in each State, FHWA recently compiled key statistical indicators relating annual natural aggregate production expressed as a ratio to lane-miles of pavement in each State for 2017. This was done to normalize potential resources based on the total amount of constructed and managed lane-miles of roadways in each State. Total aggregate production includes current United States Geological Survey (USGS) data of annual supplies of construction crushed stone and sand and gravel available in each State. Natural aggregate availability regions for sand and gravel, and for the different types of crushed stone, often do not follow State boundaries, but are important considerations in local pavement material selection.

Some States and regions, such as the High Plains and the Gulf Coast, have limited availability of quality natural aggregates. Therefore, aggregates have to be transported long distances at greater economic and environmental costs. Alternatively, project planners may consider other options, such as tailoring pavement base and pavement layer construction methods to available local or marginal materials, greater use of stabilized local soils and materials for subbases and bases, and more aggressive pavement preservation techniques using surface treatments and thin overlays to maintain pavement serviceability.

Many States east of the continental divide and along the Gulf Coast have lesser amounts of natural aggregates (sand, gravel, and crushed stone) available. Rocky Mountain and Appalachian States, and those closer to the mountains, tend to have more natural aggregate resources as a ratio per lane mile in these roadway systems. States in the upper Midwest also typically have higher amounts of resources per lane mile because of glacial sand and gravel deposits, as well as ample limestone and dolomite bedrock sources in the region.

The top States for carbonate crushed stone as a percentage of the total natural aggregate resources include West Virginia, Kentucky, Missouri, Iowa, Tennessee, Florida, Texas, Indiana, Ohio, Michigan, and Illinois. States like these with high percentages of carbonate crushed stone, which is relatively soft, may face challenges in locating hard mineral aggregates for pavement

wearing surfaces and surface treatments that provide required friction and texture performance.

"Understanding the local availability of various natural aggregates can help project planners determine the best methods and solutions to meet the needs of each project," says Bob Younie, Director of Maintenance for the Iowa Department of Transportation.

Recent FHWA Aggregates Research

FHWA's research has helped to advance the understanding of aggregates and pavement materials.

For example, an ongoing TFHRC study using FHWA's Pavement Test Facility (PTF) examined different percentages of RAP and recycled asphalt shingles in both conventional and warm-mix asphalt (WMA) pavements to quantify the cracking resistance of high RAP mixtures and the effect of lower WMA mixing and compaction temperatures on RAP performance. Lanes containing recycled shingles and high RAP using the stiffer binder were more susceptible to fatigue damage. The warm mix and hot mix materials provided similar performance. While this study

FHWA's Pavement Test Facility at TFHRC.
Source: FHWA.

focused on binder issues, the research advanced a method for determining the workability of loose hot mix based on deformation conducted at a fixed deformation rate. This can be used as a quality control test for RAP mixes and RAP materials.

An earlier study at the PTF looked at the use of a 4.75-millimeter nominal maximum aggregate size mixture containing 20 percent RAP to study effects on delaying top-down cracking. This was a less permeable mix and provided good performance prior to its aging.

FHWA plans additional research at the PTF to include research topics such as recycled materials and the development of data on performance of asphalt mixtures and overlays as well as the incorporation of preservation strategies, which ultimately affects pavement life-cycle cost analysis and performance.

Other research from FHWA's Chemistry, Concrete, and Petrographic Laboratories has explored aggregate durability and performance issues, as well as characterizing the variability and quality of recycled concrete aggregates. FHWA developed a chemistry test called T-FAST to identify the potential alkali silica reactivity of coarse and fine aggregates. The test specification for coarse aggregates was recently approved by AASHTO. Research to date has shown that this test gives 100 percent agreement with block farm data and can be run quite rapidly and more efficiently than traditional methods.

FHWA has also conducted a field study to research the concept of inverted pavement in cooperation with the Virginia Department of Transportation and the aggregates industry. An inverted pavement uses the same materials as a conventional pavement, but the layers are arranged differently. In conventional designs, the layer above protects the layer below (stiffer layers higher up). The inverted pavement uses a stiff base and essentially flips the middle layer. The field study found that the performance of the inverted pavement sections was comparable to standard Virginia pavement sections.

Looking to the Future: Aggregate Research Needs

FHWA and its partners continue to update the Aggregates Research Roadmap. Currently, the roadmap indicates research needs for aggregate granular bases, aggregates in asphalt paving mixtures and in concrete, and designs and methods of using recycled aggregates and excess supplies of some natural aggregate sizes.

For aggregate granular bases, inverted pavements provide one option for road foundations based on compaction of quality crushed aggregate base against a more rigid treated subbase. Research needs include achieving more uniform quality compaction of granular aggregate layers that will provide stiffer, long-lasting foundations for roads that will resist permanent deformation under heavy truck traffic.

Ongoing research is examining the quality of RAP and how much can be used in asphalt mixtures, as well as exploring how well a coating of aged asphalt on the RAP blends with the new materials. FHWA has also initiated research to assess the role that aggregate gradation plays in pavement macrotexture. Other research needs indicated by the roadmap are finding methods for balanced design of performance asphalt mixtures, including aggregate grading

Total Annual Construction Aggregate Resources Available in the U.S.

- **Crushed stone—1,510,000,000 tons**
  - Carbonate crushed stone (includes limestone, dolomite, and marble)—1,040,000,000 tons
- **Sand and Gravel—969,000,000 tons**
- **RAP (includes aggregate and binder)—102,000,000 tons**
  - Use as aggregate—10,300,000 tons
  - Use in manufactured product—91,800,000 tons
  - Use in asphalt mixtures—estimated 82,200,000 tons
- **RCA (includes aggregate, mortar, and adhering cement paste)—334,000,000 tons**
  - Use as aggregate—301,000,000 tons
  - Use in manufactured product—32,800,000 tons
- **Slag aggregate (blast furnace and steel furnace)—14,200,000 tons**

optimization and the interaction of binder types with aggregate surface properties to resist moisture and freezing exposures and to provide longer-lasting ride quality.

FHWA and its partners are developing and refining test methods for use with the new AASHTO standard for performance-engineered mixtures for concrete pavements. These methods address both the workability and placeability of the mixture for slip-form paving, but also the important durability criteria for aggregates in concrete to resist freeze-thaw, deicing chemical, and alkali aggregate reaction exposures that can shorten concrete pavement service.

All pavements require aggregates at the wearing surface with hard, wear-resistant minerals that provide consistent friction and texture. Research related to improving the measurement of friction and texture on pavements at traffic speeds on a more continuous basis is ongoing, so that these performance data can improve traction and safety during wet weather.

The roadmap indicates that research is needed to better characterize recycled and reclaimed aggregates and develop pavement designs for using and blending these materials in new pavement layers, as well as to determine treatments to extend or renew service life. In addition, in many areas, crushed stone quarries have high demand for clean coarse aggregate sizes, but that leads to the challenge of how to best use the excess crushed fine aggregate and oversize rock materials on a sustainable basis so that aggregate resources can be used more effectively locally for highway construction and improvements.

"Achieving sustainable pavements isn't simply a matter of maximizing the use of recycled and locally available aggregates," says Dr. Cheryl Richter, Director of FHWA's Office of Infrastructure Research and Development. "To be sustainable, the pavement must be durable. FHWA research is providing information and guidelines needed to support use of RAP, reclaimed asphalt shingles, and other materials to achieve long-lasting, truly sustainable pavements."

RICHARD MEININGER is the manager of FHWA's Aggregates and Petrography Lab at TFHRC and has been an FHWA highway materials researcher at TFHRC for 20 years. He holds a B.S. and an M.S. in civil engineering from the University of Maryland and is a registered professional engineer.

HEATHER DYLLA is the program manager for FHWA's Pavement Sustainability Program. She holds a Ph.D. and an M.S. in engineering science from Louisiana State University and a B.S. in civil engineering from Bradley University.

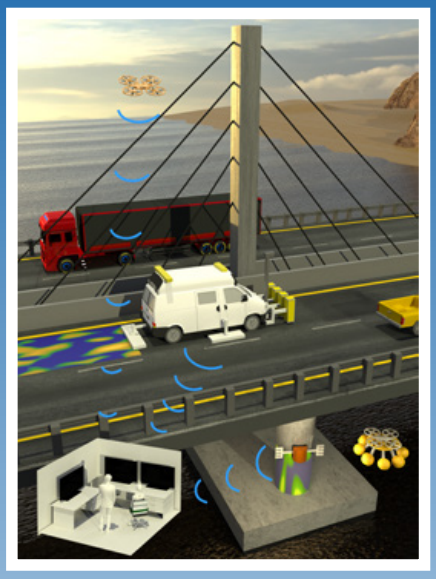
JACK YOUTCHEFF is the leader of FHWA's Infrastructure Materials Team in the Office of Infrastructure Research and Development at TFHRC. He has a Ph.D. in fuel science and a bachelor's degree in chemistry from Pennsylvania State University.

For more information, see *https://highways.dot.gov/research/turner-fairbank-highway-research-center/laboratories/laboratories-overview*, and *www.fhwa.dot.gov/pavement/sustainability*, or contact Richard Meininger at 202–493–3191 or *Richard.Meininger@dot.gov*, Heather Dylla at 202–366–0120 or *Heather.Dylla@dot.gov*, or Jack Youtcheff at 202–493–3090 or *Jack.Youtcheff@dot.gov*.

A large power shovel loads blasted granite rock from a crushed-stone quarry in Virginia into a hauling vehicle for transportation to the crushing and screening plant nearby.

Source: FHWA.

FHWA's State-of-the-Art NDE Research



Source: FHWA.

Non-destructive evaluation (NDE) is a means of analyzing and assessing the condition of structural components of highway infrastructure including pavement, bridges, and tunnels without damaging them.

Capabilities include:

- Ground Penetrating Radar Testing
- Infrared Thermography Testing
- Impact Echo Testing
- Surface Wave Testing
- Structural Health Monitoring Systems
- Numerical Simulation
- Automated Data Collection, Analysis, Interpretation, Visualization, and Fusion
- Conventional/Phased Array/Full Matrix Capture Ultrasonic Testing
- Conventional/Advanced Eddy Current Testing
- Acoustic Emission
- Noncontact and Remote Sensing

FHWA's Advanced Sensing Technology (FAST) NDE Laboratory conducts state-of-the-art research, development, and implementation of nondestructive testing systems and technologies to improve the Nation's highway infrastructure assets.

The lab also developed the *NDE Web Manual* (available on the InfoTechnology website, starting July 2021) to assist bridge practitioners in selecting appropriate NDE technologies for their projects.

For more information, visit *http://bit.ly/2vup7F9*.

Colorado's Highway of Legends is one of 49 additions to America's Byways®.
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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.

Personnel

USDOT Appoints Chief Science Officer

The U.S. Department of Transportation recently announced that it is appointing a Chief Science Officer for the entire Department for the first time in more than four decades.

U.S. Secretary of Transportation Pete Buttigieg has designated the Assistant Secretary for Research and Technology as the Department's Chief Science Officer. Robert C. Hampshire, Ph.D. is currently acting in this role. In his role as Chief Science Officer, Dr. Hampshire will serve as the principal advisor to Secretary Buttigieg on science and technology issues. He is charged with ensuring that USDOT's research, development, and technology programs are scientifically and technologically well-founded and conducted with integrity.

Dr. Hampshire was previously an associate professor at the Gerald R. Ford School of Public Policy at the University of Michigan (U-M) and at both the U-M's Michigan Institute for Data Science and the Human Factors group of the U-M Transportation Research Institute. He holds a Ph.D. from Princeton University.

"The reintroduction of a Chief Science Officer underscores transportation's key role in addressing the complexity and criticality of our dynamically changing climate. I look forward to working across all modes of transportation to address the immediate concerns, and to ensure our future transportation system is sustainable," said Dr. Hampshire in a press release. "It is important that USDOT incorporate scientific research to advance climate change initiatives that are fair and equitable to all."

Public Information and Information Exchange

FHWA Announces New America's Byways® Designations

In February, Federal Highway Administration officials announced 49 new designations to the America's Byways® collection, including 15 All-American Roads and 34 National Scenic Byways in 28 States. This increases the number of America's Byways to 184 in 48 States. Created in 1991, the program is a collaborative effort to help recognize, preserve, and enhance selected roads throughout the United States. The USDOT recognizes certain roads based on one or more archeological, cultural, historic, natural, recreational, and scenic qualities.

The Reviving America's Scenic Byways Act of 2019 required the U.S. Secretary of Transportation to solicit nominations for the designation of All-American Roads and National Scenic Byways, resulting in 63 nominations. Each application was reviewed by subject-matter experts on historic preservation, design, cultural resources, visual impacts, tourism and economic development, highway safety, Federal lands, and Native American history and culture. The U.S. Departments of Agriculture and Commerce also provided input.

USDOT urges all Americans to follow CDC guidance and local regulations on safe travel during the COVID-19 public health emergency. The public is encouraged to explore these newly designated distinct and diverse roads once it is safe to do so. The full list of 2021 All-American Roads and National Scenic Byways designations is available at *https://highways.dot.gov/newsroom/usdot-announces-new-americas-bywaysr-designations.*

USDOT Implements Efforts to Promote Scientific Integrity

In addition to appointing a Chief Science Officer, USDOT has taken several additional steps to act on the Biden-Harris

Administration's commitment to address climate change. The Department announced that it has begun work to reestablish its Climate Change Center and has made significant strides to improve public access to climate-related reports, program information, and other scientific and technical information.

The Department's actions stem from the President's Executive Order on Protecting Public Health and the Environment and Restoring Science to Tackle the Climate Crisis, as well as from the Presidential Memorandum on Restoring Trust in Government Through Scientific Integrity and Evidence-Based Policymaking.

The Climate Change Center will help coordinate the Department's related research, policies, and actions and support the transportation sector in moving toward net-zero carbon emissions. Originally established in 1999 to serve as the multimodal focal point for information and technical expertise on transportation and climate change, coordinating climate-related research, policies, and actions, the center has been dormant since early 2017.

The Department has also assessed public websites and information repositories, including the National Transportation Library, to ensure the public has access to comprehensive climate-related reports, program information, and other scientific and technical information.

The Department will also designate a Scientific Integrity Officer, responsible for research policy implementation, who reports directly to the Chief Science Officer.

The transportation sector is the number one producer of greenhouse gases in the United States, which underscores the ability of the transportation industry and the Department to quickly and meaningfully reduce greenhouse gases and address the environmental concerns. These actions are the first steps in establishing the Department as a leader in addressing climate change and environmental justice.

NHTSA has initiated two studies on bicycle and pedestrian safety.

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FHWA Publishes Pedestrian and Bicycle Case Studies

Pedestrian fatalities have been on the rise throughout the United States, and as more Americans are walking and bicycling, many agencies have been working to improve safety for these vulnerable road users.

A new report from FHWA highlights the work of transportation agencies at the Federal, State, and local levels to improve safety for pedestrians and bicyclists. *Case Studies for FHWA Pedestrian and Bicycle Focus States and Cities* (FHWA-SA-21-021) provides information on agency efforts through FHWA's Pedestrian and Bicyclist Safety Focused Approach Program. The case studies include the city of Austin, TX, and Arizona, California, Florida, Georgia, New Mexico, and New York. The case studies describe the lessons learned from processes related to implementing safety initiatives and countermeasures. The document is available at: *https://safety.fhwa.dot.gov/ped_bike/ped_focus/docs/FHWA_FocusApproach_CaseStudies_508.pdf.*

For more information, visit *https://safety.fhwa.dot.gov/ped_bike/ped_focus.*

Work Zone Fatalities at Highest Level Since 2006

During April's Work Zone Awareness Week, FHWA joined State departments of transportation and other organizations nationwide to urge drivers to keep highway workers and the traveling public safe as construction activities increase. In 2019, the most recent year for which data are available, 842 people died in highway work-zone crashes, compared to 757 the year before. The 11.2-percent increase is the largest percentage increase of highway work zone fatalities since 2006.

Crashes in highway work zones happen most frequently when drivers are not paying attention to changing road conditions. Distracted driving is a key element of many crashes, leading many drivers to crash into other vehicles, highway equipment, or safety barriers.

Though highway workers are often among the victims of work zone crashes, the dangers of reckless driving more often affect those behind the wheel and their passengers. Four out of five work zone fatalities were drivers or passengers, according to FHWA data.

FHWA has supported work zone safety efforts for more than 20 years and, since 2005, has awarded more than $40 million in grants to States for specialized work zone safety training. To date, nearly 4,300 courses have been provided to over 120,000 State and local DOT personnel or other transportation agency staff.

NHTSA Announces New Projects on Pedestrian and Bicyclist Safety

The National Highway Traffic Safety Administration (NHTSA) recently initiated two new projects focusing on pedestrian and bicyclist safety.

A 3-year project will focus on identifying and developing educational materials and products on pedestrian and bicyclist safety for drivers' education and training courses. A second 2-year study will conduct a comparative analysis between States and cities with low percentages of pedestrian fatalities and those that have made improvements yet continue to have higher percentages of pedestrian fatalities. The team will identify common strategies or characteristics that result in better safety outcomes to inform new approaches for places with high pedestrian fatalities.

For more information, contact Ruth Esteban-Muir, the NHTSA project manager, at *Ruth.Esteban-Muir@dot.gov.*

The web-based IPaC tool helps users determine if a transportation project will impact protected habitats or wildlife, like this marbled murrelet.

Source: USFWS National Conservation Training Center Image Library.

by **DANIEL BUFORD, VICTORIA FOSTER** and **CHELLBY KILHEFFER**

Transportation planners always need to be aware of potential impacts from their projects to federally listed endangered species and designated critical habitats. If a project may impact these wildlife populations or habitats, Section 7 of the Endangered Species Act requires planners to create a biological assessment and complete a consultation with the U.S. Fish and Wildlife Service (USFWS). To assist with Section 7, USFWS developed the web-based application Information for Planning and Consultation (IPaC) that helps users determine if a project will impact protected wildlife or habitats.

In December 2020, USFWS launched an expansion of IPaC—the Consultation Package Builder (CPB). The CPB provides the information, tools, and guidance necessary to submit biological assessments to USFWS in compliance with the Endangered Species Act. It also helps project planners identify conservation measures designed to avoid or minimize effects to listed species.

Improving Information and Accuracy

As a decision-support tool, IPaC, including the CPB, improves the consultation process by informing more accurate and consistent determinations. The CPB is an interactive, step-by-step process that helps IPaC users prepare full consultation packages while leveraging USFWS data and recommendations. The CPB results in better, more complete consultation packages, thereby saving time and resources while reducing the workload for all consulting parties. It provides enhanced functionality to existing IPaC tools, including official species lists and determination keys.

Determination keys are logically structured sets of questions that assist users in determining if a project qualifies for a streamlined, programmatic consultation outcome. Qualifying projects can generate USFWS concurrence letters instantly through IPaC. Determination keys provide consistent and transparent outcomes, and significantly reduce the time to complete consultation for qualifying projects.

"One benefit to IPaC is having a central location to obtain a project Official Species List for species to be addressed during Section 7 review. Prior to IPaC, [the process] was time-consuming," says Amy Golden with the Virginia Department of Transportation (VDOT). "VDOT typically updates Section 7 and threatened and endangered species reviews every 6 months or at project development milestones...It [is] easy to go to IPaC to obtain an updated Official Species List for projects."

Streamlining Consultations

Determination keys and the CPB assist users in conducting more thorough analyses and determining what effects their projects may have on federally listed species and critical habitats. Benefits of using the CPB include:

- Producing consistently formatted and more complete consultation packages ready for submission to USFWS
- Saving time and resources while drafting a biological assessment
- Prepopulating USFWS information into the biological assessment for consideration during the analysis
- Receiving fewer requests for additional information during consultation
- Reducing workloads by streamlining the overall consultation process

"Using IPaC has definitely streamlined the endangered species coordination process," says Betty Ketchum with the New York State Department of Transportation. "It is straightforward and easy to use."

For more information, visit *https://ecos.fws.gov/ipac* or contact *FWHQ_IPaC@fws.gov.*

DANIEL BUFORD is an ecologist with FHWA's Office of Project Development and Environmental Review.

VICTORIA FOSTER is USFWS's national IPaC program coordinator.

CHELLBY KILHEFFER is a biologist on the USFWS Headquarters' IPaC team.

NHI now offers some of its structures courses in a virtual instructor-led format.

© one photo / Shutterstock.com

NHI's Commitment to Virtual Training for Engineers

by **MIGNON WHITTED** and **AMBER CLARK**

Despite the shift in how to meet the needs of today's workforce, the National Highway Institute (NHI) prides itself on its commitment to provide quality training to engineers. To continue to do so, NHI now offers some of its structures courses in an online, instructor-led format.

With this new training format, engineers can learn current information on key topics such as bridge and tunnel inspection, fracture-critical inspection techniques for steel bridges, and load rating of concrete and steel superstructures from the comfort of their home or office. The virtual environment offers engineers access to expert instructors worldwide while earning continuing education units.

Virtual Structures Courses

The following courses are, or will soon be, available in an online, instructor-led format.

Bridge Inspection Refresher Training (FHWA-NHI-130053V/ FHWA-NHI-130053A). This virtual training teaches learners how to effectively inspect and manage bridge inspection programs. Individuals will refresh their skills and knowledge on conducting bridge inspections and learn information on other related topics through various techniques and tools.

Load and Resistance Factor Rating of Highway Bridges (FHWA-NHI-130092V) (coming soon). The Load and Resistance Factor Rating of Highway Bridges course offers both novice and experienced bridge engineers the fundamental knowledge necessary to apply the most recent American Association of State Highway and Transportation Officials Load and Resistance Factor Design specifications to bridge ratings. Participants are introduced to applications of these specifications that can be used to enhance bridge safety and to identify and discuss the steps needed to ensure a successful transition for this new state-of-the-art methodology.

Tunnel Safety Inspection Refresher (FHWA-NHI-130125V). The Tunnel Safety Inspection Refresher course provides learners with the foundation needed to successfully manage and execute a tunnel inspection. This highly interactive virtual training enhances participants' prior knowledge of bridge and/or tunnel inspections. Prior to taking this training, participants must complete the FHWA-NHI-130110 and FHWA-NHI-130124 courses.

Strut-and-Tie Modeling (STM) for Concrete Structures (FHWA-NHI-130126V) (coming soon). This online course provides engineers with a straightforward analysis and design tool for deep concrete bridge elements and disturbed regions that would otherwise require a rigorous refined analysis.

How to Attend or Host a Course

NHI invites professionals interested in earning continuing education units or professional development hours to visit *http://bit.ly/NHIHome* and browse the complete digital course catalog, which encompasses more than 400 courses spanning 18 program areas. To sign up for alerts when a course session is scheduled, visit the individual course's description page and select the "Sign Up for Session Alerts" link.

Interested hosts can submit a Host Request Form or find more information about hosting NHI courses by visiting *www.nhi.fhwa.dot.gov/training/host.aspx*.

NHI is an approved Accredited Provider by the International Association for Continuing Education and Training (IACET). As an IACET Accredited Provider, NHI offers continuing education units for its programs that qualify under the American National Standards Institute/IACET Standard.

MIGNON WHITTED is an acting NHI training program manager.

AMBER CLARK is a contracted marketing analyst for NHI.

COMMUNICATION PRODUCT UPDATES

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).

Compiled by **LISA A. SHULER** of FHWA's Office of Corporate Research, Technology, and Innovation Management

When ordering from NTIS, include the NTIS publication number (PB number) and the publication title. You also may visit the NTIS website 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:

National Technical Information Service
5301 Shawnee Road
Alexandria, VA 22312
Telephone: 703–605–6050
Toll-free number: 1–888–584–8332
Website: www.ntis.gov
Email: customerservice@ntis.gov

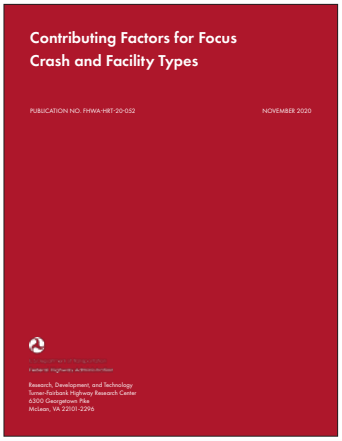
Requests for items available from the R&T Product Distribution Center should be addressed to:

R&T Product Distribution Center
Szanca Solutions/FHWA PDC
700 North 3rd Avenue
Altoona, PA 16601
Telephone: 814–239–1160
Fax: 814–239–2156
Email: report.center@dot.gov

For more information on R&T communications products available from FHWA, visit FHWA's website at *www.fhwa.dot.gov*, the FHWA Research Library at *https://highways.dot.gov/research/resources/research-library/federal-highway-administration-research-library* (or email *fhwalibrary@dot.gov*), or the National Transportation Library at *ntl.bts.gov* (or email *library@dot.gov*).

Contributing Factors for Focus Crash and Facility Types

Publication Number: FHWA-HRT-20-052



Identifying and implementing systemic safety improvements leads not only to the reduction of crashes, but also to the reduction of the severity of crash incidents. Safety improvements are also bolstered by the identification of focus crash and facility types (FCFTs) and crash-contributing factors.

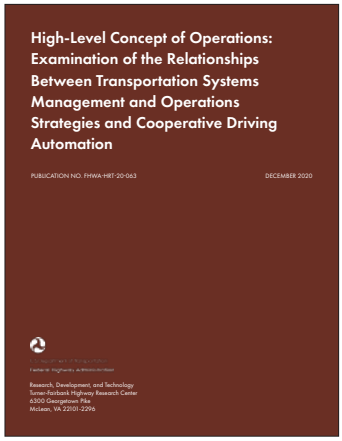
A study by FHWA explored FCFTs and contributing factors and how improvements can directly impact incidents that are deemed prevalent but are somewhat disperse in their occurrence.

This report details several key goals of the study, which included identifying FCFTs, contributing factors, and possible low-cost safety measures to support systemic improvements, as well as identifying and applying quality data, statistical methodologies, the analysis process, and tools.

The publication is available at *www.fhwa.dot.gov/publications/research/safety/20052/20052.pdf.*

High-Level Concept of Operations: Examination of the Relationships Between Transportation Systems Management and Operations Strategies and Cooperative Driving Automation

Publication Number: FHWA-HRT-20-063



The convergence of transportation systems management and operations (TSMO) and cooperative driving automation (CDA) continues to advance FHWA's CARMA Platform℠. This report explores the high-level concept of operations, its support of CARMA, and the ties between TSMO and CDA.

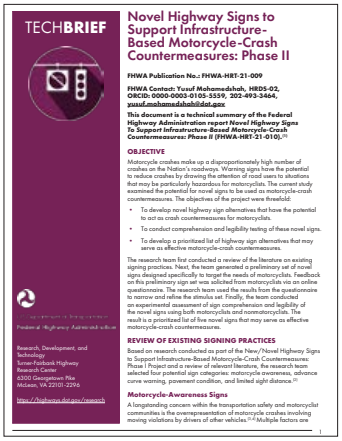
The research team examined several factors integral to the TSMO/CDA relationship, including traditional TSMO strategies relevant to transportation infrastructure; identification of key criteria that would likely be affected by implementation of CDA; and consideration of four groups of use cases, including basic travel, traffic incident management, road weather management, and work zone management.

The report also explores what technologies and processes may need to be modified or introduced to accommodate new roles and functions for TMSO, while examining the challenges associated with traditional vehicles and CDA-equipped vehicles sharing the Nation's roads.

The publication is available at *www.fhwa.dot.gov/publications/research/operations/20063/index.cfm.*

Novel Highway Signs to Support Infrastructure-Based Motorcycle-Crash Countermeasures: Phase II

Publication Number: FHWA-HRT-21-009 (TechBrief)
Publication Number: FHWA-HRT-21-010 (Final Report)



Identifying safety countermeasures to prevent motorcycle crashes on the Nation's roadways remains a top priority for FHWA.

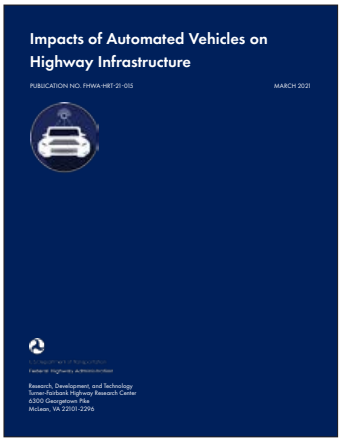
To improve motorcycle safety, FHWA recently conducted a human factors study on highway signage for motorcyclists. The research consisted of reviewing existing highway signs, developing an initial group of signs targeting motorcyclists, and advancing sample signs into a review phase. To ensure the clarity of messaging on the signs, FHWA also included nonmotorcyclists in its review phase. The research resulted in the identification of five novel signs that could significantly reduce motorcycle crashes.

The TechBrief is available at *www.fhwa.dot.gov/publications /research/safety/21009/21099.pdf.*

The final report is available at *www.fhwa.dot.gov/publications /research/safety/21010/index.cfm.*

Impacts of Automated Vehicles on Highway Infrastructure

Publication Number: FHWA-HRT-21-015



Infrastructure owner-operators and highway agency policymakers have become increasingly interested in the impact of automated vehicles (AV) on roadways now and in the future.

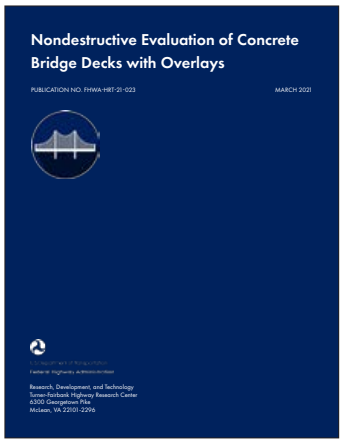
A recent FHWA study explored the rise in interest in AV, and how that interest could impact infrastructure owner-operators as they begin integrating AV into their own transportation systems. The study included the examination of several factors that pertain to roadway infrastructure, including traffic control devices, intelligent transportation system devices, pavement and bridge structural mandatories, multimodal impacts, and additional roadside infrastructure, like guardrails.

This report also details AV and infrastructure deployment from a stakeholder perspective, providing recommendations and strategies for infrastructure owner-operators to implement in the future.

The publication is available at *www.fhwa.dot.gov/publications /research/operations/21015/index.cfm.*

Nondestructive Evaluation of Concrete Bridge Decks with Overlays

Publication Number: FHWA-HRT-21-023



For decades, highway agencies have used concrete bridge deck overlays to repair bridges and extend their service life. However, concrete overlays deteriorate in different ways over time, making evaluations of underlying decks challenging.

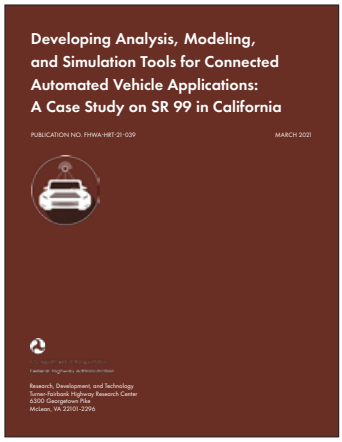
A study by FHWA evaluated use of nine nondestructive evaluation technologies on seven varying types of overlays to identify defects in the concrete deck and debonding between deck and overlay.

This report documents and details the capabilities and limitations of each technique to detect certain types of defects in concrete decks with overlay.

The publication is available at *www.fhwa.dot.gov/publications /research/infrastructure/structures/bridge/21023/21023.pdf.*

Developing Analysis, Modeling, and Simulation Tools for Connected Automated Vehicle Applications: A Case Study on SR–99 in California

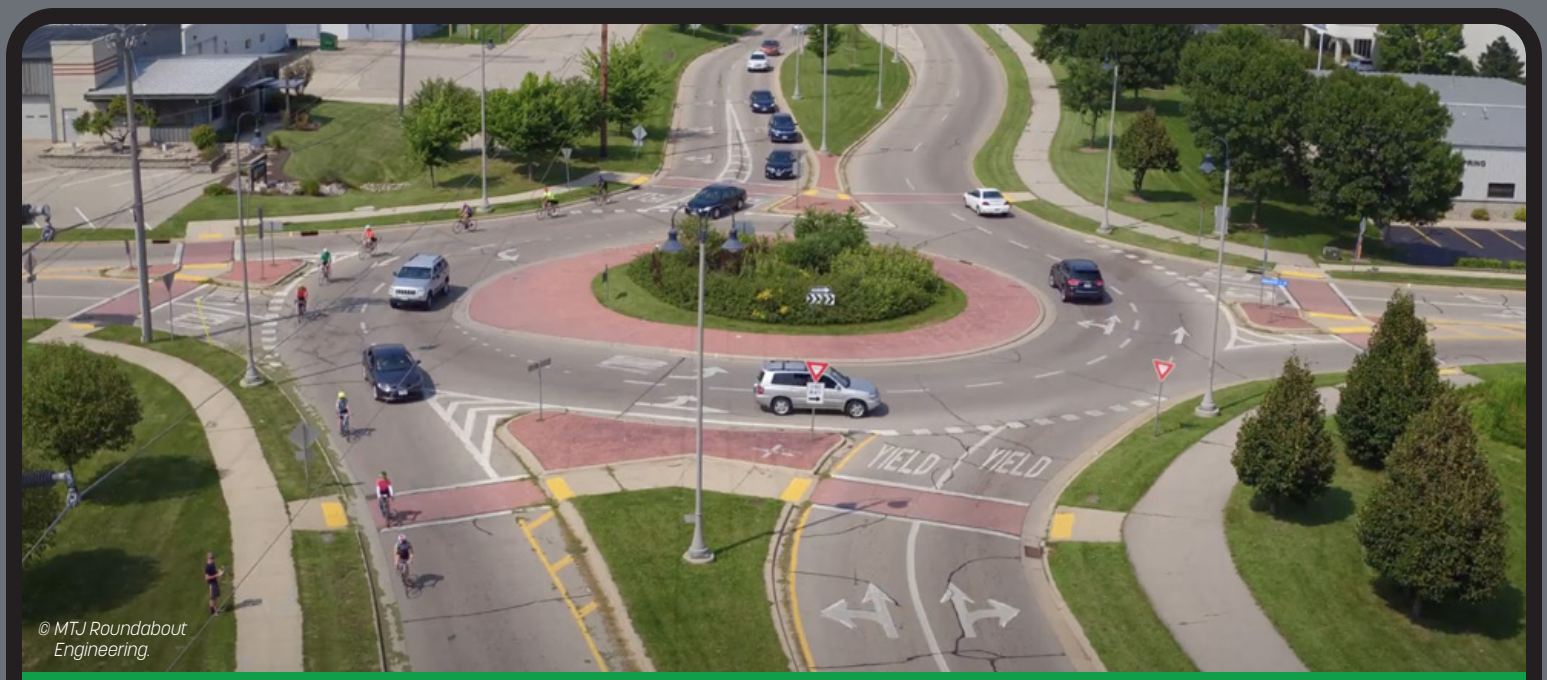
Publication Number: FHWA-HRT-21-039



A recent study conducted by FHWA examined the use of automation technology in a real-world setting—a 13-mile (21-kilometer) portion of SR–99 near Sacramento, CA—that is a heavily traveled commuter corridor. The traffic simulation study examined how the implementation of vehicles equipped with cooperative adaptive cruise control (CACC) could impact traffic flow, congestion, and fuel consumption.

The research team examined scenarios with heavy traffic congestion during morning peak travel, 6:30 a.m. to 9 a.m., with several on-ramp bottleneck locations also included in the case study parameters. One of several key findings from the research shows that when CACC penetration was 100 percent, the busy commuter corridor enabled approximately 30 percent more traffic to enter the facility, with no drop in travel time.

The publication is available at *www.fhwa.dot.gov/publications /research/operations/21039/index.cfm.*



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September 20–24, 2021

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- Reduce speeds to 15–25 miles/hour
- Provide benefits for pedestrians and bicyclists
- Reduce congestion and delay
- Provide a Safe System solution

Share your roundabout success story on social media using #RoundaboutsWeek.

#RoundaboutsWeek

For more information, tips, and facts, visit **https://safety.fhwa.dot.gov/nrw** and **https://safety.fhwa.dot.gov/provencountermeasures/roundabouts**.

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