PUBLIC ROADS

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Winter 2020

CARMA

FHWA's cooperative driving automation program is transforming transportation.

U.S. Department of Transportation
Federal Highway Administration

Also in this issue:

Source: FHWA.

CARMA℠: Driving Innovation | PAGE 28

PUBLICROADS

Winter 2020 | Vol. 83, No. 4

FEATURES

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DEPARTMENTS

COVERS—Some of FHWA's vehicles are equipped with Cooperative Automation Research Mobility Applications, or CARMA. Passenger vehicles, like the ones shown, are designed to communicate with each other, roadways, infrastructure, and other vehicles to enable cooperative driving automation. The vehicles pictured are equipped with the latest version, CARMA3, which is now called CARMA℠. See "CARMA℠: Driving Innovation" on page 28 of this issue of *Public Roads*.

Source: FHWA.

U.S. Department of Transportation
Federal Highway Administration

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Collaborating for the Future of Transportation

Automated vehicle technology holds the promise of improving safety and has the potential to transform the Nation's roadways. A key driver for its success is collaboration. Automation provides an opportunity for the U.S. Department of Transportation, State and local leaders, and industry stakeholders to partner in new ways to prepare communities and road users for the future of transportation.

While the industry explores and tests the benefits of automated vehicle technology, the Federal Highway Administration is helping to facilitate collaboration and equip the owners and operators of roadways with information to make decisions that will improve safety and mobility for all road users. FHWA is well positioned to serve the highway community in this capacity because it works closely with transportation agencies in every State, the District of Columbia, and Puerto Rico. FHWA plays a key role in providing technical expertise and funding opportunities. In addition, the agency promotes the exchange of noteworthy practices and data to enhance knowledge on adopting and implementing automated vehicle technologies.

In 2018, FHWA launched a series of listening sessions with key transportation stakeholders and innovators in six cities to gather information and to have a better understanding of the technologies' implications for the transportation system. The goals of this National Dialogue on Highway Automation were to encourage collaboration and information-sharing and to receive input to inform FHWA actions. The sessions focused on planning and policy, digital infrastructure and data, freight, operations, and infrastructure design and safety. Using input from the National Dialogue, FHWA is developing resources to support the safe and efficient integration of automated driving systems. For more information, see "Mainstreaming Transportation Systems Management and Operations" on page 11 in this issue of *Public Roads*.

FHWA is also facilitating collaboration in research among diverse stakeholders interested in cooperative driving automation applications. Cooperative Automation Research Mobility Applications, or CARMA^{SM}, is an open-source software platform that is available to help advance and refine the communications technology used with automated vehicles. CARMA aims to accelerate an understanding of the safety and operational benefits of cooperative driving automation by testing new automation features. This initiative is providing the research community opportunities to cultivate relationships, share expertise, pilot transportation technologies, implement cooperative driving automation, and strengthen the transportation industry for public benefit. For more information, see "CARMA^{SM}: Driving Innovation" on page 28.

Important to these efforts is the multimodal approach USDOT takes under Secretary Elaine L. Chao's leadership. For example, the Federal Motor Carrier Safety Administration is a close partner in FHWA's research to advance truck platooning applications. These applications explore safe, automated truck freight delivery and its implications for traffic patterns. Another example is FHWA's collaboration with the Federal Transit Administration to improve safety, access, and mobility for underserved populations, including rural communities and people with disabilities, through research coordination and the development of the Complete Trips Deployment Program. This program enables communities to plan and showcase deployments that apply technology and emerging mobility services to expand access and mobility for all.

To fulfill the promise that automated vehicle technology holds for the future state of transportation, it is incumbent upon transportation leaders and innovators to work together at all levels. FHWA stands ready to do our part.

Mala Parker
Deputy Administrator
Federal Highway Administration

From the Center for Transportation Workforce Development:

A VISION TO MEET WORKFORCE DEMANDS

by **MARIA ROMSTEDT**

The number of projected job openings in transportation fields continues to outpace the number of people completing transportation-related education and training programs, and a shortage of skilled workers presents a growing concern for the industry.

When Karen Bobo became the director of the Center for Transportation Workforce Development (CTWD) within the Federal Highway Administration's Office of Innovative Program Delivery (OIPD) in May 2019, she knew the workforce challenges she would be facing. Over her 29-year career with FHWA, Bobo has been involved in recruitment and mentoring. "As a participant in the Highway Engineer Training Program and then as the program coordinator, I was coaching and mentoring from the very beginning of my career," says Bobo.

Bobo has held positions in several FHWA division offices, the Office of Federal Lands Highway, and the Office of Human Resources. "Every job I've had, I have stayed involved in recruitment, coaching peers and students, and talking to the industry," she says.

Bobo and her team are defining CTWD's plans to deliver initiatives that build awareness of transportation careers and improve the development, capability, and diversity of the Nation's transportation workforce. From primary school to professional development, the center provides program support, technical assistance, and workforce development activities in partnership with Federal, State, and local partners; industry organizations; and education providers.

Karen Bobo, director of the Center for Transportation Workforce Development, is inside a historic toll plaza office during a visit to the I-74 Mississippi River Bridge project.

Source: FHWA.

TAPPING UNTAPPED POTENTIAL

Women, African Americans, and Native Americans have been historically underrepresented in the U.S. transportation industry. Because of the potential for growth, many CTWD programs emphasize reaching these groups.

One example is the Garrett A. Morgan Technology and Transportation Education Program. CTWD aims to transform the program, which provides grants to State and local education agencies to develop and deliver K–12 transportation-related curricula with an emphasis on underrepresented groups.

"We're doing a lot of planning and looking at how we can integrate the Garrett Morgan program into other workforce development efforts," Bobo says. "Our goal is to reinvigorate it and ensure it is doing what it is designed to do."

Bobo's vision is to integrate workforce development into education, especially middle school through adult practitioners. That means educating students as well as school professionals on transportation career opportunities. CTWD will also work with the U.S. Department of Education to identify collaboration opportunities.

DRAWING ON PARTNERSHIPS

Partnerships are a cornerstone for reaching CTWD's goals. The center's approach to partnerships includes improving collaboration with the other centers in OIPD, State departments of transportation, national transportation organizations, and other Federal agencies.

One of the center's goals is to expand the Highway Construction Workforce Pilot, which included 12 partners. The program will now be called the Highway Construction Workforce Partnership. The partnership program aims to establish relationships between highway construction contractors in need of key skill sets (the demand) and the workforce system that identifies qualified applicants (the supply).

"We're working to make sure the partnership program meets the needs of all organizations through webinars, educational pieces, and peer exchanges," says Bobo. "We're aiming to expand from the 12 pilot partners to having a partnership in all States."

"If we don't have workers, infrastructure projects won't get completed," she says. "Infrastructure will fail to meet the demands of travelers, and our transportation network will no longer serve the public. We're working hard to make sure that possibility does not become a reality."

MARIA ROMSTEDT is the Publication Manager at FHWA's Turner-Fairbank Highway Research Center and serves as the Editor-in-Chief of *Public Roads.*

A special thematic issue of

PUBLICROADS

WOMEN IN TRANSPORTATION

Coming in Spring 2020

The face of transportation is changing, and the Spring 2020 issue of Public Roads will highlight examples of significant contributions by women to the industry.

- *Meet women who are using their talents to further FHWA's mission.*
- *Discover the ways women are contributing to FHWA's initiatives and technologies.*
- *Be inspired by how FHWA and its partners are encouraging the next generation of young women to pursue careers in transportation.*

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SMALL BUSINESS
INNOVATION RESEARCH OPPORTUNITIES

Source: iStock

Seeking Innovative Solutions to the Nation's Transportation Challenges

The U.S. Department of Transportation's highly competitive Small Business Innovation Research (SBIR) program awards contracts to domestic small businesses to address research challenges from across the Department's modal agencies. The fiscal year 2020 solicitation provides new opportunities to conduct research and capitalize on potential for commercialization while supporting topics in safety, infrastructure, materials, automation, and more.

Visit the Department's SBIR website at www.volpe.dot.gov/sbir to:

- Learn more about the solicitation and research topics.
- Engage with the Department through public meetings and online forums.
- Learn about 2020's new solicitation format and schedule.
- Sign up to receive notifications about the program.

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REACHING NEW HEIGHTS

Unmanned aircraft systems offer inspectors another tool for assessing the condition of bridges.

© iStock.com/pixone.

by **HODA AZARI, DENNIS O'SHEA,** and **DEREK CONSTABLE**

During a 2-year study, FHWA took a closer look at the state of the practice for using unmanned aircraft systems (UAS) for bridge inspections.

Bridge inspectors may need to use several access methods and tools to adequately meet the objectives of a bridge inspection in accordance with governing National Bridge Inspection Standards (NBIS). However, some of these access methods, such as an under-bridge inspection truck (UBIT), can be costly to operate because the equipment is expensive to maintain and run and disruptive to traffic because it requires lane closures. Using an unmanned aircraft system (UAS) can be a cost-effective solution to obtaining stand-alone, high-quality visual inspection data, or to supplement standard inspection methods and equipment. Some UASs can also improve inspector safety and enable examination of areas that are difficult to access.

UASs can produce live streaming video, providing opportunity for the inspector to inspect while remaining on the ground. If inspectors identify deterioration in UAS images, they can then decide whether to perform a physical inspection to determine the severity and extent of the deterioration. Using UAS in this manner can provide more efficient use of standard access equipment and physical inspection techniques for assessing deterioration, in addition to increasing safety.

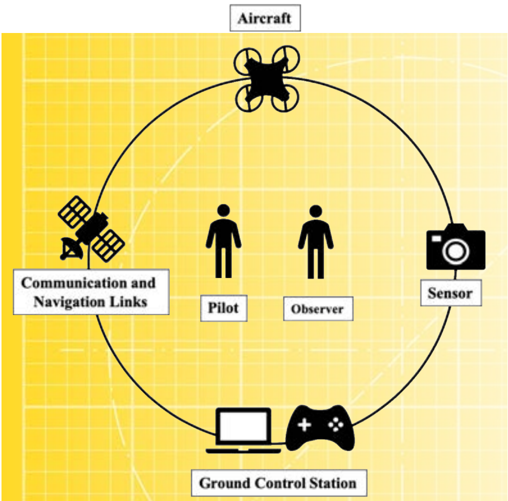
In an ongoing study, the Federal Highway Administration is conducting research to identify types of sensors used in UASs; quantity and quality level of data needed to perform satisfactory inspection using UASs; best practice guidelines for efficient and reliable use of the sensors; and guidance on how the collected data should be assessed, presented, and stored to provide reliable and actionable information to owners to support data-driven decisions. This research study also identifies the minimum requirements of sensors to provide comparable information as other visual inspection techniques.

"We felt it was very important to take a closer look at how State departments of transportation are using unmanned aircraft systems for bridge inspections because of the potential benefits of this technology," says FHWA Executive Director Thomas Everett. "UASs are proving to be incredibly useful to bridge inspection staff to supplement inspection practices."

FHWA expects to conclude the research project in March 2020. What follows are key findings of the research to date.

Components of a UAS

A UAS for bridge inspection includes the unmanned aircraft, control station, sensors, and pilot. A certified pilot is the most important piece of the system, controlling and flying the aircraft in a safe and professional manner. While not always a requirement, a visual observer can aid in

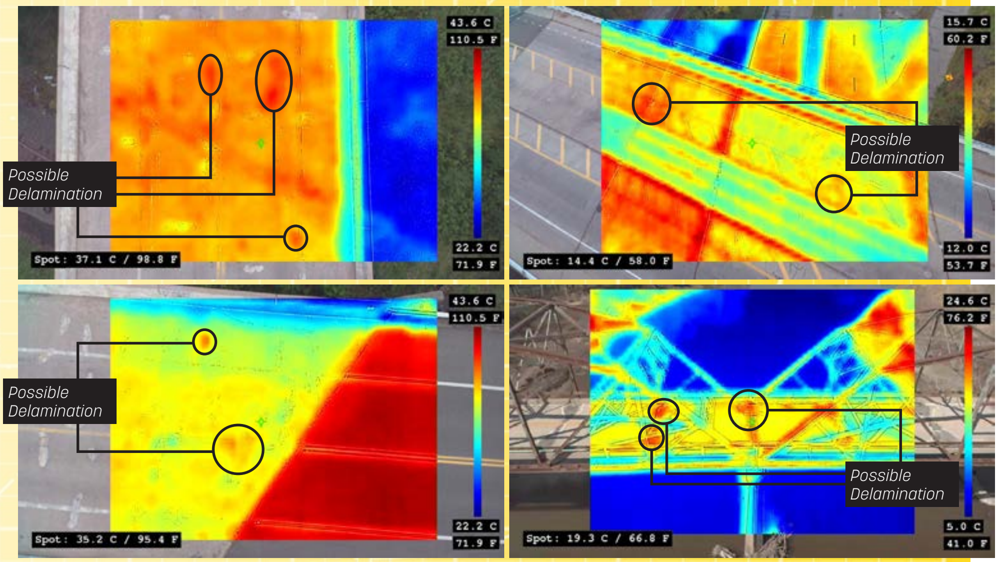


The major components of an unmanned aircraft system are the unmanned aerial vehicle, the pilot and observer, the sensor, the ground control station, and the communication and navigation links.

© Futron Aviation.

Inspectors can see irregularities on the bridge deck in this optical image taken by a UAS. The photo quality is sufficient to enlarge areas of interest, as shown on the right-hand side of the photo.

© ARE/AirShark.



This infrared thermography image shows possible bridge deck delamination. The yellow and orange areas shown above in the IR map (labeled with circles), indicate possible delaminations.

© Minnesota Department of Transportation.

scanning the sky to ensure safe flight while the pilot concentrates on the operation of the aircraft. As required by Federal law for all bridge inspections, an inspection team leader must be on site during the inspection.

Optical cameras, infrared cameras, and LiDAR (light detection and ranging) systems are the most common types of sensors used. Depending on the tasks, an inspector can determine the appropriate types of UAS platform and sensor types. Optical sensors capture the imagery data (video as well as still images), which enable inspectors to see deficiencies in an up-close or magnified manner without having to physically access the specific area on the bridge. UAS-captured high-resolution images may reveal defects missed using distant visual inspection techniques.

High-resolution imagery can also serve other purposes, from providing a record of surface defects to measuring and tracking some types of defects over time.

Infrared thermography (IR) sensors can detect areas of deterioration in concrete by identifying and viewing temperature gradients. Demonstrations have shown the areas of bridge deck delamination identified using IR sensors correspond well to the areas discovered using traditional sounding techniques.

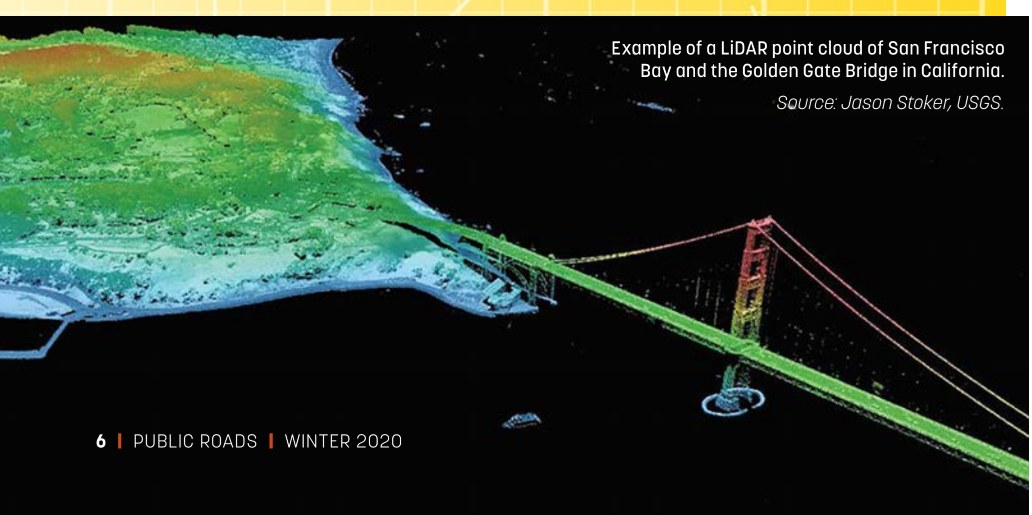
LiDAR sensors actively emit pulses of light—up to hundreds of thousands of returns per second—to accurately measure the distance between the sensor and a target object. The main advantages of LiDAR over photogrammetry are the ability to penetrate vegetation with multiple returns, faster imagery processing times, and improved capabilities to resolve fine features. Inspectors can use a LiDAR point cloud to create a three-dimensional (3D) model of the bridge.

Employing a UAS sensor is beyond simply manipulating the aircraft controls and pointing the sensor at a location. To adequately capture the quality visual information required, personnel must also understand the basics as well as some of the more advanced principals of photography. An understanding of the individual camera's available settings helps to maximize effectiveness.

What UAS Can Do

Typically, bridges that present challenges to gaining access to all parts of the structure for a comprehensive inspection are good candidates for UAS augmentation. For example, on a bridge with an excessively wide sidewalk or tall pedestrian barrier, a UBIT would be limited to access from one side only. A more typical case is a wide bridge where the center is not accessible from a UBIT even when used from both sides. In this case, a UAS could provide imagery from both sides of the bridge.

Some State DOTs have conducted research studies or implemented programs employing UASs for bridge inspections to detect certain types of bridge defects. Their efforts have successfully identified bridge defects and collected information important to the bridge planning process. Bridge engineers also have used the imagery captured during bridge inspections to create accurate two-dimensional and 3D models of a bridge for analytical and planning purposes. State DOT efforts have shown that UASs can enhance traffic safety



Example of a LiDAR point cloud of San Francisco Bay and the Golden Gate Bridge in California.

Source: Jason Stoker, USGS.

Summary of Detectable Bridge Defects Discovered with UAS Imagery

Defects	Florida[1]	Idaho	Minnesota[2]	Michigan	Oregon
Concrete cracks	X	X	X		X
Missing fasteners	X		X		X
Rust	X	X			X
Peeling paint					X
Delamination (using IR sensor)	X	X[3]	X	X	
Spalling	X		X	X	X
Stress cracks (wood)	X				
Vegetation/debris	X	X			X
Efflorescence	X	X			X
Corrosion	X	X	X		
Concrete wear	X			X	
Fatigue crack (weld)		X			
Paint condition	X	X			X
Galvanizing condition			X		
Previous repairs	X		X	X	X

1. This column lists the results of two studies conducted in Florida in 2015 and in 2018.
2. The Minnesota results are from a three-phase study that was conducted from 2015 to 2018.
3. The delamination the Idaho team identified was simulated in lab conditions.

This table summarizes the types of bridge defects that inspectors from several States detected using UASs. In these instances, UASs enhanced the inspection process or improved the accuracy of results. The table represents a sample of the defects noted by States and should not be interpreted to mean that these are the only defects that can be detected using a UAS-mounted sensor.

Source: FHWA.

for the public and safety for the inspection team in many cases. For example, during a 2018 study performed by the Minnesota Department of Transportation (MnDOT), contractors flying a collision-tolerant UAS captured imagery inside an enclosed steel arch. Using this type of UAS inside the bridge structure eliminated the need for personnel to enter the potentially dangerous confined space. (Entering a confined space requires specific training for members of the inspection team, and requires the receipt of entry permits in accordance with current safety regulations and practices.) MnDOT reported a potential 66 percent cost savings using UAS compared to traditional methods in 2017 and an average cost savings of 40 percent for the case studies reviewed in 2018.

Identifying which aspects of a bridge inspection are best suited for a UAS according to the needs of State DOTs is useful in determining efficient use. The Oregon Department of Transportation (ODOT) identifies major bridge reporting categories and applies a scale of 1 to 4 to rate the usefulness of a UAS for providing inspection information. ODOT also evaluates how useful a UAS is in conducting various types of inspections. They identified a monetary savings of around $10,000 per bridge and a 10 percent savings in personnel time per project compared to inspections done without UAS.

For more information on UAS application in transportation, see "Ready for Takeoff" in the Winter 2018 issue of *Public Roads*.

Limitations of UASs

UASs can provide many advantages to a bridge inspector. However, they currently cannot replace a person where tactile or other contact inspection methods are necessary or required. For example, inspectors cannot employ only UAS for fracture critical member inspections because of the FHWA requirement for using hands-on inspection techniques. The reason is because today's cameras and sensors still have limited capability to see through dirt, debris, and corrosion that may hide critical defects.

"In no way should a UAS be considered a complete solution that will solve all user needs," says Cheryl Richter, director of the Office of Infrastructure Research and Development at FHWA. "It is a tool that may bring efficiencies in time, cost, and safety [of the] bridge inspection process when successfully employed."

UAS operators in both the public and private sectors must adhere to the statutory and regulatory requirements issued by the Federal Aviation Administration (FAA). Public aircraft operations (including UAS operations) are governed under the statutory requirements for public aircraft established in 49 United States Code (U.S.C.) § 40102 and § 40125. In addition, both public and civil UAS operators may operate under the regulations promulgated by the FAA. The provisions of 14 Code of Federal Regulations (CFR) part 107 apply to most operations of UAS weighing less than 55 pounds (24.9 kilograms). Operators of UASs weighing greater than 55 pounds may request exemptions to the airworthiness requirements of 14 CFR part 91 pursuant to 49 U.S.C. §44807. UAS operators should also be aware of the requirements of the airspace in which they wish to fly. The FAA provides extensive resources and information to help guide UAS operators in determining which laws, rules, and regulations apply to a UAS operation. For more information, visit *www.faa.gov/uas*.

Oregon DOT Assessment of UAS Usefulness

Inventory		Condition rating		Appraisal Items		Inspection Types	
Geometric Data	4	Deck	4	Structural Evaluation	4	Initial	4
Structure Type and Inventory	3	Superstructure	4	Deck Geometry	4	Routine	4
Navigation Data	3	Substructure	4	Under-Clearances	4	Damage	2
Age and Service	2	Channel and Channel Protection	3	Approach Roadway Alignment	4	In-depth	2
Proposed Improvements	2	Culvert	3	Waterway Adequacy	3	Fracture Critical	2
Identification	1			Traffic Safety Features	3	Underwater	1
Classification	1			Scour Critical Bridges	2	Special Inspections	1-4
Load Rating and Posting	1						
Inspections	1						

Ratings scale: 1 = not useful 2 = limited use 3 = useful 4 = very useful

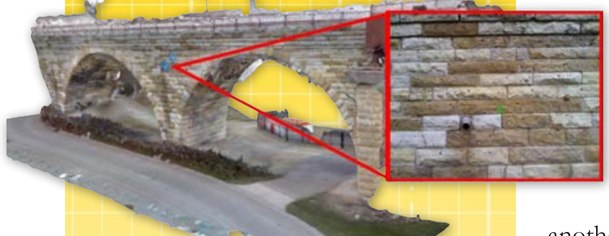
Analyzing and Storing Data

When employing a UAS during bridge inspections, inspectors capture large amounts of data that require storage, post-processing, analysis, and dissemination. For most UASs, the imagery and data captured during a flight is stored on a removable media storage device, such as a secure digital (SD) memory card, integrated into the aircraft platform. The files stored on the SD card are a variety of common file types that are accessible by media-viewing and post-processing software.

Inspectors process the captured and stored data into different products to supplement inspection documentation, better inform decisionmakers regarding the structures, and improve future inspection planning. Common information products include images, video, 3D models, and surface models. Bridge engineers can use UAS imagery of the entire structure to create bridge "plans" for bridges that do not have records of the original structural drawings. Also, inspectors can use this visual information, and the associated geographic position information related to the images, to update the structure inspection records, identify and assess new deficiencies, track the extent of specific defects over several inspections, and update bridge repair recommendations.

In general, an inspector will use the standard inspection report format that complies with the NBIS, supports reporting data to the National Bridge Inventory, and satisfies State DOT policies and standards. When using a UAS to supplement an inspection, the inspector will select the imagery captured by the UAS sensor to include in the report. Thus, using a UAS for inspection purposes should not generate additional paperwork but the information and defects found in the images should be documented in the inspection notes and element condition data, as applicable.

"Data management can be the most challenging aspect of using a UAS," says Joey Hartmann, director of the Office of Bridges and Structures with FHWA. "The substantial amount of data collected requires an appropriate data management plan to ensure the inspectors capturing the data have (1) a standard approach for collecting and transferring the data, (2) a known and secure location and structure for storing and retrieving the data, and (3) a well understood process for sharing the data and inspection products generated by the UAS."



MnDOT created this 3D bridge model with selectable image locations using data it collected with a UAS.

© Minnesota Department of Transportation.

Cataloguing is the process of creating a directory of stored imagery files. It includes identifying where the data are located, identifying the types of data stored, establishing a process for version control, and instituting file naming conventions to which all users will adhere. A more advanced method of cataloging images is using a photogrammetric 3D model of the bridge, which requires creating a photogrammetric point cloud. This method is an alternative that enables all the inspection images for the bridge to be stored as a 3D model. Inspectors can select the bridge section of interest on the model (that is, where a defect exists) to view the image for analysis.

MnDOT tested this 3D modeling method to catalogue images. It enabled MnDOT inspectors to click on a point in the model and view images at that point to view defects. This can reduce the need for a manual photolog because the photogrammetry software will locate the image on the structure.

Future Advancements

As more bridge owners and inspectors incorporate UASs into their processes, the technologies available to improve inspections will continue to advance. For example, first-person view (FPV) devices or goggles are a relatively recent entry to the bridge inspection process. FPV gives the user a unique perspective from which to wirelessly view imagery and control the camera. Some FPV systems provide high-definition 1080p video and enable the user to control the sensor in real time with head movements. The image presented equates to looking at an 18-foot (5.5-meter) high-definition television from about 9 feet (3 meters) away. Some FPV systems also provide inspectors with the ability to digitally magnify the image, making it appear significantly closer and allowing a bridge inspector to see hairline cracks in the structure. For more information on FPV goggles for bridge inspectors, see "A New View for Bridge Inspectors" in the Summer 2018 issue of *Public Roads*.

Artificial intelligence (AI) is another technological advancement that inspectors may choose to incorporate into the UAS. AI can enable the system to navigate independently without human input throughout the structure (other than instructing the aircraft when and where it is supposed to fly and overriding the system in the event of a malfunction or signal loss). Flying the UAS in the same flight paths using AI can enhance the identification and tracking of defects over time. Inspectors could also use AI to collect and analyze many infrastructure images.

The speed of technological advances and improvements in the integration of new technologies is impacting bridge inspection. More and more bridge owners are employing UAS and exploring new ways to integrate UAS within established guidelines. FHWA is moving forward in partnership with those in the field to find efficiencies in inspection methods, reduce the cost of conducting inspections, enhance the comprehensiveness and quality of collected data, and improve the safety of inspection teams by using UAS, all while assuring the Nation's bridges are safe for travelers.

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DENNIS O'SHEA is FHWA's senior bridge safety engineer for the North region. He serves as a technical resource for the National Bridge Inventory and National Tunnel Inventory programs for 13 FHWA division offices in the Northeast. He has a B.S. in civil engineering from the University of South Alabama and is a licensed professional engineer in Delaware and Pennsylvania.

DEREK CONSTABLE is a bridge management engineer with the FHWA Office of Bridges and Structures. He holds B.S. and M.S. degrees in civil engineering from The Cooper Union for the Advancement of Science and Art.

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COMING BACK FROM DISASTER

by **FERDINAND ORTIZ**

After the most devastating hurricane to hit Puerto Rico in recent history, FHWA helped the island recover.

Atlantic hurricane season begins on June 1 each year and lasts through November 30. In 2017, a historic series of hurricanes tore through the Caribbean, including two that made direct hits on U.S. territories that are home to approximately 3.3 million U.S. citizens.

On September 6, Hurricane Irma struck the U.S. Virgin Islands with recorded winds of 105 miles per hour (170 kilometers per hour). And on September 17—although landfall for the slowly moving storm would not occur until September 20—Hurricane Maria began to pummel Puerto Rico with winds that would reach up to an estimated 155 miles per hour (250 kilometers per hour). Meteorologists have no land-based records of Maria's maximum winds on Puerto Rico because the storm damaged the island's wind sensors, designed to withstand winds of 135 miles per hour (220 kilometers per hour), before making landfall.

"After surviving two Category 5 hurricanes within 2 weeks, Puerto Rico and the U.S. Virgin Islands were changed forever," says Michael Avery, the associate division administrator of FHWA's Puerto Rico and U.S. Virgin Islands Division.

To an area still reeling from the aftermath of Hurricane Irma, Hurricane Maria caused about $90 billion in damages, making it the third costliest hurricane in U.S. history behind Harvey and Katrina. The total included more than $575 million in damage to federally eligible roads and bridges in Puerto Rico. The island suffered a total loss of power, and in some places, electricity was not restored for a year.

The damage literally hit home for the Federal Highway Administration. With power and communications down across the territory, buildings and bridges destroyed, and roads impassable, some employees of FHWA's local division office could not be located for more than a week following landfall. Those that could began reporting to their workplace the day after the disaster, beginning the agency's immediate emergency response.

ASSESSING THE DAMAGE

The day after Hurricane Maria made landfall, Puerto Rico was a different island. The storm destroyed the communication system, including cellphone towers, making contact among families as well as emergency responders nearly impossible. The damage to the power grid seriously curtailed the operation of gas stations, and in the days following, waiting lines of 8 hours to get gas were normal. Officials reported more than 6,000 separate incidents on heavily damaged transportation infrastructure, including 388 on bridges and 400 related to landslides caused by the extreme rainfall. Nearly 20 percent of Puerto Rico's bridges were damaged, including 26 that collapsed completely.

Despite destruction, damage, injury, and death, residents rallied to help one another. Michael Figueroa, a transportation finance manager with FHWA's Puerto Rico and U.S. Virgin Islands Division, was one of the first employees to arrive at the Division's San Juan office.

INSET: Hurricane Maria devastated Puerto Rico when it hit the island in September 2017, destroying many bridges and roads. High winds and heavy rain caused major damage to this bridge on PR-111 in Moca, Puerto Rico.

BACKGROUND: Emergency relief work included reconstruction of the PR-111 bridge, shown here after completed repairs.

Sources: FHWA.

Hurricane Maria destroyed roads such as this one near Naguabo, Puerto Rico.

Source: FHWA.

A landslide blocks PR-191 near Naguabo, Puerto Rico. The residents in the area wrote on the rocks to warn of the road closure.

Source: FHWA.

"Soon I could make out the sound of heavy equipment and chainsaws," Figueroa says, describing the scene in his neighborhood. "[It was] the rush of volunteers scrambling to move debris from the roads to clear a path to the highway. The community was taking a stand."

Along with Figueroa, several employees managed to get to the division office in San Juan the day after the hurricane to assess the destruction, which included extensive water damage to files and computers. It took more than a week to locate and account for every FHWA employee—thankfully, all were safe.

EMERGENCY RESPONSE

While dealing with its own recovery efforts, FHWA responded quickly to the island's catastrophe.

"We provided the Puerto Rico Highways and Transportation Authority with immediate guidance on emergency-related topics and worked side by side throughout the first critical days," says Avery, the division's associate administrator.

One of the immediate needs of the Puerto Rico government was funding, and FHWA provided more than $40 million in quick release Emergency Relief funds within 10 days of the event. The agency released additional Emergency Relief funds in the months following the hurricane as recovery efforts continued.

On September 18, before the hurricane even made landfall on Puerto Rico, President Donald J. Trump declared a state of emergency in the territory already suffering from the approaching storm. The declaration enabled the Federal Emergency Management Agency (FEMA) and the Department of Homeland Security to mobilize and coordinate disaster relief efforts. Within days, thousands of FEMA and other U.S. Government personnel began to arrive.

FHWA employees served as key partners in emergency support duties and coordinated with multiple Federal, Puerto Rico, and U.S. Virgin Islands agencies. The active involvement in the initial response and then recovery phases of the emergency required significant resources and additional help. FHWA provided satellite phones and equipped backpacks for engineers. Mainland FHWA division staff provided food and other essentials to the Puerto Rico and U.S. Virgin Islands Division to ensure it could serve local residents and emergency responders.

More than 40 FHWA volunteers from 15 States came to Puerto Rico between October 2017 and December 2018 to help supplement the division office's emergency response and recovery efforts. The volunteers conducted field assessments and inspections, prepared detailed damage inspection reports, and provided essential onsite guidance to all stakeholders. This help from FHWA had a direct impact on how effectively Puerto Rico recovered from the emergency, reinforcing the capacity of the agency to execute tasks necessary for a quick and efficient response.

Government executives, including President Trump and U.S. Secretary of Transportation Elaine L. Chao, also visited the island to see firsthand the damages caused by the hurricanes.

LONG-TERM RECOVERY

At of the end of 2017, nearly half of Puerto Rico's residents were still without power, and by the end of January 2018, recovery efforts had restored electricity to only about 65 percent of the island. Full restoration of power and water took a year after the hurricane hit.

FHWA's involvement continues long after the initial emergency response. The Eastern Federal Lands Highway Division (EFL) has been a fundamental partner in the recovery of Puerto Rico and the U.S. Virgin Islands, as it is performing the majority of the long-term recovery work in Puerto Rico. EFL is designing projects and preparing environment; right-of-way; and plan, specification, and estimate documents for construction projects. The EFL division is also advertising, awarding, and administering contracts for road construction, bridges, traffic signage, safety improvements, and landslide repairs. In all, EFL provides design, procurement, and construction management services valued at close to $1 billion.

The response to Hurricane Maria was unprecedented. It was the largest and longest Federal response to a domestic disaster in the history of the United States. Although much work remains to be done over the next 3 to 5 years, progress is being made in getting Puerto Rico and the U.S. Virgin Islands back to normal. Recovery efforts successfully restored power, communications systems, water, fuel, and other essential services to both territories. As a result, tourism is on the rise. Many construction projects are still underway, providing jobs to local workers and growing the economy—the Association of General Contractors estimated that hurricane reconstruction would require an additional 50,000 employees over 3 years.

"Irma and Maria hit us hard," says Andres Alvarez, the division's engineering team leader, "but both territories have bounced back and are ready to receive visitors from all over the world."

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MAINSTREAMING
TRANSPORTATION SYSTEMS MANAGEMENT AND OPERATIONS

by **TRACY SCRIBA, AARON JETTE,** and **PEPPER SANTALUCIA**

The current (and future) traveler demands improved reliability and efficiency. Is your TSMO program ready to deliver?

In today's connected world, U.S. travelers have come to expect ever-improving ways of using real-time information to make their lives better. As road users see rapid advances in information and transportation technologies, such as navigational apps, shared mobility services, and connected and automated vehicles, they expect more reliable travel and access to accurate, real-time information about travel conditions. Travelers are less tolerant of unexpected delays and demand greater accountability from public officials to ensure effective spending of public funds to maximize the performance of the transportation system.

Faced with heightened traveler expectations and funding constraints, as well as growing opportunities from advances in technology and data, transportation agencies are increasingly turning to operations strategies that optimize the use of existing roadway capacity. These strategies are known collectively as transportation systems management and operations (TSMO). TSMO is defined as a set of integrated strategies that enable transportation agencies to better manage and operate existing roadway capacity to improve the reliability and efficiency of the system and the mobility of system users. TSMO looks at performance from a systems perspective so that strategies to improve the operation of the transportation network are coordinated across multiple jurisdictions, agencies, and modes.

One key effort that helped agencies advance TSMO was the second Strategic Highway Research Program (SHRP2). For a decade, SHRP2 provided critical funding and technical resources to agencies to assist with developing and deploying innovative TSMO solutions. SHRP2 was a national partnership of the Federal Highway Administration, the American Association of State Highway and Transportation Officials, and the Transportation Research Board. A set of SHRP2 tools and training resources, the SHRP2 Reliability Solutions, focuses on improving the capability of transportation agencies to analyze and address congestion and travel time reliability. Every State, as well as the District of Columbia and Puerto Rico, has implemented these solutions.

Today's road users expect accurate, real-time information about travel conditions to help them make informed decisions, especially when encountering congestion. Variable message signs like the one shown here are one way to provide real-time information.

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How are State departments of transportation building and implementing effective TSMO programs? The following sections detail elements of success and provide examples that give a snapshot of 21st-century operations programs using SHRP2 solutions and beyond.

EXAMPLES OF TSMO STRATEGIES

- Active transportation and demand management
- Congestion pricing
- Freight management
- Integrated corridor management
- Managed lanes
- Parking management
- Road weather management
- Special event management
- Traffic incident management
- Traffic signal coordination
- Transit signal priority
- Traveler information
- Work zone management

Each of these categories has a number of individual strategies. More information on TSMO is available at *https://ops.fhwa.dot.gov/tsmo/index.htm*.

A Toolbox of Strategies

TSMO strategies include a wide range of operations strategies from work zone management and traffic signal timing and coordination, to congestion pricing and demand management. Many TSMO strategies leverage intelligent transportation systems (ITS) and advanced information technologies, but the TSMO toolbox also includes relatively low-tech operational enhancements and design treatments, such as snow fences, pullout areas, and part-time shoulder use.

TSMO looks at management and operations of the transportation system as a whole, and how it can effectively move people and goods safely, reliably, and efficiently to their destinations. Examples include use of traffic management centers to actively manage traffic flow between freeways and arterials during delays and crashes, real-time information that enables travelers to choose other routes or modes of travel to avoid delays, and coordinated incident response to reopen lanes sooner.

TSMO strategies can often mitigate, or even solve, many issues and improve traffic flow. However, addressing growing demand may sometimes necessitate adding lanes or other significant capital improvements. Integrating the best possible combination of solutions requires planning, data, organizational capabilities, and coordination among a range of partners.

TSMO helps system operators get the most out of their transportation facilities by smoothing everyday traffic flow and mitigating disruptions caused by weather, traffic incidents, planned events, and work zones. However, agencies must do more than deploy ITS projects to achieve the full potential of TSMO. To be most effective, TSMO must be recognized as a formal core function of State and local DOTs, just as project delivery is considered a core function today.

"Moving forward, managing roadways through a TSMO framework must become as much a part of the Massachusetts Department of Transportation's (MassDOT's) DNA as fixing potholes and plowing snow," said Stephanie Pollack, transportation secretary and CEO at MassDOT, in a recently published news release. "Advancing, expanding, and institutionalizing these kinds of [TSMO] solutions will help limit the effects of crashes, work zones, and weather on already lengthy commutes."

Championing TSMO

SHRP2 Reliability Solutions arrived at the right time to help early TSMO champions with products based on research and input from stakeholders. Research identified the importance of travel time reliability and the gap in how to analyze reliability and use it in decisionmaking. This led to the development of analytical tools and resources. Research focused on what differentiates agencies that are most effective at TSMO. The research found that the key differentiating factor between agencies most effectively implementing TSMO and other agencies was not the amount of technology deployed or money spent (however, both of these factors are necessary). It was whether an agency had effective processes and organizational capabilities for TSMO. These elements help create an organizational culture that supports TSMO and enables it to become the standard way of doing business.

The SHRP2 products and implementation assistance helped bring energy, attention, funding, and new tools to advance TSMO and create buy-in across transportation agencies. Monica Harwood Duncan, TSMO development engineer for the Washington State Department of Transportation (WSDOT), noted the value of the SHRP2 tools in helping to advance TSMO at WSDOT. "We have been fortunate enough to have received support for using around eight different SHRP2 products," Duncan says. "To summarize what those products meant to us as an agency—they created a conversation of innovation for us, to look at what's next for us, which may not have happened without SHRP2 products. It set very clear focus areas for us. We have to have TSMO be part of [our organization]—not champion driven, but fully integrated."

Reflecting on SHRP2 experiences and observations from other recent

WHAT ARE SHRP2 RELIABILITY SOLUTIONS?

Authorized by the 2005 highway reauthorization act, SHRP2 undertook more than 100 research projects designed to address critical State and local challenges, such as aging infrastructure, congestion, and safety. Reliability was one of the four focus areas of the SHRP2 program. The SHRP2 Reliability research projects developed analytical techniques, decision-support tools, strategies, and institutional and workforce approaches to improve the effectiveness of transportation operations. Many of the solutions developed in SHRP2's Reliability focus area are intended to help agencies implement TSMO more effectively.

To help State DOTs and metropolitan planning organizations deploy SHRP2 solutions, FHWA and AASHTO created the SHRP2 Implementation Assistance Program. This program conducted seven rounds of funding awards between 2013 and 2016. This program made 36 awards to States and MPOs for implementing SHRP2 Reliability solutions.

collaborations with agencies on TSMO, some elements that are helping agencies advance TSMO are:

- Treating TSMO as a core agency program.
- Integrating TSMO into existing processes, including planning for operations, and enabling it to compete effectively for funding.
- Developing an agency culture that supports and values TSMO by gaining leadership support and building support through the organization.
- Communicating the value of TSMO and making a business case for TSMO investments.
- Including reliability in analysis for project investments and system performance.
- Developing workforce capabilities for TSMO.
- Developing effective partnerships and collaboration between internal agency departments and with external partners across regions.

A recent National Operations Center of Excellence (NOCoE) report confirmed these observations by sharing the findings from a series of engagements with five State DOTs about their TSMO programs. This report identified common characteristics to a successful environment for TSMO including strong leadership and a champion at the senior staff level; prioritization, visibility, and availability of resources to do the job; the importance of culture in breaking down silos; collaboration, communication, and coordination; and attention to the workforce of the future.

Enhancing Organizational Capacity

SHRP2 Organizing for Reliability Tools provide solutions to help agencies integrate and mainstream operations. These products focus on orienting and improving key aspects within the agency to facilitate effective management and operations programs and projects. Using a capability maturity model (CMM) framework, these tools are designed to help agencies assess their TSMO programs. By systematically assessing distinct aspects of their TSMO programs using the CMM framework, agencies can identify and prioritize changes to their business and technical processes, as well as their organizational structure and institutional partnerships. These changes will enhance their ability to manage congestion and more effectively operate their transportation system.

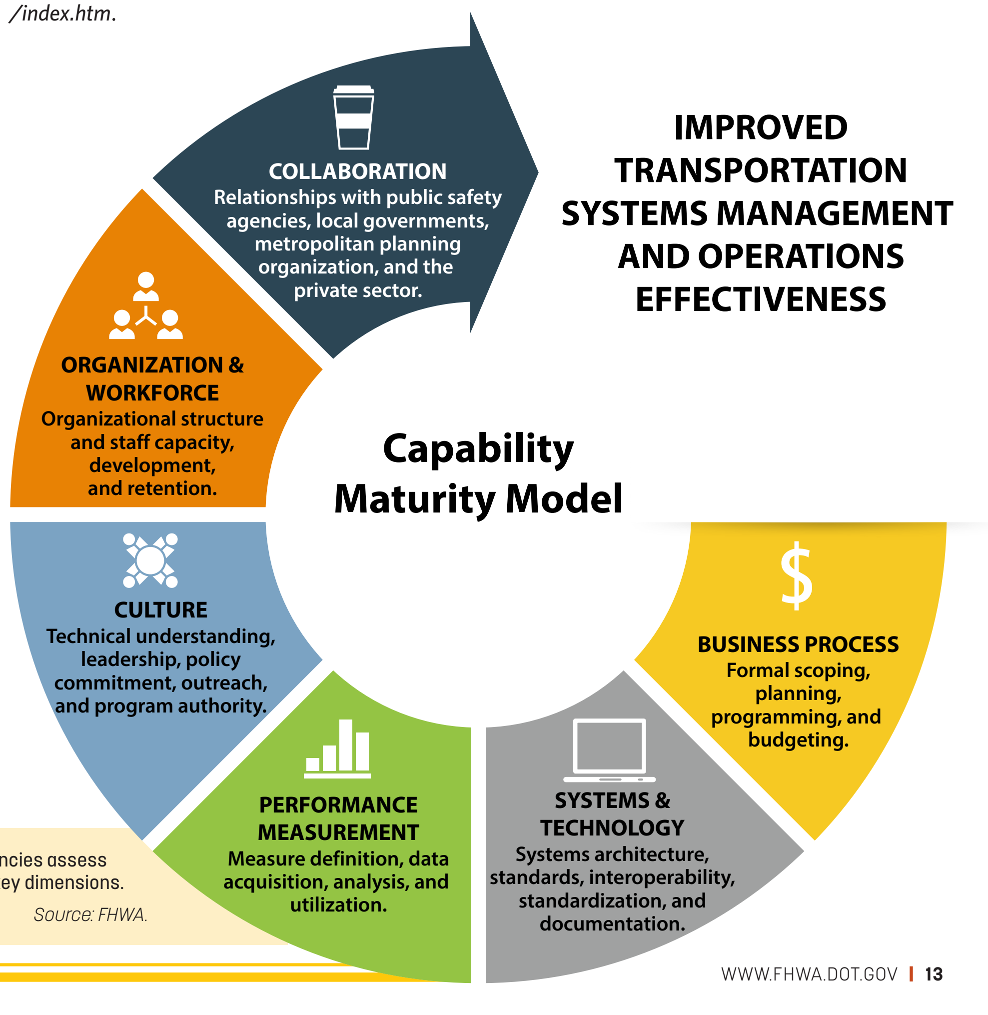
The Organizing for Reliability Tools garnered a high level of interest. Twenty-seven State and regional agencies applied for and received implementation assistance through the SHRP2 program to deploy these products. Interest in the CMM framework has continued to increase, and more than 50 States and regions have hosted workshops during which they used the CMM framework to evaluate their strengths and weaknesses and develop action plans to improve their TSMO capabilities. Agencies have used the results of these workshops to guide the development of TSMO program plans, build buy-in from agency leadership and key stakeholders, restructure organizations or business processes to integrate TSMO, increase workforce understanding and knowledge of TSMO approaches, and strengthen interagency partnerships.

Companion tools and case studies that apply the CMM approach to individual program areas like work zone management and road weather programs are available at *https://ops.fhwa.dot.gov/tsmoframeworktool/index.htm*.

CMM in Action

The Maryland Department of Transportation (MDOT) has used the CMM to assess its TSMO capabilities. After MDOT conducted an initial CMM assessment, they decided to develop and adopt a TSMO strategic plan. The agency also restructured the board overseeing the statewide traffic management system to include senior-level personnel and experts on the TSMO elements of planning, operations, and maintenance. As a result, MDOT has made progress toward integrating TSMO into its planning and project development processes, developing TSMO performance measures, and fostering a TSMO culture across the agency. MDOT established a leadership position to serve as the program manager to oversee implementation of the TSMO strategic plan. An assessment after 3 years showed improvement in five out the six CMM dimensions.

The Iowa Department of Transportation (Iowa DOT) also assessed its TSMO processes and capabilities using the CMM framework. Based on the results of its assessment, the agency developed a TSMO strategic plan, a TSMO program plan, and TSMO service layer plans. Through this comprehensive planning



The capability maturity model helps agencies assess their TSMO capabilities across six key dimensions.

Source: FHWA.

process, Iowa DOT sought to improve TSMO business processes and develop TSMO tools to enable the effective application of integrated TSMO strategies across eight different service areas such as traveler information, work zones, and connected and autonomous vehicles. Iowa DOT held an executive briefing and a workshop to launch its TSMO plan, developed a business case for TSMO to communicate the value of TSMO efforts to address its transportation challenges, and implemented other communication and education efforts, including a TSMO website and video. A reassessment using the same CMM showed that Iowa DOT's scores increased in three of the six CMM dimensions.

Program Planning

As in Iowa, many of the action plans coming out of the CMM self-assessment efforts of other States identified the need to develop a TSMO program plan. A program plan helps guide the agency in advancing its institutional focus on TSMO. Many States have plans for specific TSMO services, projects, and activities (such as ITS or incident response plans), but those plans often do not describe the role of TSMO in support of the agency's mission and do not address all TSMO functions or explain how they integrate. States and agencies have recognized a need to better mainstream TSMO within their agencies and to set priorities for activities and investments. As a result, more than 20 States and regional agencies have developed TSMO program plans.

The process of TSMO program planning, as described in FHWA's primer on TSMO program planning, *Developing and Sustaining a Transportation Systems Management & Operations Mission for Your Organization: Primer for Program Planning*, identifies the strategic, programmatic, and tactical elements to advance TSMO as a critical part of an agency's mission. In addition to identifying goals, objectives, performance measures, and specific projects, TSMO program plans define the programmatic structure for organizing an agency's activities, functions, and workforce to accomplish the goals and objectives of the program. Through the plans, agencies can establish TSMO as a core agency program.

Institutionalizing TSMO within agencies can help it endure over time as champions come and go; raise awareness and support for TSMO in agency policy, business processes, and budgets; and integrate it throughout the whole project life cycle. FHWA's primer on TSMO program planning is available at *https://ops.fhwa.dot.gov/publications/fhwahop17017/index.htm*.

Business Processes

Business processes are vital to guiding how an agency conducts its day-to-day business, establishing consistent steps for getting work done. Business processes can help integrate TSMO into agency project development and procurement processes, and increase the effectiveness of TSMO strategy deployment.

SHRP2 created resources to enhance business processes for TSMO. These resources provide a methodology and incorporate best practices to help transportation agencies change their business practices to strengthen systems operations, address nonrecurring traffic congestion, and improve travel time reliability. FHWA released a guide and workshop, which provide a methodology that managers can follow to develop and improve TSMO operational and programmatic processes. The guide, *Improving Business Processes for More Effective Transportation Systems Management and Operation* (FHWA-HOP-16-018), is available at *https://ops.fhwa.dot.gov/publications/fhwahop16018/index.htm*.

State and regional agencies have used the methodology and workshops to develop a process for activating and deactivating a storm desk (a special transportation management center function that activates during major weather events) at their transportation management centers, providing feedback on work zone traffic management plans from the field back to designers to improve future plans, and coordinating traffic management between arterials managed by local agencies and the State freeway system during major incidents on the freeway.

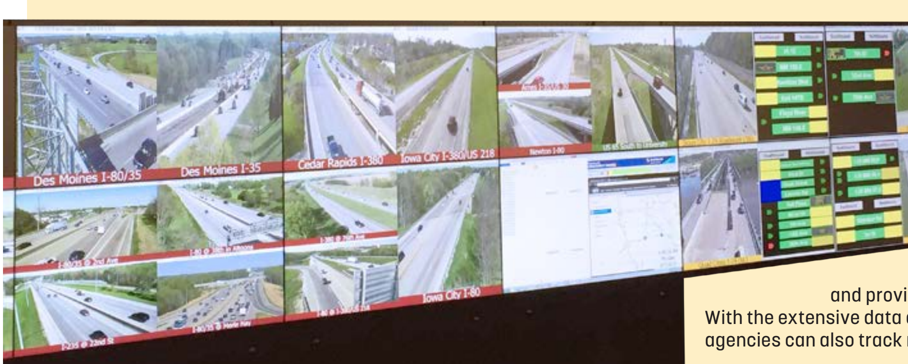
Changing the Culture

In general terms, efforts to advance TSMO have been described as moving an agency to become operations oriented—going from ad hoc activities to a complete TSMO program with integrated services that improve the performance of the existing transportation system. This is a cultural shift for many agencies.

Agencies advancing TSMO have built a TSMO culture working from both the leadership level and from staff-level champions. Leadership can provide indication of the agency's support for considering TSMO approaches to transportation issues and investing in TSMO strategies and workforce skills. Even with leadership support, senior staff champions play a key role in integrating TSMO into agency processes and working relationships, and helping identify where resources are needed. In some cases, staff-level champions have been in place for several years and TSMO efforts build slowly until leadership is in place that is ready to increase support for TSMO. Other times, new leaders come in emphasizing TSMO and staff-level support follows.

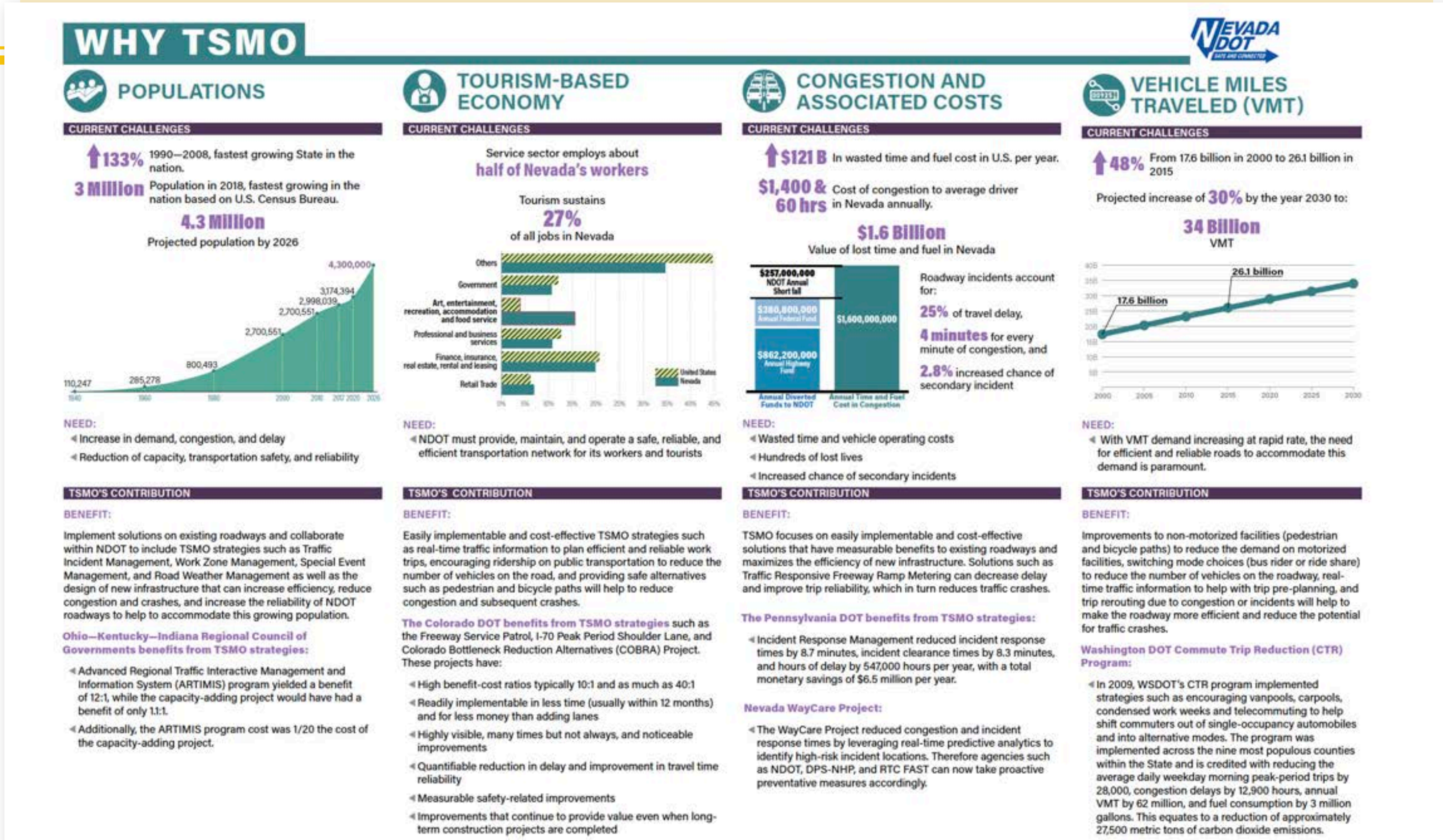
Many agencies have found it helpful to build a strong business case for TSMO, which can effectively communicate the value of operations and gain support and resources for TSMO.

The Nevada Department of Transportation's (NDOT's) SHRP2 CMM assessment led the agency to identify the need for a stronger internal understanding of TSMO. The NDOT Traffic Operations Division saw a business case as a way to enhance culture and collaboration for TSMO across NDOT's divisions. NDOT developed a case for TSMO that looks at eight current challenges and TSMO's contribution to addressing the challenges. NDOT drew these challenges from those already identified in the statewide



Technology and data come together in traffic management centers like this Iowa DOT facility to help agencies quickly identify traffic and roadway issues and make adjustments to traveler information and provide incident response. With the extensive data available today, agencies can also track roadway performance.

Source: FHWA.



The Nevada Department of Transportation developed a business case for TSMO that considers current transportation challenges in Nevada and explains TSMO's contribution to addressing those challenges.

© Nevada Department of Transportation.

transportation plan. NDOT's business case addressed challenges related to (1) a growing population, (2) a tourism-based economy, (3) growing congestion, (4) increasing vehicle miles of travel, (5) the need to repair roads and bridges, (6) safety issues, (7) trucks and freight movement, and (8) asset and performance management. NDOT formatted its business case in an easy-to-read two-page layout.

Other States, such as Iowa, Michigan, Oregon, Pennsylvania, and Utah have also created a business case for TSMO to help increase understanding and awareness of its value. As a result of their efforts to make a compelling case and build support for TSMO, a few States have established a mechanism to provide some dedicated funding for TSMO projects. For example, DOTs in both Michigan and Ohio have established competitive processes to which their regions or districts can submit projects for funding.

Another way some agencies have indicated support for TSMO is by incorporating TSMO into their agency missions, goals, and objectives. This is a visible way of establishing the key role that TSMO plays in a DOT and its transportation programs.

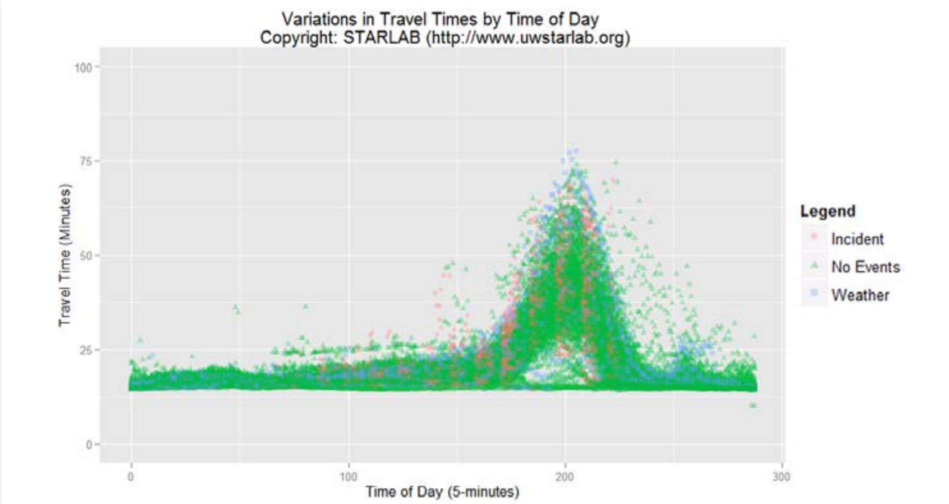
Two key resources for building a business case are the SHRP2 *Business Case Primer Communicating the Value of Transportation Systems Management and Operations*, available at ***https://transportationops.org/business-cases/business-case-primer-communicating-value-transportation-systems-management-and***, and FHWA's *Advancing TSMO: Making the Business Case for Institutional, Organizational, and Procedural Changes* (FHWA-HOP-19-017), available at ***https://ops.fhwa.dot.gov/publications/fhwahop19017/index.htm***.

Incorporating Reliability into Data and Analysis

Traditionally, analytical tools used by transportation agencies for highway operations have focused on average conditions. They have not taken into account a range of travel times or how travel times vary in response to changing conditions. To improve travel time reliability, transportation agencies need new tools for monitoring and analyzing fluctuations in traffic. With such tools, agencies can better analyze and diagnose the causes of travel time delays and select the appropriate management strategies to address specific issues.

Many TSMO strategies help manage disruptions caused by crashes, storms, or roadwork that can lead to unreliable travel times. The SHRP2 Reliability Program produced a suite of analytical tools to help transportation agencies better identify the sources of travel time delays, analyze the likely impact on travel time reliability from implementing various strategies, and incorporate these considerations into the transportation planning and funding process. These analytical tools also enable agencies to include reliability in their assessment of transportation alternatives.

WSDOT piloted SHRP2 tools to improve the monitoring and analysis of travel time reliability in both urban and rural areas of the State. WSDOT used the tools to enhance the capabilities of its existing data management and analysis system called the Digital Roadway Interactive Visualization and Evaluation Network (DRIVE Net). This system, developed by the University of Washington, uses geospatial, traffic, and other types of data to calculate a range of performance measures and conduct other types of analyses. WSDOT modified DRIVE Net to accept additional data sources and to perform new analytical functions based on the SHRP2 tool set. With the additional data sources and enhanced capabilities, WSDOT is now able to provide comprehensive travel time reliability measures for the statewide traffic



Reliability analytical tools help the Washington State Department of Transportation (WSDOT) understand the effect of incidents and weather on travel times in particular corridors in the State. WSDOT can then select the most relevant TSMO strategies.

© University of Washington.

network in days rather than months.

The Florida Department of Transportation (FDOT) is actively working toward integration of TSMO planning and reliability analysis into its processes with support from the SHRP2 tools and Implementation Assistance Program. FDOT developed the *Planning for Travel Time Reliability Guide* and *The Planning for TSM&O Guidebook*. FDOT then conducted outreach to its staff about integrating TSMO planning and reliability analysis into its processes. These efforts built on FDOT's earlier efforts, including a Central Office reorganization that changed an ITS office to a TSMO office in 2015. The reorganization recognized the importance of TSMO and the need for strong champions for implementation to be successful. FDOT also built off a 2016 TSMO CMM self-assessment that led to the development of a TSMO strategic plan. In addition, FDOT prepared the *Evaluation of Project Processes in Relation to Transportation Systems Management and Operations (TSM&O)* in 2018, which explored what would be required to integrate and mainstream TSMO throughout FDOT's entire project development process.

Developing Workforce Capabilities

Implementing TSMO strategies effectively may require enhancing the knowledge and skills of the current transportation agency workforce. This is especially true as transportation rapidly evolves to incorporate new data sources (such as crowdsourcing, where data comes from travelers themselves rather than from sensors or cameras managed by infrastructure operators), measures (such as reliability), technologies, and modes (such as dockless bikes and autonomous shuttles), in addition to more proactive approaches to system operations and management.

NOCoE identified TSMO workforce as a key challenge and selected it as the topic for its first national summit. To address TSMO capabilities in the transportation workforce, several entities, including FHWA and the SHRP2 program, have developed different types of TSMO training.

Regional Operations Forums. One of the key reliability solutions that SHRP2 developed was the Regional Operations Forum (ROF), a week-long immersion program in TSMO that includes peer exchange, learning from experts, and interactive group exercises. Over 5 years, a combination of FHWA, AASHTO, and SHRP2 implementation efforts have supported 26 ROFs with participants from all 50 States, Puerto Rico, and the District of Columbia, and as well as some staff from metropolitan planning organizations, municipalities, and public safety agencies. Some of these efforts were led by State DOTs using their SHRP2 implementation assistance funding. Based on feedback from the early forums, FHWA worked with AASHTO to adapt the ROF format to a condensed 2.5-day version called the Regional Operations Leadership Forum that is being delivered to every region of the country.

The forums enable program leaders at public agencies to build knowledge in TSMO while also developing a strong network of TSMO peers. Topics covered include core areas such as business processes, culture, organization, and workforce, as well as some technical topics such as integrated corridor management and emerging technologies.

TSMO Educational Program. Led by the Kansas Department of Transportation, the ITS Heartland regional chapter of the Intelligent Transportation Society of America (ITS America) used SHRP2 implementation assistance funding to establish a TSMO educational program based on the ROF model for its five member States: Iowa, Kansas, Missouri, Nebraska, and Oklahoma. As part of its training program, ITS Heartland has delivered a series of TSMO webinars and in-person training sessions, two TSMO train-the-trainer workshops, and a self-paced TSMO course. The program has reached more than 600 participants to date and received a 2018 NOCoE TSMO Award. Webinar recordings and other training resources are available on ITS Heartland's website at *https://itsheartland.org/tsmo-university/*.

TIM Responder Training. Traffic Incident Management (TIM), an important TSMO strategy, is the planned and coordinated

multidisciplinary process to detect, respond to, and clear traffic incidents and restore traffic flow as safely and quickly as possible. A strong TIM program equips responders of all disciplines to work together effectively and consistently, which decreases incident duration and reduces the number of secondary crashes.

The SHRP2 program created a TIM training curriculum that offers a set of practices to enable safer and faster clearance of traffic crashes. The training brings police officers; firefighters; DOT, towing, and medical personnel; and other incident responders together to engage in joint learning and interactive, hands-on exercises. A train-the-trainer program has created a national network of instructors, enabling quicker and more consistent training of the entire responder corps. To reach even more responders, the program developed a web-based version of the training for individuals who cannot access a classroom session.

More than 445,000 responders have completed one form of the training to date. In addition, more than 65 public safety academies in at least 38 States have integrated the training content into their curricula.

A formal evaluation of the SHRP2 TIM training program found that States that adopted the TIM training saw strengthened responder

FHWA has developed fact sheets to explain how TSMO relates to other DOT functions such as design, construction, safety, and environment.

Source: FHWA.

Trainees attend the Tennessee Traffic Incident Management Training Facility, which is designed for them to practice responding to crashes.

© Tennessee Department of Transportation.

and agency practices, resulting in further reductions to overall roadway-clearance and incident-clearance times. Participants in the TIM trainings in Arizona and Tennessee noted that the training enabled them to understand incident response from the perspective of other agencies, which made them become aware of nuances that could help expedite incident response.

The Tennessee Department of Transportation (TDOT) created an advanced TIM course to engage responders more deeply about multiagency collaboration. Using Federal Highway Safety Improvement Program funds, Tennessee DOT also built a TIM training facility next to a training center for the Tennessee Highway Patrol.

"The SHRP2 Program has provided TDOT with a number of resources that have helped mature our—and other Tennessee agencies'—TSMO capabilities," says Brad Freeze, director of the Traffic Operations Division at TDOT. "Specifically, the program has helped TDOT in developing a strategic direction for operations with the creation of a Traffic Operations Program Plan and has advanced the state of practice of incident management in Tennessee through the National TIM Responder Training course and our subsequent development of an advanced TIM training course."

Strengthening Collaboration

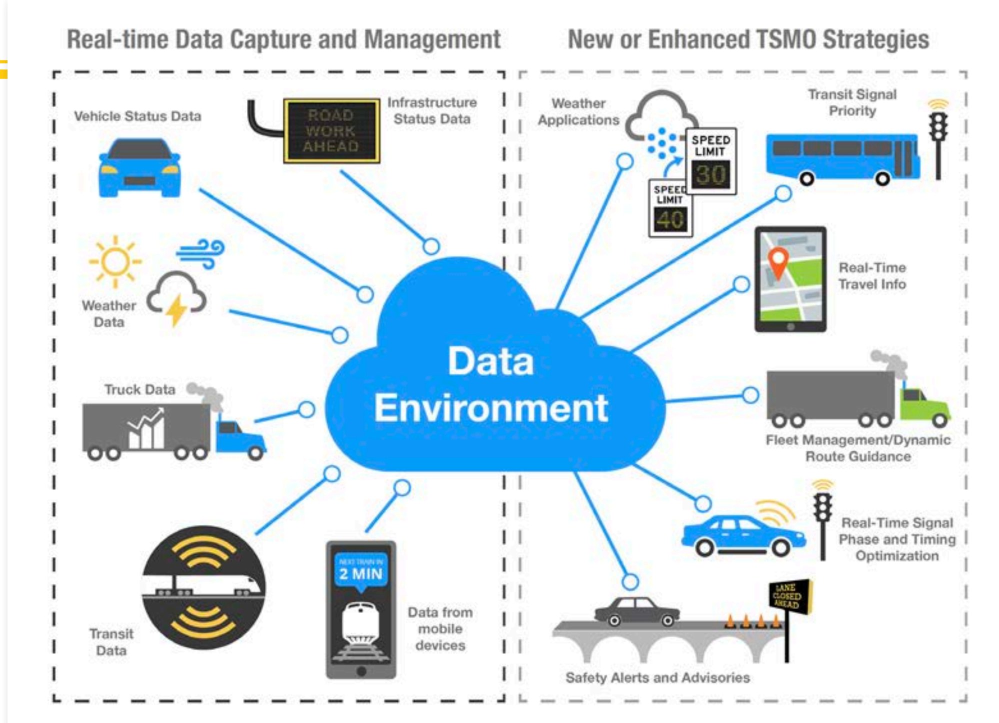
Implementing TSMO effectively requires collaboration not only within a transportation agency but also among transportation agencies from neighboring jurisdictions and from other modes such as transit. It also requires collaboration between transportation agencies and first responders. Some of the workforce development initiatives, such as the TIM responder training and the ROFs, foster collaboration while improving workforce skills. Other initiatives directly aim to build the internal and external relationships needed for effective TSMO.

Collaboration between planners and operators, commonly known in the industry as planning for operations, can improve the integration of TSMO into the entire project life cycle—from system planning and investment decisionmaking to design, construction, maintenance, and system monitoring and evaluation. Planning for operations also supports improved regional TSMO by considering operations strategies in regional transportation planning. Regional partners may include planning and operations staff from MPOs, State DOTs, transit agencies, highway agencies, toll authorities, and local governments.

TSMO often supports or benefits from other transportation agency functions and offices such as design, maintenance, and safety. Historically, these connections are not well understood or communicated, and organizational silos may exist in some agencies. However, acknowledging and strengthening these connections may result in more effective functions. FHWA has developed a series of nine fact sheets that detail how TSMO relates to other functions within a DOT and provide examples of how connecting these functions has worked in practice. For example, the Maricopa County Department of Transportation and Arizona Department of Transportation created AZTech, a regional traffic management partnership in the Phoenix metropolitan area. AZTech established a regional data-sharing system among its member agencies and jurisdictions to enable local jurisdictions to share real-time information on traffic incidents and infrastructure conditions. The FHWA fact sheets are available at *https://ops.fhwa.dot.gov/plan4ops/focus_areas/integrating/tsmo_factsheets.htm*.

National Operations Center of Excellence. Created in 2015 with support from the SHRP2 Reliability Program, NOCoE is an organization dedicated to promoting TSMO, educating TSMO practitioners, bringing together the TSMO community, and accelerating deployment of TSMO strategies. NOCoE is a partnership of AASHTO, ITS America, and the Institute of Transportation Engineers, with support from FHWA. The center offers an array of technical services, such as peer exchange workshops, webinars, and case studies, and raises awareness of TSMO strategies and successes through its TSMO awards program and technology tournament.

NOCoE maintains a website at *https://transportationops.org* that serves as a centralized source of TSMO information. On its site, NOCoE maintains a web page of resources on TSMO workforce development and offers a collection of TSMO case studies to share TSMO successes from agencies across the country.



Transportation agencies are leveraging connectivity and emerging transportation data capabilities to advance TSMO strategies. This diagram shows various types of real-time data that agencies can use for new or enhanced TSMO strategies.

Source: U.S. Department of Transportation.

Is Your TSMO Program Ready?

The transportation sector is rapidly transforming—connected and automated vehicles, ride-hailing services, micromobility vehicles such as shared bicycles and electric scooters, and the growing use of active and even proactive corridor management. Also changing is the increasing ubiquity of data about travelers and the transportation systems they are using (for example, crowdsourced data from travelers, private-sector data providers, and road condition data from connected vehicles) as well as the processing power and analytical tools to manage and make sense of the data.

Technological changes are increasing both the quantity and quality of real-time data that transportation agencies can use to implement TSMO strategies. In some cases, the effectiveness of existing TSMO strategies will be enhanced. In other cases, it will be possible to try new TSMO strategies. However, unless agencies have addressed the organizational, workforce, and analytical aspects of TSMO, they may not be able to take full advantage of new technologies and new data sources.

FHWA is working with a wide range of stakeholders to prepare the Nation's roadway systems for the coming age of connected and automated vehicles. In 2018, FHWA held the National Dialogue on Highway Automation, a series of six national workshops focused on automated vehicles. The series highlighted the importance of integrating automated vehicle considerations into TSMO strategies to ensure that these vehicles can safely navigate traffic incidents, work zones, special events, and signal disruptions. Based on the outcomes of the National Dialogue, FHWA is prioritizing programs, policies, and research to support the safe and efficient integration of automated vehicles. For example, FHWA is pursuing an update to the *Manual on Uniform Traffic Control Devices for Streets and Highways* (MUTCD) to help prepare roads for the future of automated vehicles.

"Addressing congestion issues requires transportation professionals to seek out solutions that involve optimizing performance to get more out of our existing facilities," says Martin Knopp, FHWA Associate Administrator for Operations. "We have seen growing recognition of the need for effective operations. SHRP2 efforts played a big role in that. FHWA will continue to support the development of TSMO strategies and a national TSMO community of practice and to assist its partners in their efforts to improve roadway operations."

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AARON JETTE is chief of the Program Development and Capacity Building Division at USDOT's Volpe National Transportation Systems Center. He holds a master's degree in public policy from Harvard University.

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For more information, see *https://ops.fhwa.dot.gov/tsmo/index.htm* or contact Tracy Scriba at 202–366–0855 or *tracy.scriba@dot.gov*.

WEBSITES FOR MORE INFORMATION

FHWA Planning for Operations:
https://ops.fhwa.dot.gov/plan4ops/index.htm

FHWA SHRP2 Reliability:
https://ops.fhwa.dot.gov/shrp2/index.htm

NOCoE: *https://transportationops.org*

SHOWCASING HIGHWAY RESEARCH

by **Kelley McKINLEY**

Unmanned aerial systems provide high-quality data and imagery where traditional data collection practices are inadequate or sites are difficult to access for bridge inspection, field surveys, geotechnical investigations, and routine construction inspection.

Source: FHWA.

FHWA recently put its work on display at an inaugural event to highlight innovative technologies.

Research and technology are key ingredients for helping the Federal Highway Administration reach its mission to enable and empower the strengthening of a world-class highway system.

On September 18, 2019, FHWA hosted its first-ever Research Showcase at the U.S. Department of Transportation's headquarters in Washington, DC. The event featured innovations developed through FHWA's Office of Research, Development, and Technology (RD&T), located at the Turner-Fairbank Highway Research Center (TFHRC), and other FHWA offices.

The FHWA Research Showcase featured 25 exhibits and demonstrations, and 3 presentations that provided representatives from USDOT modes and other highway stakeholders with a first-hand look at the latest transportation technology. During the event, attendees had the opportunity to interact with leading researchers and innovative technologies such as:

- CARMA^{SM}, which enables automated vehicles to share information with each other and roadway infrastructure, and to manage complex traffic issues that human drivers deal with daily.
- Ultra-high performance concrete (UHPC), the most technologically advanced concrete available in today's market. UHPC is 5 times stronger and 10 times more durable than conventional concrete.
- A hand-held spectrometer, which offers the potential to improve infrastructure performance by making it possible to very quickly determine whether materials brought to the project site meet agency requirements.
- An FHWA Hydraulics Research Program's mobile robotic system that automates the current riverbed material testing process, which can be time consuming and labor intensive.

The event also highlighted the importance of multimodal collaborations that support "one DOT." FHWA Administrator Nicole R. Nason noted how the "incredible research work being conducted by the FHWA plays an important role in improving our current and future highway and bridge infrastructure and its benefits are seen across nearly all modes of the USDOT," most notably in the multimodal efforts related to connected and automated vehicle research.

In addition, TFHRC plays a key role in ensuring that FHWA research extends beyond USDOT. At the event, U.S. Secretary of Transportation Elaine L. Chao said, "The research being conducted at the Federal Highway Administration's Turner-Fairbank Highway Research Center—in partnership with universities, startups, and industry stakeholders—has helped to advance transportation innovation. This work includes development of innovations in materials, designs, operations, and safety." She also noted that the research and technology developed at TFHRC "has enabled the highway system to move people and freight more safely and has contributed to the economic success of our country."

KELLEY McKINLEY is a marketing and communications specialist at TFHRC, where she is responsible for developing communications strategy for FHWA's research and technology. She holds a B.S. in communication studies from Northwestern University and an M.S. in communication management from Temple University.


VIVE

LEFT: Stacy Balk, who supports TFHRC's Human Factors program, shows a showcase visitor how to use FHWA's virtual reality bicycle. This technology provides an opportunity to explore and investigate new infrastructure and safety enhancing techniques, without the safety risks of real-world evaluation.

TOP RIGHT: Secretary Chao welcomes visitors to the FHWA Research Showcase.

BOTTOM RIGHT: Administrator Nason inspects a hand-held spectrometer with Terry Arnold, a chemist at TFHRC. The technology can quickly assess the composition of highway materials to detect the presence or absence of various constituent materials.

Sources: FHWA.

TOP LEFT: The RABIT™ bridge deck assessment tool collects comprehensive data on surface and subsurface conditions.

TOP RIGHT: David Kuehn, program manager of the Exploratory Advanced Research (EAR) Program, engages visitors at the EAR table. The EAR Program addresses the need to conduct longer term and higher risk breakthrough research with the potential for transformational improvements to plan, build, renew, and operate safe, congestion free, and environmentally sound transportation systems.

MIDDLE: Secretary Chao discusses the value of research in front of a large audience at the event.

BOTTOM: Visitors to the Research Showcase could view the CARMA vehicles parked on the Third Street Plaza between the West and East buildings of USDOT headquarters.

Sources: FHWA.

What Does the Changing Face of Electricity Production Mean for Concrete?

by **SAIF AL-SHMAISANI** and **MARIA JUENGER**

Fly ash from coal burning is an almost essential component of concrete mixtures. But with coal on the decline for power production, the concrete industry is looking for alternatives.

Burning coal is one of the primary means of generating electricity in the United States. The coal-burning process produces residual, incombustible materials. Fly ash—fine, glassy, rounded particles rich in silicon, aluminum, calcium, and iron oxides—is one of these residual materials, captured from the flue gas by precipitators and bag filters. Because of its chemical and physical characteristics, fly ash can substitute for a portion of portland cement in concrete mixtures as a supplementary cementitious material (SCM). Fly ash also improves many concrete properties such as workability. The spherical shape of fly ash particles compared to the shape of other SCMs can be seen in microscopic images.

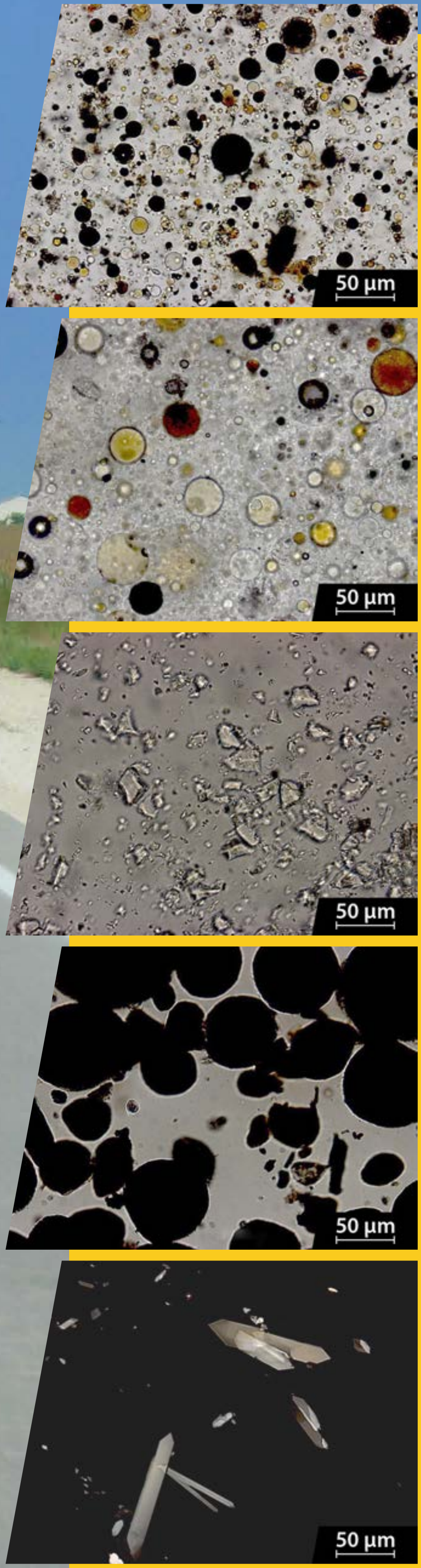
The concrete industry has used fly ash as an SCM for decades, thereby diverting it from landfills and impoundments, providing a benefit to both the power and concrete industries. According to the American Coal Ash Association's (ACAA) 2017 *Production and Use Survey*, 111.3 million tons of coal combustion products were produced that year, with 71.8 million tons beneficially used. In 2017, concrete manufacturers used 14.1 million tons of fly ash in concrete.

Fly ash is the primary SCM used in concrete in the United States. Because fly ash is a byproduct material and cement is a manufactured material, the cost of fly ash is generally lower than the cost of cement. Therefore, substituting fly ash for cement reduces the cost of concrete.

Recent environmental regulations that require emissions-control systems and the abundance of natural gas as an alternative fuel to coal have led to a decline in coal-fired power plants—a trend that is likely to continue. The U.S. Energy Information Administration (EIA) forecasts that 42 percent of existing coal-fired generation capacity will retire by 2050. As fly ash becomes less and less available, State departments of transportation and their contractors will need to seek alternatives. Many are already considering other options, such as natural pozzolans.

Concrete pavement durability and service life depend on the selection of quality materials and proper construction practices. SCMs are important ingredients in concrete for pavements—both to improve durability in freezing and thawing exposures and for the mitigation of alkali-silica reaction with some aggregate sources.

Source: FHWA.



This is a composite of images taken through a microscope of five different SCM powders used in paving and structural concretes in transportation applications. Shown here, in order from top to bottom, are Class F and Class C fly ash, slag cement, densified silica fume pellets, and metakaolin.

Source: FHWA.

The Benefits of SCMs

Fly ash and other SCMs enhance concrete properties. The spherical particles of fly ash reduce friction during mixing when concrete is in its early, fluid state, enabling the reduction of mixing water or chemical additives used to improve flow. SCMs chemically react over time in a pozzolanic reaction with calcium and hydroxyl ions in the concrete pore solution to form calcium silicate hydrates. The calcium silicate hydrates increase concrete's long-term strength and reduce porosity and permeability. The slow reaction is especially beneficial in thick concrete pavement and mass concrete applications to prevent cracking and develop long-term strength.

SCMs can reduce the risk of thermal cracking and subsequently provide good long-term mechanical properties. SCMs also help protect concrete from long-term chemical degradation. For example, SCMs reduce porosity through the pozzolanic reaction, slowing the intrusion of chlorides that can cause corrosion of steel reinforcement and sulfates that can cause expansive reactions and cracking. Lastly, SCMs can reduce expansion and cracking from alkali-silica reaction in aggregates containing reactive siliceous materials.

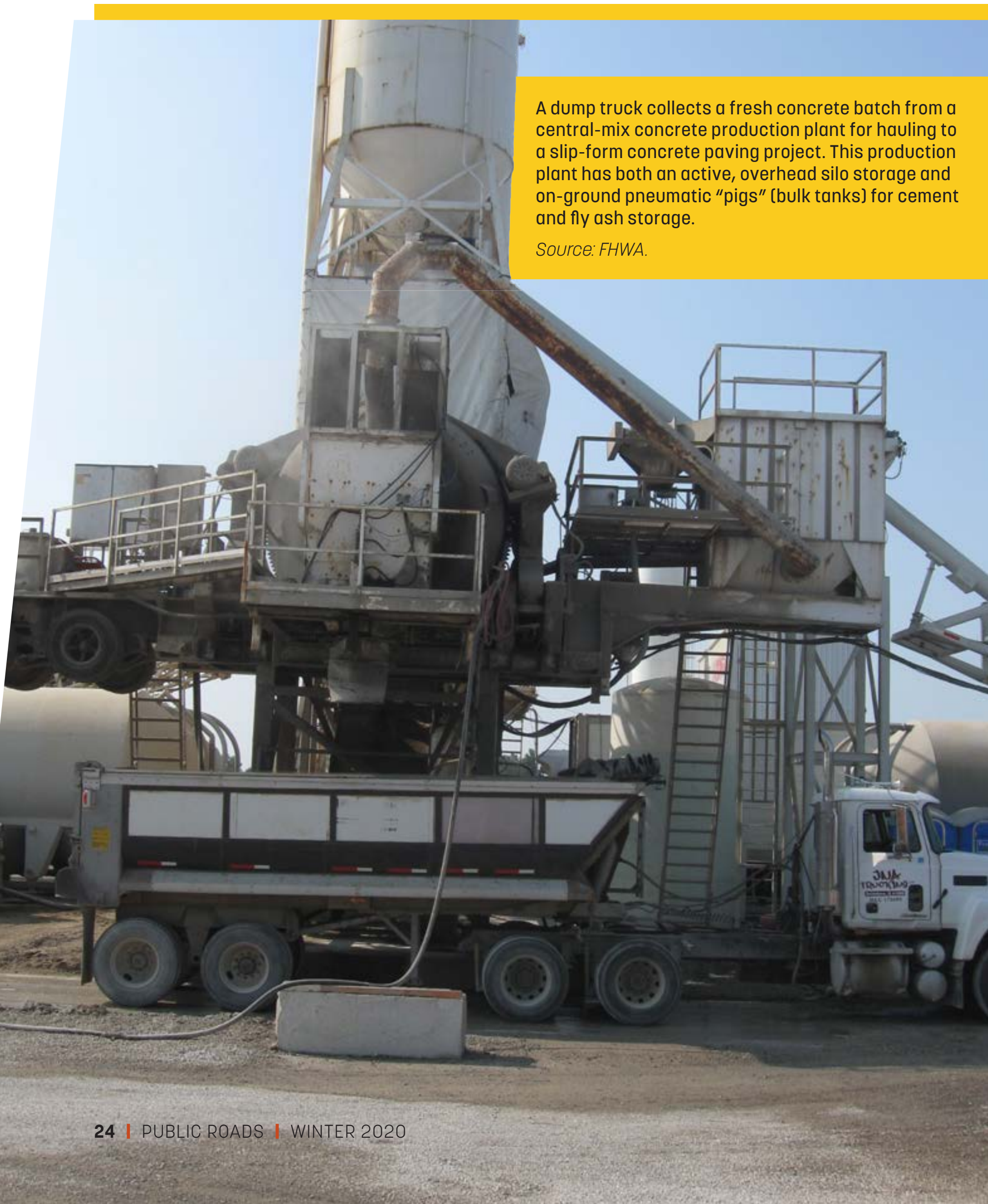
An Uncertain Future

In 2011, the Environmental Protection Agency (EPA) issued a rule regulating the amount of mercury and other air toxins emitted by power plants in response to the 1990 Amendments to the Clean Air Act. To meet these regulations, coal-fired power plants have had to install emission control systems to reduce emissions primarily from sulfur oxides, nitrogen oxides, and mercury. These systems often contaminate the fly ash produced by treating the flue gas with various substances, such as limestone powder, to react with the sulfur producing gypsum and activated carbon to absorb the mercury. Often the products of emission control systems become mixed with the fly ash, reducing its quality and performance in concrete.

In addition to the contamination of fly ash, installation and maintenance of emission control systems can be costly for smaller or older plants, forcing many to be retired. The EIA reports approximately 475 coal-fired power generator closures since the EPA finalized the 2011 regulation. Coal-fired power plants that can make the necessary modifications incur higher costs to produce electricity, which increases the cost of electricity generated by the plants. This has created a more competitive market for other energy sources, such as natural gas, solar, and wind energy.

According to the ACAA's *Production and Use Surveys*, the amount of fly ash used in concrete products has increased 5 percent between 2011 and 2017; however, the amount of fly ash produced has dropped 36 percent. The American Road and Transportation Builders Association (ARTBA) estimates that concrete production will increase more than 50 percent by 2033. Dwindling fly ash production necessitates the search for alternative sources of this material.

"The Texas Department of Transportation [TxDOT], [like] many other DOTs, has relied heavily on fly ash to improve long-term durability of concrete," says Andy Naranjo, rigid pavements and concrete materials branch manager of TxDOT. "Seasonal power plant outages, changes in coal sources, and power plant closures have significantly impacted the supply of fly ash making it challenging for the fly ash industry to meet the fly ash demand. TxDOT has worked closely with fly ash marketers as they bring in new sources of fly ash from other States and countries, and some unconventional options to ensure the immediate demand is met."



A dump truck collects a fresh concrete batch from a central-mix concrete production plant for hauling to a slip-form concrete paving project. This production plant has both an active, overhead silo storage and on-ground pneumatic "pigs" (bulk tanks) for cement and fly ash storage.

Source: FHWA.

Fly Ash Beneficiation and Harvesting

According to the ACAA, only 64 percent of the fly ash produced in the United States in 2017 was beneficially reused. The large unused quantities of fly ash produced per year are often landfilled or ponded onsite at power plants. Therefore, opportunities exist for excavating or dredging and recovering these materials, a process referred to as harvesting. In addition, coal combustion produces other residuals, such as bottom ash and economizer ash, which may be untapped resources for SCMs.

The primary obstacle to using underutilized coal combustion residuals in concrete is material quality. ASTM International (ASTM) C618 and the American Association of State Highway and Transportation Officials (AASHTO) M295 specify the chemical and physical properties that fly ash must meet for use in concrete mixtures. However, beneficiating or remediating fly ashes that do not meet these specifications can make them acceptable for use. For example, coarse material can be post-processed by classifying or grinding to increase fineness and fly ash with high unburned carbon content can be thermally, electrostatically, or chemically treated to remove carbon or reduce its absorptivity.

A construction crew pours fresh concrete on an asphalt base during construction of a jointed plain concrete slip-formed pavement.

Source: FHWA.

Research at FHWA

FHWA's Turner-Fairbank Highway Research Center (TFHRC) continues concrete research on SCMs and SCMs used with limestone powder in cooperation with FHWA Exploratory Advanced Research Program researchers and with the National Institute of Standards and Technology. To date, the research has resulted in the following documents:

- *Benefits of High Volume Fly Ash Fact Sheet* (FHWA-HRT-10-022)

  www.fhwa.dot.gov/publications/research/ear/10051/10051.pdf

- *Increased Use of Fly Ash in Hydraulic Cement Concrete (HCC) for Pavement Layers and Transportation Structures*

  https://doi.org/10.5703/1288284316554

- *Evaluation of High-Volume Fly Ash Mixtures (Paste and Mortar Components) Using A Dynamic Shear Rheometer and an Isothermal Calorimeter* TechBrief (FHWA-HRT-12-062)

  www.fhwa.dot.gov/publications/research/infrastructure/pavements/12062/12062.pdf

- "Isothermal Calorimetry as a Tool to Evaluate Early-Age Performance of Fly Ash Mixtures," *Transportation Research Record: Journal of the Transportation Research Board*

  https://journals.sagepub.com/doi/abs/10.3141/2342-06

- "Ternary Blends for Controlling Cost and Carbon Content," *Concrete International*

  https://concrete.nist.gov/~bentz/TernaryblendsforCI.pdf

- "Multi-Scale Investigation of the Performance of Limestone in Concrete," *Construction and Building Materials*

  https://tsapps.nist.gov/publication/get_pdf.cfm?pub_id=916188

Conducting laboratory research on trial concrete mixtures containing various cementitious blends is an important step in selecting materials and blends that will yield long-term concrete performance and durability in transportation infrastructure. Laboratory technicians will run workability tests on this fresh batch of concrete.

Source: FHWA.

Assessment of New Rapid Alkali-Silica Reaction (ASR) Tests. Ongoing research in the TFHRC Concrete Laboratory and the TFHRC Aggregate and Petrographic Laboratory (APL) tests the reliability of two new test methods–the concrete cylinder test and miniature concrete prism test–in assessing ASR mitigation measures. This research is in collaboration with the University of Texas and Oregon State University. Researchers plan to present the results of this project, comparing the performance of reactive aggregates in the lab with field exposure blocks containing SCMs (Class F and Class C fly ash, slag cement, or silica fume), at the Transportation Research Board's 2020 Annual Meeting.

Assessment and Refinement of Concrete Durability Testing Procedures. TFHRC is one of the research organizations looking at durability testing procedures for concrete with and without SCMs in support of the new AASHTO PP84-19 for Performance Engineered Mixtures (PEM) for concrete. The PEM project is assessing a suite of new test procedures for practicality in the lab and relation to performance. One test is electrical resistivity of a concrete cylinder as an indicator of the quality of the pore system. Concrete resistivity depends both on the pore structure and on the pore solution in the concrete. Aspects of this research, including data on concrete with fly ash and slag cement SCMs, are explained in *Formation Factor Demystified and Its Relationship to Durability* (FHWA-HRT-19-030) at *www.fhwa.dot.gov/publications/research/infrastructure/pavements/19030/index.cfm*.

As fly ash decreases in availability, the concrete industry must find alternative materials. Pumice, shown here, is a natural pozzolan with a similar oxide composition to some fly ashes.

© May 2019 Natural Pozzolan Association 1st Annual Symposium hosted by Kirkland Mining Company, LLC.

Beneficiation is not limited to as-produced fly ash. According to the EPA, more than 310 active landfills onsite at power plants have an average size of more than 120 acres (48.5 hectares) and an average depth of more than 40 feet (12 meters). In addition, more than 735 active surface impoundments have an average area and depth of 50 acres (20 hectares) and 20 feet (6 meters). Presumably, these landfills and impoundments hold vast reserves of materials that operators or fly ash distributors could harvest and beneficiate for use in construction.

As reported in the July–August 2019 issue of the *American Concrete Institute Materials Journal*, research indicates that applying thermal, mechanical, and/or chemical treatment to fly ashes harvested from landfills can result in fly ashes with very similar performance to the as-produced material. Similarly, bottom ash and economizer ashes benefit from treatments to improve their performance in concrete. After the performance of these materials is proven, the limiting obstacle is modification of the relevant standards and specifications to enable their use. To this end, several research projects recently begun through the Federal Highway Administration's Exploratory Advanced Research Program, the National Cooperative Highway Research Program, and by industry associations and SCM producers and suppliers to better define performance requirements of harvested and beneficiated fly ash and other coal combustion products.

Natural Pozzolans

Another solution to extend the resources for SCMs is to increase production of natural pozzolans. Natural pozzolans are quarried minerals with similar compositions to fly ash, making them also pozzolanically reactive. Minerals in this category include unaltered volcanic minerals such as pumice, perlite, and volcanic ash; altered volcanic minerals such as zeolites; and calcined sedimentary minerals such as clays and shales.

Natural pozzolans have a strong history of use in the United States in the early 20th century for the construction of many landmark bridges and dams. Their use decreased as fly ash came into favor during the late 20th century, but they are experiencing a renaissance as fly ash production decreases and demand for high-quality SCMs increases. In the United States, natural pozzolan producers formed the Natural Pozzolan Association (NPA) in 2017 to represent their growing industry. The NPA reports adding 500,000 tons of new production capacity in North America in 2018 and estimates producing 500,000 tons more in 2019.

Use and research on both raw and calcined natural pozzolans demonstrate excellent performance as SCMs in concrete in terms of fresh and hardened state properties and long-term durability.

Blended Ashes

Another opportunity for extending SCM resources comes from blending materials from different sources. Blending facilitates the use of underutilized materials and conserves the use of high-quality materials, enabling the production of a larger quantity of good quality material for use in concrete. For example, blending an SCM that does not meet the ASTM C618/AASHTO M295 specification for fineness with a finer material can produce an acceptable alternative. Similarly, blending an SCM with a high carbon content with one having a lower carbon content can yield an acceptable level of carbon content.

Blending of SCMs is permitted under ASTM C1697. However, the specification currently only allows the blending of materials that meet specifications for fly ashes, natural pozzolans, silica fume, and slag cement. Off-specification materials are not allowed despite research that shows off-specification fly ashes blended with natural pozzolans or other fly ashes perform quite well in concrete mixtures, as long as the blended material meets the chemical and physical requirements for a fly ash. Furthermore, blending materials such as milled bottom ash with fly ashes and other SCMs presents the opportunity to include more underutilized coal combustion residuals.

"Changes in electricity generation will continue to impact concrete mixture designs into the future," says Michael Praul, P.E., senior concrete engineer with the FHWA Mobile Concrete Technology Center. "However, there are many promising approaches to solving this problem—from beneficiating underutilized or landfilled materials to searching for new sources of SCM materials and optimizing blends for targeted performance. Now is the time to develop viable means to assure the long-term availability of SCMs so we can continue to produce high-quality concrete for the Nation's infrastructure in the future."

Ahmad Ardani, PE, and **Richard Meininger, PE**, are the FHWA points of contact for this research. Ardani is the concrete research program manager with FHWA at the Turner-Fairbank Highway Research Center (TFHRC). Meininger is a research civil engineer on the Pavement Materials Team at TFHRC. For more information, contact Ardani at *Ahmad.Ardani@dot.gov* or 202–493–3422, or Meininger at *Richard.Meininger@dot.gov* or 202–493–3191.

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MARIA JUENGER, Ph.D., is a professor of civil, architectural, and environmental engineering at the University of Texas at Austin. Juenger received a B.S. in chemistry from Duke University and a Ph.D. in materials science and engineering from Northwestern University.

This photo shows a typical sawed joint in plain concrete slip-formed pavement with the desired crack extending from the bottom of the partial-depth saw cut to the bottom of the slab. Using SCMs in concrete paving mixtures will help improve the durability of the concrete in deicing chemical exposures, which is important in long-term joint performance.

Source: FHWA.

Research at the University of Texas at Austin

The Texas Department of Transportation (TxDOT) is supporting research on fly ash and fly ash alternatives in concrete, including the role of fly ash in preventing thermal cracking in mass concrete and controlling expansion from ASR. With respect to the latter, the University of Texas at Austin maintains outdoor exposure sites to monitor long-term durability of concrete mixtures both in Austin, TX, and in the Gulf of Mexico. The long-term outdoor exposure testing enables the correlation of degradation under accelerated testing to that which occurs under more realistic conditions.

Outdoor exposure sites for durability testing at the University of Texas at Austin.
© Racheal Lute.

TxDOT-funded work on fly ash alternatives began in 2011 as changes in air pollution regulations for power plants threatened to reduce the availability of fly ash in Texas. TxDOT-sponsored research at the University of Texas at Austin targeted natural pozzolans as fly ash replacements, with excellent performance identified from pumice, perlite, and calcined clay and shale. At the time of the research, these materials were more expensive than fly ash. TxDOT continued to sponsor work on lower cost materials, such as reclaimed and remediated fly ashes and byproduct sources of natural pozzolans, such as overburden pumice. All materials with pozzolanic reactivity performed well in concrete mixtures, improving mechanical properties and durability.

TxDOT's support for research is continuing with emphasis on blended fly ashes and tools for screening good materials from marginal or poor ones, which is critically important as the industry sees an increasing variety of materials and blends introduced to the market.

CARMA℠: DRIVING INNOVATION

by **TAYLOR LOCHRANE, LAURA DAILEY,** and **CORRINA TUCKER**

FHWA's cooperative driving automation program is transforming transportation.

Cooperative driving automation (CDA) has the potential to improve transportation safety and efficiency, facilitate freight movement, increase productivity, and save money by reducing the need to widen roadway lanes. The Federal Highway Administration developed the unique CARMA Platform℠ and CARMA Cloud℠ (collectively, CARMA℠) to support the research and development of CDA features in support of transportation systems management and operations (TSMO).

"Automated vehicles, consistent with their name, operate autonomously or on their own," says Chris Stanley, the program manager for FHWA's Saxton Transportations Operation Laboratory and the senior director of surface transportation research at Leidos. "FHWA is enabling these vehicles to work together for the public good, improving transportation safety and mobility."

CARMA is a cooperative effort among FHWA, the Federal Motor Carrier Safety Administration, the Maritime Administration, the Intelligent Transportation Systems Joint Program Office, and the Volpe National Transportation Systems Center. Together, the agencies work to facilitate collaboration, research, and testing in CDA as well as the future of the Nation's transportation system.

What Is CARMA?

The overarching purpose of CARMA is to transform transportation, improving efficiency and safety through automated vehicles working together with roadway infrastructure.

To fully understand what CARMA is and how it can improve transportation efficiency and safety, it is important to understand how the current iteration of CARMA developed. CARMA1 started out as a proof of concept. A software package developed to enable vehicles to communicate their longitudinal movements with each other, CARMA1 marked the start of FHWA's cooperative automated vehicle fleet.

Next, the team developed CARMA2, a platform built on open-source software. The goal of this phase was to engage with the industry on CDA in order to expand existing automation capabilities and to reduce research and development time. CARMA2 runs on a computer inside a vehicle. The computer interacts with the vehicle's devices and microcontrollers, including onboard units and after-market sensors such as radars. The platform manages the controller area network (CAN bus) messages for the vehicle to speed up or slow down, gathers data from connected sensors to understand the vehicle's environment, transmits the onboard unit messages to other vehicles, and processes incoming messages from other vehicles and infrastructure in order to cooperate with other vehicles. The platform also provides many plug-ins that support cooperative driving tactics, such as cruising, yielding, lane changing and merging, platooning, and speed harmonizing.

The research team then developed CARMA3, the latest version of CARMA released in July 2019 and now simply called CARMA℠, to collaborate with the research and development community. It consists of CARMA Cloud and the CARMA Platform.

CARMA is an open-source software that enables researchers and engineers to develop and test their CDA features on properly equipped vehicles. It is available on the GitHub development platform at *https://github.com/usdot-fhwa-stol/CARMAPlatform* for any researcher to download and use. By making CARMA publicly available, FHWA and its partners hope to set the foundation for interoperability across vehicle makes and models and encourage the safe introduction of the technology onto the Nation's roads.

CARMA Cloud is a downloadable, cloud-based, open-source service that enables communication between cloud services, vehicles, road users, and

FHWA recently expanded its CDA fleet by four new passenger vehicles. Three different makes and models are shown here. All use the third phase of CARMA (CARMA3).

Source: FHWA.

infrastructure devices. CARMA Cloud enables the roadway to provide information to support safe operation for new TSMO strategies. This technology facilitates cooperation among vehicles and roadway infrastructure through communication.

The CARMA Platform provides cooperative research functionality to an automated driving system. By using CARMA Cloud to provide information about what's ahead (such as traffic incidents, road weather conditions, and work zones), the CARMA Platform enables automated vehicles to interact and cooperate with infrastructure and other vehicles, improving the performance of the existing transportation system.

Features of the CARMA Platform

The developers designed the CARMA Platform with flexibility in mind. It is built on Robot Operating System (ROS) to encourage modular design so that components can be easily swapped out to experiment with different combinations. It includes vehicle-to-everything (V2X) communications capabilities to compose, transmit, receive, and parse V2X messaging and can work with any radio device.

The platform also includes three application planning interfaces (APIs). The planning plug-in API enables users to install plug-ins for either strategic planning or tactical planning of vehicle behaviors and trajectories to exercise particular algorithms and cooperative interaction. The controller plug-in API provides for the implementation of low-level motion-planning algorithms. Finally, the hardware driver API enables users to install the platform on any properly equipped vehicle, as long as drivers are installed that connect to the various vehicle sensors and controller equipment.

Additionally, the third phase of CARMA software also features:

- Localization, motion planning, and obstacle detection and avoidance.
- Autoware™ components that are adaptable to work with other platforms.
- Environment sensing with light detection and ranging (LiDAR), radar, video, and MobilEye®-integrated roadway-sensing devices.
- Society of Automotive Engineers (SAE) level 2 steering and speed control while staying in lane.
- Basic safety message broadcasting using data from the CARMA system.

FHWA and its partners are developing further CARMA features, and more information will be available online as these features are identified and created.

Developing Strategies for Key Scenarios

The CARMA Program aims to develop a concept of operations for TSMO

PARTNER SPOTLIGHT: FMCSA

The Federal Motor Carrier Safety Administration (FMCSA) is the leading Federal government agency that is responsible for regulating safety of commercial motor vehicles. FMCSA's priority is to reduce crashes, injuries, and fatalities that involve large trucks and buses. FMCSA has joined the CARMA Collaborative in order to push the limits of CARMA by improving transportation safety. The four tractors provided by FMCSA are the next generation for test vehicles that will support Society of Automotive Engineers (SAE) Level 2 and Level 3 commercial motor vehicle automation research. The areas of research for the tractors include roadside inspections, advanced driver-assistance systems, performance, platooning, driver readiness, and cybersecurity.

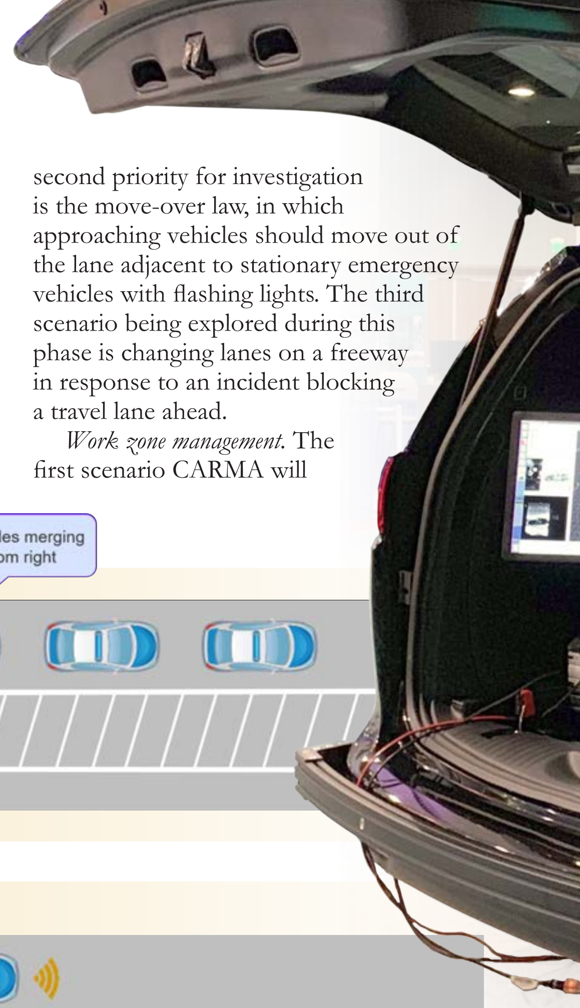
strategies, including basic travel, traffic incident management (TIM), work zone, and weather scenarios.

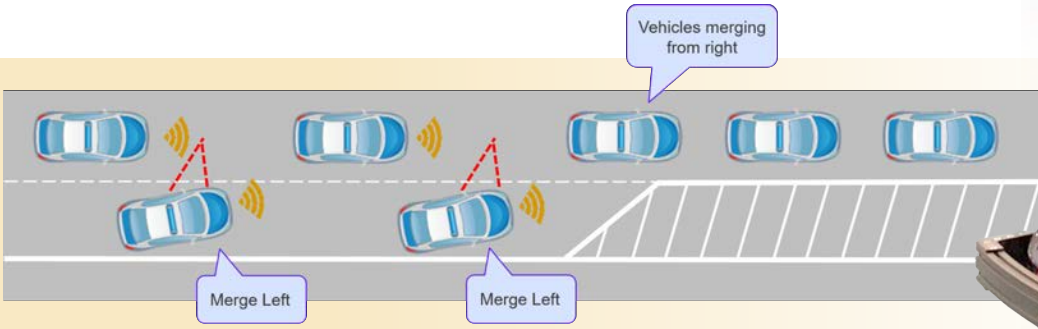
"The results of this research will accelerate stakeholder collaboration expediting identification of readiness needs that will stimulate deployment of cooperative driving automation technology while advancing safety, security, data, and application of artificial intelligence," says John Harding, the leader of FHWA's Connected/Automated Vehicles and Emerging Technologies Team.

Basic travel. The first basic travel scenario CARMA will explore is merging onto a highway. The second research priority is navigating a signalized intersection.

Traffic incident management. The CARMA team will research three TIM-related scenarios. The first is when vehicles must move out of the way of first responder vehicles driving toward an incident. The second priority for investigation is the move-over law, in which approaching vehicles should move out of the lane adjacent to stationary emergency vehicles with flashing lights. The third scenario being explored during this phase is changing lanes on a freeway in response to an incident blocking a travel lane ahead.

Work zone management. The first scenario CARMA will



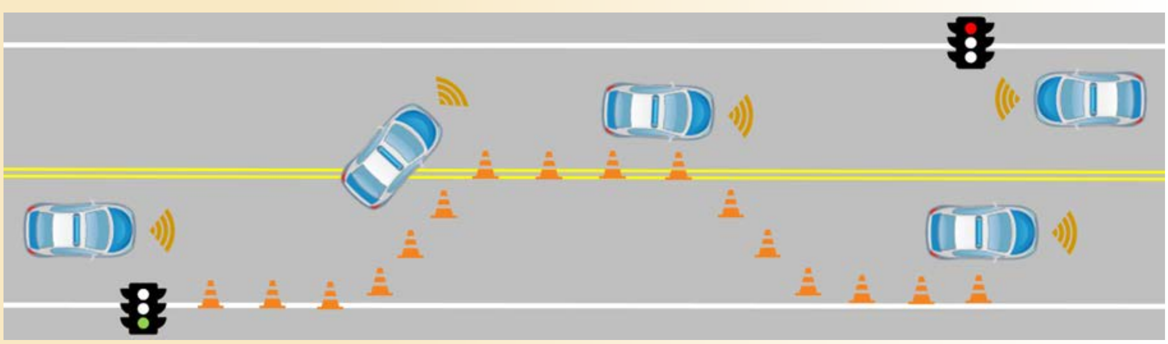


CARMA will explore two basic travel scenarios, including merging onto a highway. Here, the text bubbles indicate in-vehicle warning messages for cars that are merging as well as cars in the travel lane.

Source: FHWA.

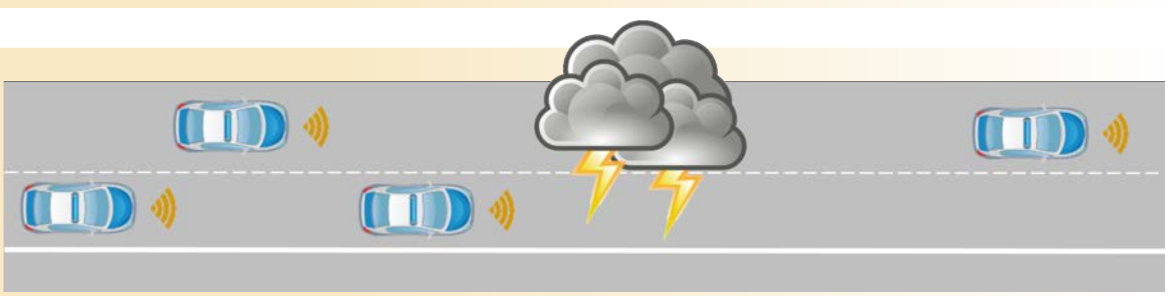
This phase of the CARMA project investigates three scenarios related to traffic incident management, including changing lanes on a freeway in response to an incident ahead with a responding emergency vehicle.

Source: FHWA.



The CARMA team will examine two work zone management scenarios, including one-lane, two-way traffic taper in which a single lane is used for alternating traffic in each direction, as shown here.

Source: FHWA.



CARMA will explore a road weather management scenario in which vehicles must change speed and prepare for other adjustments at the beginning of a weather event zone.

Source: FHWA.

FHWA and its partners recently released the third iteration of the CARMA software platform. CARMA promotes collaboration and participation from communities of engineers and researchers to advance the understanding of cooperative automated driving.

Source: FHWA.

explore is a one-lane, two-way traffic taper. The second-priority scenario for investigation is a road closure with diversion.

Road weather management. CARMA will investigate the scenario of a vehicle adjusting speed and preparing for other adjustments at the beginning of a weather event zone.

CARMA Collaborative

FHWA established the CARMA Collaborative to bring together diverse stakeholders supporting the future of the transportation industry. The effort bridges gaps among several stakeholder groups and forms a community of existing and prospective CARMA users invested in developing intelligent transportation solutions and cooperative automated driving systems to improve transportation efficiency and safety. The CARMA Collaborative provides opportunities to cultivate relationships, share expertise, pilot transportation technologies, implement cooperative automated driving systems, and strengthen the transportation industry for public benefit.

The CARMA Collaborative advances the understanding of CDA and the impacts it can have on mobility, cultivates technology that enables cooperative automated driving systems, and accelerates use of CARMA by stakeholders to support the collaborative development and adoption of cooperative and automated technologies. The collaborative facilitates active engagement, interaction, and discussion on the use of CARMA through its open-source platform, stakeholder engagement, and webinars to share information.

Get Involved!

The latest version of CARMA is now live on GitHub and open for collaboration. The unique CARMA Platform enables users to download and add this software to a properly equipped vehicle with automated driving technology. Download the software to begin collaborating with FHWA and its partners in improving the roadways today.

TAYLOR LOCHRANE is the technical program manager for CARMA, leading the open source development and collaboration efforts of CARMA with partners and stakeholders. He earned B.S, M.S., and Ph.D. degrees in civil engineering focused in transportation from the University of Central Florida.

LAURA DAILEY is the communications manager of the Saxton Transportation Operations Laboratory, overseeing marketing and engagement activities. She earned an M.S. degree from Drexel University and B.S. degree with a marketing concentration from Elon.

CORRINA TUCKER is a junior communications specialist in the Saxton Transportation Operations Laboratory leading outreach activities. She holds a B.A. degree in digital media from Penn State and specializes in technical writing and multimedia.

For more information, contact Taylor Lochrane at *taylor.lochrane@dot.gov* or visit *https://highways.dot.gov/research/research-programs/operations/CARMA*.

Saluting 50 Years of Transportation Training

FHWA's National Highway Institute Celebrates Its Golden Anniversary in 2020

by **STAN WORONICK** and **CHRISTINE KEMKER**

In 1970, the Nation was at the height of Eisenhower's Interstate Era. Federal and State highway agencies worked to plan and build the interstate highway system, the largest civil works project ever constructed in the United States. At the same time, people across all industries looked for new ways to protect natural, social, and cultural environments. As the Nation's interstate routes expanded, the Federal Highway Administration recognized that maintaining and updating this system would require a contemporary, trained workforce, one able to implement new methods and technologies. More and larger projects, developing and adapting new innovations, and a growing workforce meant a need for training to meet the demands.

To rise to the challenge of providing new skills and staffing for the transportation industry, Congress authorized the creation of the National Highway Institute (NHI) as part of the Federal-Aid Highway Act of 1970. As FHWA's training arm, NHI was tasked with the development and delivery of training for State and local highway organizations across the United States.

In the beginning, NHI was a lean organization with just a few employees who completed all course registrations, scheduling arrangements, and certificates by hand. With this limitation, the agency understandably offered only a small selection of courses. Today, NHI regularly collaborates with partners across the transportation industry, both nationally and internationally, to offer a catalog that has grown to include more than 400 courses in 18 broad categories, including more than 200 distance-learning courses that capitalize on the latest web technologies. With 205 web-based trainings, 20 web-conference trainings, and an ever-increasing number of blended courses (part online, part instructor led) on the books, NHI aims to train more transportation professionals, accessibly and affordably, in the fields they need most.

Even though the technology and teaching formats are relatively new, NHI's commitment to excellence in training is not. As FHWA's training and educational business unit, NHI has provided quality technical training to the Nation's broad network of transportation professionals for the past 50 years. And this year, as NHI celebrates its golden anniversary, it proudly continues to serve as the country's principal source of transportation-related course materials and training.

COLLABORATION AND INNOVATION

NHI ensures the Nation's transportation professionals remain at the forefront of their chosen disciplines and helps to safeguard the country's infrastructure as a national asset. NHI develops its technical training in collaboration with FHWA program offices, FHWA's Resource Center, State departments of transportation, local agencies, and industry partners, which encourages nationwide application of state-of-the-practice techniques.

NHI's portfolio of training products covers a wide variety of transportation-related program areas ranging from asset management and structures to intelligent transportation systems and highway safety. The instructor-led and web-conference sessions provide a direct line of communication with experienced practitioners considered by their peers to be experts in their respective fields.

NHI strives to be the authoritative source for transportation training by offering relevant and organized curricula, providing outstanding customer service, and delivering training formats that support various learning needs and workforce trends. The organization is dedicated to improving the performance of the transportation industry by providing effective and innovative instruction, both in the classroom and online.

To ensure that current training needs are being met, NHI is conducting a 3-year initiative to update the entire 418-course catalog. The goal of this undertaking, as well as that of the new web-based courses, is to make NHI more affordable and accessible to professionals across the industry.

NHI's new director, Michael Davies, is the push behind this effort. "We recognize the ever-changing landscape of the transportation industry and its workforce development needs," says Davies. "That's why we are laser-focused and committed

For 50 years, the National Highway Institute has delivered innovative and expert transportation training. As the primary training and education branch of the Federal Highway Administration, NHI aims to provide transportation professionals with the knowledge they need to perform and advance their careers.

Image compilation by Schatz Strategy Group. Photos, left to right: © Shutterstock.com/ Matej Kastelic, © Shutterstock.com/ Matej Kastelic, © Shutterstock.com/Sean Pavone.

to providing a high-quality learning experience through the most innovative training solutions available."

OFFERING EXCELLENCE

NHI uses the latest adult learning principles to keep learners engaged and enthusiastic about applying what they learn as soon as they return to work. NHI uses an iterative course development process, through which accredited instructional designers and subject matter experts work closely to determine training needs, design and develop a solution, and deliver a high-quality product based on the customers' unique objectives, timelines, and budget. That means that each course is not a cookie-cutter lecture, but instead uses local examples and tailored content to meet the specific challenges faced by attendees.

The organization pursues strategic partnerships that enhance and attest to the quality of its training. These partnerships include university transportation centers, State DOTs, and FHWA's Resource Center. Collaboration with these partners has helped NHI to provide better training to more customers.

Beyond offering state-of-the-art and state-of-the-practice training, NHI is accredited by the International Association for Continuing Education and Training (IACET) as an authorized provider of continuing education units (CEUs). As an authorized provider, NHI can offer CEUs for its courses that qualify under the American National Standards Institute/IACET 1-2007 Standard. Accredited training may be used by highway industry professionals to maintain State-issued professional engineer licenses or other designations. For its planning and freight series courses, NHI is also an approved provider of the American Institute of Certified Planners certification maintenance credits.

"Accreditation gives our courses validity as high-quality trainings," says Carolyn Eberhard, an NHI instructor liaison and historian.

In addition to the IACET accreditation, several of NHI's courses meet Federal and State requirements as approved training for industry certifications. Maintaining Federal and State approval for many of NHI's courses means enforcing rigorous standards and providing up-to-date trainings on transportation policies, technologies, and best practices. These efforts ensure added value, above and beyond CEUs, for individuals who take these courses.

NHI uses innovative training delivery methods that increase accessibility to learning without sacrificing the quality or comprehensiveness of the content. This includes staying up-to-date on adult learning theory and converting many introductory courses into accessible, user-oriented formats. NHI implements blended learning strategies to encourage the most efficient expenditures of participant and instructor time.

"Blended courses address participants' needs to learn at their own pace and when it's convenient to them," says Melonie Barrington, an NHI training program manager.

This dedication to excellence has results. In the last decade, NHI has significantly increased its reach in the transportation industry, training 173 percent more

NHI Training Categories

LEFT: FHWA's Administrator Francis C. Turner (left) with Emmett H. Karrer, the first director of NHI, in September 1971.

Source: FHWA

RIGHT: FHWA's Executive Director, Thomas Everett (left), poses with NHI's newest director, Michael Davies, who took the position in January 2019. While proud of the last 50 years, Davies is looking ahead to NHI's future through innovative training and collaborative efforts.

Source: FHWA

participants in 2018 than in 2008 thanks to the incorporation of new training delivery formats, such as web-based training (first offered in 2003) and blended courses (first course offered in 2006). In the last 5 years alone, NHI has trained more than 200,000 personnel from Federal agencies, State DOTs, local public agencies, international industry organizations, and institutes of higher learning.

Developers continually update courses as needed to reflect the latest guidance, methods, and knowledge, and to incorporate feedback received from participants. As an organization dedicated to learners, NHI provides access to highly skilled subject matter experts from government and industry, incorporates hands-on learning opportunities and practical exercises that make real-world application a priority, and offers opportunities to collaborate, solve problems, and share successful practices with industry peers across the United States.

The vision for the future of NHI continues a longstanding history of forward-thinking ideas. In observation of NHI's 50th anniversary, the focus this year revolves around one central theme: Moving forward, giving back.

MOVING FORWARD

To celebrate its momentous anniversary, NHI plans to rebrand, increase visibility, and focus on innovation.

Rebranding. NHI has developed a new style guide and introduced a redesigned logo, an all-new color scheme, and a revamped look and feel with modernized fonts and icons.

Visibility. NHI plans to participate in more key industry events and develop a stronger digital and social media presence. The kickoff for NHI's 50th year takes place at the Transportation Research Board's 99th Annual Meeting, held January 12–16, 2020, at the Walter E. Washington Convention Center, in Washington, D.C

Innovation. NHI is exploring new technologies and finding innovative ways to communicate to broader audiences by modernizing its video library and training curriculum and implementing more opportunities to use state-of-the-art virtual reality technology. NHI currently offers three computer-based trainings that use virtual inspections, including the popular Safety Inspection of In-Service Bridges (course 130055), which was hosted 35 times in 2018.

GIVING BACK

2020 offers a golden opportunity to give back to the transportation community and further support industry professionals.

Financial Support. To strengthen its partnerships with State and Federal agencies, NHI will provide resources to the transportation workforce throughout 2020. This will include discounted courses across the board and curated sessions for industry professionals hosted at NHI's training facilities just outside of Washington, DC. NHI is also promoting its 50th anniversary by offering select NHI-sponsored "Golden Anniversary Courses" to State DOTs, local agencies, Tribal governments, and other FHWA partners.

Website Chat Box. To make it easier for online users to get access to the answers they are looking for, NHI is developing a chat box interface for its website. The feature will assist customers in finding information, offer help with hosting a session, and

Fiscal Year 2018 Course Highlights	
Course with the Most Sessions	Bridge Inspection Refresher Training (FHWA-NHI-130053)
Most Popular Web-Based Training	FHWA Planning and Research Grants: The Uniform Guidance (2 CFR Part 200) – Part 2 (FHWA-NHI-151059)
Web-Conference Training with the Most Sessions	Transportation Performance Management for Congestion including Freight (FHWA-NHI-138010) (this course has been replaced by a web-based version without the live conference session: FHWA-NHI-138019)
Highest Rated Course	Basic Relocation under the Uniform Act

RIGHT: NHI uses virtual inspections in three courses, such as this one of a steel truss bridge from the updated Safety Inspection of In-Service Bridges course. NHI hopes to incorporate more virtual reality technology into its courses in the coming years.

Source: NHI.

answer questions about NHI courses in real time.

Collaboration. NHI has been working to build new and better partnerships internally and externally to create better opportunities for our customers. These collaborations include the Resource Center's "Call For Service" (an initiative designed to identify and meet the technical and training needs of FHWA's division partners), a joint training facility with the Federal Motor Carrier Safety Administration, and a new agreement with the Office of Innovative Program Delivery to offer all NHI web-based training at no cost to local agencies and Tribal governments.

"We want to advance the industry and better support the many transportation professionals we serve," says NHI Director Davies. "Throughout our 50th anniversary and beyond, NHI is committed to reinvesting in their technical training needs, shoring up and strengthening the lines of communication, and uncovering new ways to better serve the transportation community."

Source: FHWA.

"For the last 50 years, FHWA's National Highway Institute has been training and building the transportation workforce of the future. While our teaching methods may look different today and certainly will be different in the future, our goal for the next 50 years remains: to continue to deliver high-quality, leading-edge training for the transportation industry."

–AMY LUCERO, FHWA Chief Technical Services Officer

STAN WORONICK is the training delivery and customer service manager at NHI. Previously, he worked at the FHWA Missouri Division as an administrative officer and finance specialist. He holds a bachelor of science in workforce development from Southern Illinois University-Carbondale and a master's degree in human resource development from Webster University.

CHRISTINE KEMKER is a contracted marketing specialist for NHI.

For more information, visit ***www.nhi.fhwa.dot.gov/home.aspx***.

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.

Public Information and Information Exchange

Secretary Chao Celebrates Groundbreaking of New Volpe Center

In a ceremony on October 30, 2019, U.S. Secretary of Transportation Elaine L. Chao celebrated the official groundbreaking of the new U.S. Department of Transportation John A. Volpe Transportation Systems Center in Cambridge, MA. Secretary Chao was joined by Massachusetts Governor Charlie Baker, Cambridge Mayor Marc McGovern, U.S. General Services Administration (GSA) Chief of Staff Robert Borden, U.S. Senator Edward Markey's State Director James Cantwell, and Massachusetts Institute of Technology (MIT) Vice President for Research Maria Zuber for the groundbreaking ceremony.

The Volpe Center currently occupies approximately 14 acres (5.7 hectares) of land in the Kendall Square section of the city. Following the conclusion of a two-phase solicitation process, GSA entered into an exchange agreement with MIT, which will pay $750 million to design and construct a state-of-the-art-facility for Volpe on approximately four acres (1.6 hectares). In exchange, the portion of the property no longer needed by the Federal Government will be conveyed to MIT for mixed-use development.

The new facility will replace Volpe's six existing buildings and surface parking lots with an energy-efficient structure accompanied by underground parking and approximately 100 bicycle parking spaces. As part of the Federal Government's Art in Architecture program, which commissions artworks for new buildings nationwide, the new building will feature an art piece designed by Maya Lin integrated into the landscape on the east side of the site.

USDOT Holds Inaugural Meeting of Rural Transportation Infrastructure Council

In November 2019, USDOT hosted the first meeting of the ROUTES Council, which will improve the use of the Department's discretionary grant funds in support of the Nation's rural transportation system. The initiative, known as the Rural Opportunities to Use Transportation for Economic Success (ROUTES) Initiative, will analyze the Department's discretionary funding and financing opportunities to ensure rural communities' transportation infrastructure helps the national transportation network meet desired outcomes for safety and economic competitiveness.

Rural transportation infrastructure has significant challenges. While one-fifth of Americans live in rural areas, 70 percent of the Nation's road miles are in rural areas, carrying nearly 50 percent of truck traffic. The highway fatality rate is more than twice that of urban areas, and 90 percent of the Nation's bridges that are posted for weight limits are in rural locations.

The new ROUTES Initiative will address these national transportation challenges by assisting rural stakeholders in

OPPOSITE PAGE: ROUTES is an initiative to address disparities in rural transportation infrastructure.

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understanding how to access USDOT grants and financing products, and developing data-driven approaches to better assess needs and benefits of rural transportation projects.

For more information, visit *www.transportation.gov/rural*.

USDOT Awards Automated Driving System Demonstration Grants

Eight projects in seven States will receive a total of nearly $60 million in Federal grant funding to test the safe integration of automated driving systems (ADS) on the Nation's roadways. The grants aim to gather significant safety data to inform rulemaking and foster collaboration among State and local governments and private partners.

U.S. Secretary of Transportation Elaine L. Chao made the announcement at the Federal Highway Administration Research Showcase, an event promoting the importance of research and innovation in transportation. The event featured exhibits and demonstrations of the ongoing research, emerging technologies, and capabilities of the Turner-Fairbank Highway Research Center.

USDOT's top priority is safety. Automation offers the potential to improve safety for vehicle operators, occupants, and other travelers sharing the road. To address this potential, USDOT solicited applications for the ADS grants, highlighting key goals for safety, data for safety analysis and rulemaking, and collaboration. The Department received 73 proposals.

For more information, visit *www.dot.gov/av/grants*.

BELOW: One goal of USDOT's new mobility initiatives is to increase availability and decrease cost of aftermarket modifiers that improve accessibility of vehicles for all users.

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Helping States Plan for ITS Cybersecurity

USDOT's Intelligent Transportation Systems (ITS) Joint Program Office (JPO) recently released Cybersecurity and Intelligent Transportation Systems: A Best Practice Guide (FHWA-JPO-19-763). This report presents the best practices in ITS cybersecurity, particularly in planning and conducting a penetration test.

The report details the methodology of scoping a test, including the objectives, requirements, success criteria, test type, management, and test readiness. It includes a template test plan to help local and State departments of transportation get started on their own cybersecurity plan and penetration testing. The National Institute for Standards in Technology Critical Infrastructure Cybersecurity Framework and the Department of Homeland Security Implementation Guidance for Transportation provide context for using penetration testing as a mechanism to identify vulnerabilities.

The report is available at *https://rosap.ntl.bts.gov/view/dot/42461*.

Improving Access and Mobility for All Americans

At the Access and Mobility for All Summit held in October 2019, U.S. Secretary of Transportation Elaine L. Chao announced nearly $50 million in new initiatives to expand access to transportation for people with disabilities, older adults, and individuals of low income. The initiatives include new programs to develop and deploy innovations in technology and further interagency partnerships to improve mobility.

The summit assembled leaders from industry, academia, nonprofits, and government to participate in panel discussions and breakout sessions focused on interagency coordination, advanced vehicle technologies, and innovations in mobility services.

As part of her keynote address, Secretary Chao announced a planned Complete Trip Deployment solicitation, which will make up to $40 million available to enable communities to showcase innovative business partnerships, technologies, and practices that

New USDOT initiatives aim to expand mobility and access to transportation for people with disabilities, older adults, and individuals of low income.

promote independent mobility for all. "Complete trip" means that a user can get from point A to point B seamlessly, regardless of the number of modes, transfers, and connections.

A planned inclusive design challenge will make up to $5 million in cash prizes available to innovators who design solutions to enable accessible automated vehicles. USDOT aims to increase availability and decrease cost of aftermarket modifiers that improve accessibility of vehicles today and spark development for future automated vehicles.

For more information, visit *www.transportation.gov/accessibility*.

Understanding the Business Case for Automated Bus Technologies

Automation technology for personal vehicles is widely researched and discussed, but much less information is available about automation technologies in public transportation, specifically bus systems. This information gap can make it difficult for transit agencies to decide which, if any, technologies to invest in.

Economists at USDOT's Volpe Center analyzed the cost-effectiveness of a selection of bus automation technologies to help transit agencies evaluate which technologies may yield returns in the form of reduced labor or operations costs. Different from a traditional public policy analysis or benefit-cost analysis, a business case analysis offers a decisionmaking framework for fiscally constrained transit agencies.

In a report published in the Transportation Research Record, Volpe Center economists studied the costs of installing and maintaining busses with five different categories of automation technology. The technologies include a range of automation concepts, from near-term, readily available technologies to longer term or early-stage ideas. The technologies also spanned different levels of automation.

For more information, visit *www.volpe.dot.gov/news/understanding-business-case-automated-bus-technologies*.

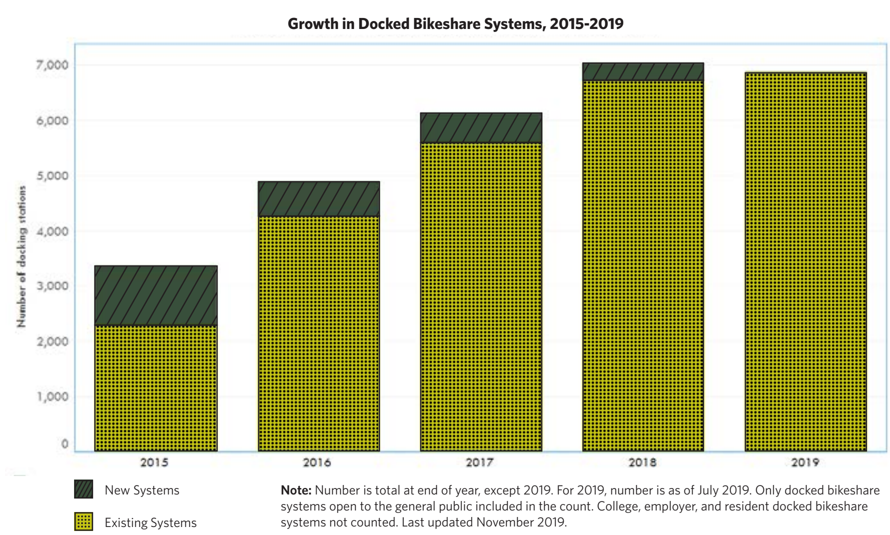
Source: Volpe Center

BTS Interactive Map Shows Growth of Urban Mobility Systems

USDOT's Bureau of Transportation Statistics (BTS) released an interactive map that documents the rapid growth of bikeshare (docked and dockless) and e-scooter systems across the country from 2015 to 2019. The total number of these systems reached more than 350 systems serving more than 200 cities as of July 2019.

BTS' interactive bikeshare and e-scooter map shows, by city, the name of the bikeshare system (docked or dockless) and e-scooter system serving it for every year from 2015 to 2019. For cities with a docked bikeshare system, the map can be zoomed in to the locations of the docking stations at the street level.

Of 111 docked bikeshare systems in operation, 85 launched across the U.S. from 2015 through July 2019. More than 30 of the systems operate across multiple cities. Only docked bikeshare systems open to the general public are included in the count. College, employer, and resident docked bikeshare systems are not counted. The top five largest docked bikeshare systems in metro areas are Boston's Blue Bikes; San Francisco's BayWheels; Capital Bikeshare in Washington, DC; Chicago's Divvy; and Citi Bike in New York City.



Source: U.S. Department of Transportation, Bureau of Transportation Statistics, Bikeshare and Scooter Systems, available at https://data-usdot.opendata.arcgis.com/ as of November 2019.

Dockless bikeshare systems and e-scooters first appeared in the United States in 2017 and have expanded coverage since then. As of July 2019, dockless bikeshare systems serve 38 cities and e-scooters serve 100 cities.

For more information, visit *www.bts.gov/topics/passenger-travel/bikeshare-and-e-scooters*.

Source: BTS

Georgia DOT Launches Middle School Educational Program

The Georgia Department of Transportation (GDOT) joined with Scholastic, a global children's publishing, education, and media company, on a multiyear educational initiative designed to help educate the next generation of drivers. Developed for middle school students across the State, the Recognizing the Risk campaign provides students, teachers, and parents with resources addressing the dangers of distracted driving and walking. The program builds upon GDOT's existing Drive Alert Arrive Alive and See & Be Seen campaigns.

In 2018, 70 percent of the 1,514 fatalities on Georgia roads occurred as a result of distracted behavior, including 265 fatalities involving pedestrians. As a result of the new collaboration, Georgia teachers will provide their students with a number of classroom activities focused on promoting pedestrian and driver safety by discussing the hazards of texting, headphones, and more. The program enables teachers, students, and parents to engage in a wide range of collaborative discussions on real-world scenarios to foster responsible and safe alternatives to risky behaviors.

For more information, visit *www.dot.ga.gov/DriveSmart/SafetyOperation/Pages/Scholastic.aspx*.

Source: Georgia DOT

GDOT recently launched a new campaign to educate middle schoolers, teachers, and parents on the dangers of distracted driving and walking.

TOP: © Ryan DeBerardinis / Shutterstock.com.
BOTTOM: © tab62 / Shutterstock.com.

TRAINING FOR LOAD AND RESISTANCE FACTOR RATING OF HIGHWAY BRIDGES

BY **DR. MELONIE BARRINGTON** AND **ALANA WELCH**

Load and resistance factor rating (LRFR) is a methodology closely aligned with load and resistance factor design (LRFD) for new highway bridges. While LRFD specifications focus on the design of bridges, LRFR takes a parallel track aimed at determining the load ratings for existing in-service bridges.

To help States successfully implement LRFR, in 2009 the Federal Highway Administration developed Fundamentals of LRFR and Applications of LRFR for Bridge Superstructures (FHWA-NHI-130092), offered by the National Highway Institute (NHI). NHI designed the course to provide State agencies and consulting engineers with the training they needed to implement this new method effectively based on a core curriculum in the fundamentals and applications of the American Association of State Highway and Transportation Officials (AASHTO) LRFR specifications.

With an increasing number of States implementing LRFR, NHI recently overhauled the course to reflect modifications and revisions made over the last decade to AASHTO LRFD Bridge Design Specifications (AASHTO LRFD) and the AASHTO Manual for Bridge Evaluation (MBE). Now titled Load and Resistance Factor Rating of Highway Bridges, this course is designed in accordance with the AASHTO MBE, 3rd Edition (2018 with 2019 Interim Revisions), and the AASHTO LRFD Bridge Design Specifications, 8th Edition.

Designed for the Modern Workforce

The newly updated course includes brief lessons in an additional six topics at the end of each instructional day and a revision to the end-of-course assessment that ensures participants are receiving the latest possible information about LRFR bridge ratings. The six new topics are load rating of timber bridges, State load rating policies and procedures, State load posting and permitting policies and procedures, load rating of reinforced concrete box culverts, load rating of superstructures, and load rating of gusset plates.

The content covered in this 4-day course is designed to provide both the foundational knowledge needed by less experienced engineers and the technical rigor and expertise needed by seasoned professionals.

NHI suggests this course for State agency bridge and struc-

tures engineers or practitioners responsible for load rating of highway bridges, including designers, consultants, reviewers, maintenance and management engineers, and load raters.

While there are no prerequisites for this course, it is best suited for professionals who have taken NHI LRFD for Highway Bridge Superstructures (course 130081). Individuals attending this course should have at least a bachelor of science in civil engineering, a working knowledge of the current MBE and AASHTO LRFD specifications, and relevant experience using these specifications on at least one load rating project.

For more information, visit *www.nhi.fhwa.dot.gov*. To register for a course or to sign up for alerts when a course session is scheduled, visit the individual course description page and select the "Sign Up for Session Alerts" link.

MELONIE BARRINGTON is a training program manager and **ALANA WELCH** is a contractor for NHI.

States are increasingly implementing load and resistance factor rating on highway bridges. The National Highway Institute offers a course to help engineers at all levels understand this methodology.

HOW TO HOST OR ATTEND A TRAINING COURSE

NHI invites professionals interested in earning continuing education units or professional development hours to visit *www.nhi.fhwa.dot.gov* to browse the complete digital course catalog, which lists more than 400 courses spanning 18 program areas. Interested hosts can submit a Host Request Form or find more information about hosting NHI 130092.

NHI is approved as an 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 ANSI/IACET Standard.

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/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*).

Automation in Highway Construction Part I: Implementation Challenges at State Transportation Departments and Success Stories

Publication Number: FHWA-HRT-16-030

The Federal Highway Administration conducted research to document gaps for implementing automation in highway construction and to develop guidance for State departments of transportation to assist agencies in implementing and using automation to improve project delivery. There are two volumes of the final report. Part I presents a description of the key automation technology areas and the associated benefits, challenges, and solutions.

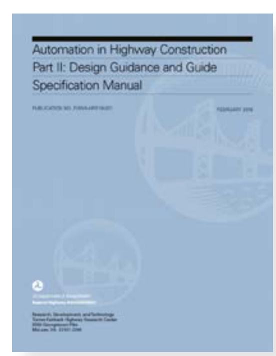
This volume provides State DOTs a focus on five key technology areas: remote sensing, technologies for locating underground utilities, three-dimensional (3D) design, machine control and automation, and field technology and inspection. This volume documents success stories and best practices for automation in highway construction; best uses for individual technologies, including the types of costs and resources required by the industry and agencies for implementing these technologies; and the associated returns on investment. This volume also documents the challenges of automation technology in the areas of surveying, utilities, real-time verification, and data management.

The document is available to download at *www.fhwa.dot.gov/publications/research/infrastructure/pavements/16030*.

Automation in Highway Construction Part II: Design Guidance and Guide Specification Manual

Publication Number: FHWA-HRT-16-031

The second volume of FHWA's report on research on implementing automation in highway construction and guidance for State DOTs presents an overview of enabling technologies and policies as well as implementation strategies, design procedures, and practical guidelines to properly generate 3D models for use in construction and other phases of highway project delivery.



3D design practices are common in State DOTs, but automation technology requires added detail in 3D design models to output data in a reusable and robust format, and it requires additional organization and description of the data. This report provides the accuracies needed for both survey control and topographic survey. The report describes how construction specifications can incorporate practices to manage the use of automation technology in a manner that adapts to project characteristics and evolving technologies. State DOTs interested in developing 3D digital design for use in automation in highway construction would benefit from reading this volume.

The document is available to download at *www.fhwa.dot.gov/publications/research/infrastructure/pavements/16031*.

Mechanisms of Hydration and Setting of Ordinary Portland Cement in Simple and Complex Systems

Publication Number: FHWA-HRT-17-102

This summary report provides a description of research conducted to improve the understanding of the mechanisms of hydration of portland cement in complex and simple mixtures. The summary report also describes research that develops analytical methods to directly observe hydration processes in real time, and develops and validates improved computer models to design optimal concrete composition, curing methods, performance, and durability.

The goal of FHWA's project, "Mechanisms of Hydration and Setting of Ordinary Portland Cement in Simple and Complex Systems," was to develop more efficient and effective ways to use concrete. Project scientists developed innovative analytical technologies to observe the mechanisms of hydration in three dimensions at the nano-, micro-, and macroscopic scales. These unprecedented observations have provided a depth of understanding of hydration mechanisms that was not previously possible.

This perspective enabled researchers to develop a new and clearer hypothesis to understand the mechanisms of cement hydration. Computer models based on the new hypothesis will provide engineers and practitioners with tools to produce more efficient, durable, and cost-effective concrete products and structures.

The document is available to download at *www.fhwa.dot.gov/publications/research/ear/17102/index.cfm*.

LTPP InfoPave™: Knowledge Into Action…Performance Data For Pavement Innovation

Publication Number: FHWA-HRT-18-011

The FHWA Long-Term Pavement Performance (LTPP) program's web portal—LTPP InfoPave™ at *https://infopave.fhwa.dot.gov*—facilitates access and analysis of LTPP and other pavement-performance data through a variety of online data selection applications and data viewing tools, organized into hubs.

This brochure highlights each LTPP InfoPave hub, including Home, Data, Visualization, Analysis, Tools, Operations, Reference Library, and Non-LTPP data. The data retrieved from LTPP InfoPave can be used for research, pavement design, and product development for decades to come.

The LTPP program was initiated in 1987 to satisfy a wide range of pavement information needs. Over the years, the program has accumulated a vast repository of research-quality data, extensive documentation, and related tools, which compose LTPP's comprehensive information management system.

The document is available to download at *www.fhwa.dot.gov/publications/research/infrastructure/pavements/ltpp/18011/index.cfm*.

LTBP InfoBridge: Gateway to Bridge Performance Information

Publication Number: FHWA-HRT-19-009

The FHWA Long-Term Bridge Performance (LTBP) Program's web portal—LTPP InfoBridge at *https://infobridge.fhwa.dot.gov*—provides for storage, retrieval, dissemination, analysis, and visualization of data collected through State, national, and LTBP Program efforts to enable users with the ability to holistically assess bridge performance on a network or individual bridge basis.

This brochure highlights key LTBP InfoBridge modules, including Find Bridges (also Advanced Find and Map Find), Performance Dashboard, Bridge Information, Visualize Bridge Data, Bridge Analytics, Library, and Help. LTBP InfoBridge is a comprehensive bridge performance portal enabling researchers to develop tools and products that will enhance understanding of the performance of highway bridge assets, leading to more efficient design, construction, rehabilitation, maintenance, preservation, and management of those assets.

The LTBP Program is designed to collect critical performance data that are not available elsewhere and merge them with data gathered from available sources.

The document is available to download at *www.fhwa.dot.gov/publications/research/infrastructure/structures/ltbp/19009/index.cfm*.

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