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Crash Data Model for the Future

Resource Center: Excellence in Action

Designing Stronger Pavements

U.S. Department of Transportation

Federal Highway Administration

Public Roads

Autumn 2018 www.fhwa.dot.gov Vol. 82, No. 3

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

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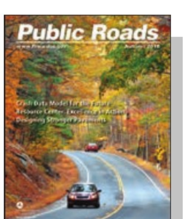


Front Cover—To improve safety on Connecticut's roads, the Connecticut Department of Transportation teamed up with FHWA, the University of Connecticut, and local law enforcement to overhaul the State's process for collecting and handling crash data. For more information, see "Better Information for Better Roadway Safety" on page 8 in this issue of PUBLIC ROADS. *© Songquan Deng, 123RF.com*.

Back Cover—Federal, State, Tribal, and local transportation agencies around the country are working to reduce fatal and serious injury crashes and improve safety on U.S. roadways. Experts in FHWA's Resource Center can provide technical assistance and training to help keep roads safe and operating efficiently. For more information, see "20 Years of Creative Problem Solving" on page 16 in this issue of PUBLIC ROADS. *© Robert Crum, Shutterstock*.

Public Roads (ISSN 0033-3735; USPS 516-690) is published quarterly by the Office of Research, Development, and Technology, Federal Highway Administration (FHWA), 6300 Georgetown Pike, McLean, VA 22101-2296. The business and editorial office of *Public Roads* is located at the McLean address above. Phone: 202–493–3375. Fax: 202–493–3475. Email: lisa.a.shuler@dot.gov. Periodicals postage paid at McLean, VA, and additional mailing offices (if applicable).

POSTMASTER: Send address changes to *Public Roads*, HRTM-20, FHWA, 6300 Georgetown Pike, McLean, VA 22101-2296.

Public Roads is sold by the Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402. Requests for subscriptions should be sent directly to New Orders, Superintendent of Documents, P.O. Box 979050, St. Louis, MO 63197-9000. Subscriptions are available for 1-year periods. Paid subscribers should send change of address notices to the U.S. Government Printing Office, Claims Office, Washington, DC 20402.

The electronic version of *Public Roads* can be accessed through the Turner-Fairbank Highway Research Center home page (www.fhwa.dot.gov).

The Secretary of Transportation has determined that the publication of this periodical is necessary in the transaction of the public business required by law of this department.

Guest Editorial

Resource Center Celebrates 20 Years

This is a special year for the Federal Highway Administration's Resource Center. 2018 marks 20 years of solving transportation challenges through technical assistance and support. First established in October 1998, the Resource Center was initially four independent centers. Later, in 2003, the four centers were integrated into one organization as we know it today.

The transportation landscape has changed dramatically in 20 years. Two decades ago, self-driving cars were only in science fiction. Now, we have cars that drive themselves on our public roads. Wireless communication and GPS mapping make navigation easier than ever, and transportation network companies are changing the relationships we have with our vehicles. New materials enable pavements to last longer, bridges are built faster and more cost effectively, and roundabouts are a common roadway safety feature.

The Resource Center itself was a revolutionary concept for FHWA when it was founded. The structure of the center represented a move away from a model of regional technical assistance to a national model built on customer service and strong partnerships. From the start, FHWA designed the Resource Center to deliver innovative solutions to complex problems and world-class technical expertise. To this day, the Resource Center upholds this mission to embrace new ways of thinking and to support program delivery with technical assistance and technology deployment across the Nation. Essential to the success of FHWA, the Resource Center partners with agency program offices and divisions to support multiple disciplines.

The Resource Center coordinates with the Turner-Fairbank Highway Research Center to deploy innovations and technologies. In partnership with headquarters offices, the Resource Center deploys new products and services that align with FHWA strategic goals and policy priorities. Through FHWA division offices and the Federal Lands Highway Divisions, we work directly with State, local, and Tribal agencies to tackle specific projects and challenges. Resource Center specialists collaborate closely with National Highway Institute staff to develop and present new coursework.

Every year, the Resource Center trains hundreds of transportation practitioners, in person and online. With creative solutions and dedication, our incredible workforce has earned transportation agencies' confidence and numerous internal and external awards. Staff are on call and ready to deploy where they are needed anywhere in the country. Through personalized assistance, customized training, and ongoing support, the Resource Center helps practitioners address immediate technical needs and build expertise to solve future challenges. In addition, partnering and participating with national and international associations positions the Resource Center to share innovations that improve safety and efficiency in the United States, and to bring home new ideas from other nations.

This anniversary also offers FHWA an opportunity to look ahead at the next 20 years and beyond. The Resource Center is evolving—organizationally moving toward a holistic approach to address the changing needs of transportation partners. More than just a combination of technical teams, the Resource Center operates as a technical unit that can collectively provide full answers to the most important challenges. For example, when a transportation agency calls upon the Structures team to assess a potentially unsafe bridge, the Operations team and the Pavement and Materials team can also work in collaboration to help resolve the issue. Twenty years from now, transportation professionals may view the Resource Center not as a collection of teams, but as a single nimble entity equipped to handle every angle of any challenge from the outset.

FHWA's Resource Center delivers the highest level of customer service and is always ready to provide assistance. Read more about the 20th anniversary on page 16 in this issue of PUBLIC ROADS to find out how we can help transportation professionals at all levels of government serve the traveling public better and smarter. We are the FHWA Resource Center, at your service.

Are you interested in what the Resource Center can do for your agency? Visit www.fhwa.dot.gov/resourcecenter or contact bernetta.collins@dot.gov.

Bernetta L. Collins
National Resource Center Director
Federal Highway Administration

HOT TOPIC

by Victoria Peters

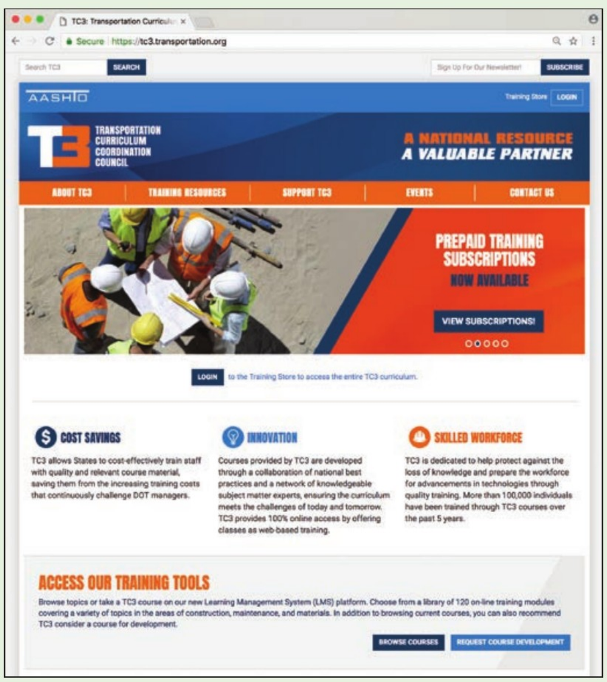
Partnering to Train Local and Tribal Transportation Agencies

Local government and Tribal transportation practitioners across the United States are responsible for about 80 percent of the Nation's highway network, roughly 3.1 million miles (5 million kilometers) of roadway. These agencies continue to voice the concern that they have only limited financial resources to address the vast needs of these highway assets.

Budget concerns are not the only resource-related challenge pressing local and Tribal governments. The longstanding issues of training, retaining, and replacing dedicated employees are also a concern.

Building and maintaining the skills necessary to operate a highway system requires access to consistent, quality training, not only on foundational concepts but also on new and innovative technologies and practices.

In a recent survey on local agency needs by the Federal Highway Administration, county governments reported that 15 to 30 percent of their workforce is eligible to retire in the next 3 to 5 years—a trend prevalent across the transportation industry. Agencies shared stories about having to choose between outfitting their highway crews with new equipment and acquiring the needed training to address their workforce challenges.



Transportation practitioners with local and Tribal governments now have access to the resources of AASHTO's Transportation Curriculum Coordination Council (TC3) training library.

FHWA is seeking ways to ensure local and Tribal agencies can acquire the skills they need to maintain a strong transportation workforce and take advantage of the innovations of today.

As a major step in that effort, FHWA purchased access for local and Tribal governments to the American Association of State Highway and Transportation Officials' (AASHTO) Transportation Curriculum Coordination Council (TC3) training library.

Expanded Training Capacity

This collaboration with AASHTO enables local and Tribal governments to access the TC3 training library at no cost to them. The Web-based training platform offers more than 190 courses on fundamental technical topics in the areas of construction, maintenance, and materials. This resource significantly augments the training capacity of the Local Technical Assistance Program (LTAP) and Tribal Technical Assistance Program (TTAP) portfolios to better meet the needs of the local and Tribal transportation sector moving forward.

LTAP centers and the TTAP can rebalance their offerings with these fundamental online resources and introduce more advanced training on innovative technologies and practices at the local level.

"The partnership between AASHTO and FHWA to make the TC3 curriculum available to the local and Tribal agencies provides space in the LTAP/TTAP portfolio to enable expansion into the advancement of innovations," says Tony Furst, FHWA chief innovation officer. "Providing local and Tribal practitioners access to the training available through TC3 broadens the portfolio of training and technical assistance to local and Tribal transportation professionals, and FHWA will continue to look for additional partnerships to broaden this portfolio even further."

Professional Development

In addition to needing to stay relevant and up to date, many local professionals seek courses with professional development hours to acquire the necessary continuing education credits for maintaining the licenses and certificates of their trade. Sometimes it is difficult to find enough relevant courses that fit within work schedules or budgets to meet these requirements. Individuals can fill the gap with the TC3 courses. More than 90 percent of the curriculum qualifies for professional development hours.

To browse and access TC3 courses, visit https://tc3.transportation.org.

To learn more about the Center for Local Aid Support, a part of FHWA's Office of Innovative Program Delivery, visit www.fhwa.dot.gov/innovativeprograms/centers/local_aid.

Victoria Peters is the director of the Center for Local Aid Support in FHWA's Office of Innovative Program Delivery.

INNOVATION CORNER

by Thomas Harman

On-Ramp to Innovation
every day counts

Introducing the EDC-5 Innovations

Enhancing safety on rural roads, bundling projects to reduce construction backlogs, and capturing the value of infrastructure investment to fund more projects are among the innovations in round five of Every Day Counts (EDC-5). Stakeholders suggested more than 160 innovations and collaborated with the Federal Highway Administration to evaluate and select 10 innovations that will be promoted and deployed in 2019 and 2020.

The EDC program facilitates the deployment of technologies and processes that enhance safety, speed up project delivery, reduce congestion, and improve environmental sustainability. Every 2 years, the Federal Highway Administration works with key stakeholder groups to identify a new set of innovations that merit accelerated deployment.

"The EDC-5 innovations support [the Department's] priorities to enhance safety, improve infrastructure, deploy innovation, and serve the Nation efficiently and effectively," says FHWA Acting Administrator Brandye Hendrickson. "We look forward to building on the success of past EDC cycles to expand adoption of proven innovations that save lives, money, and time."

The EDC-5 Roster

Advanced Geotechnical Exploration Methods. This initiative promotes advanced methods that can improve the characterization of a site's subsurface conditions, reducing design costs while minimizing delays and cost escalations during construction.

Collaborative Hydraulics: Advancing to the Next Generation of Engineering (CHANGE). Compared to traditional techniques, advanced hydraulic modeling tools provide a more comprehensive understanding of the complex flow patterns at river crossings, enabling agencies to design safer, more cost-effective, and more resilient structures on waterways. The graphical results from these tools facilitate more effective communication and collaboration throughout the design and evaluation process.

Reducing Rural Roadway Departures. This initiative provides tools to help agencies systemically reduce the number and severity of roadway departures on rural road networks. The proven countermeasures address head-on, rollover, and fixed-object crashes, the most harmful events for nearly 90 percent of fatalities caused by rural roadway departures.

Project Bundling. States have increasing numbers of highways and bridges that need attention, many on local systems. By awarding a single contract for several preservation, rehabilitation, or replacement projects, agencies can streamline design and construction, reduce costs, and ease project backlogs.

Safe Transportation for Every Pedestrian (STEP). Pedestrians account for 16 percent of roadway fatalities, and the vast majority of these occur at midblock and intersection crossing locations. The STEP initiative advances cost-effective countermeasures with known safety benefits at uncontrolled and signalized crossing locations.

Unmanned Aerial Systems (UAS). By collecting high-quality data automatically or remotely, UAS can provide safety, productivity, and cost improvements in transportation applications. This initiative helps transportation agencies harness UAS technology for use in inspection, construction, and operations.

Use of Crowdsourcing to Advance Operations. Using crowdsourced data can help agencies increase their situational awareness of real-time traffic conditions. This initiative promotes crowdsourced data as a real-time data source, outside the boundaries of fixed sensors and cameras, to enhance transportation system management and operations.

Value Capture: Capitalizing on the Value Created by Transportation. Public investment in transportation assets that improve access and increase opportunity can benefit adjacent property owners through greater land value and other economic impacts. This innovation showcases strategies for the public sector to share in a portion of this increased land value to build, maintain, or reinvest in the transportation system.

Virtual Public Involvement. This initiative promotes methods for enhancing public input during transportation planning and project development using virtual public involvement techniques, such as telephone town halls, online meetings, and street teams using virtual tools such as tablets. Strong public involvement can accelerate project development by identifying issues early in the process.

Weather-Responsive Management Strategies. Building on EDC-4 strategies, this initiative helps agencies use traffic management and traveler information systems to reduce delays and crashes resulting from adverse weather. It also promotes the use of road weather data to deploy anti-icing strategies that reduce chloride use, decreasing costs, and environmental impacts.

Round Five Kickoff

"An EDC-5 focus will be to engage local agencies in innovation implementation," says Tony Furst, FHWA's chief innovation officer and head of the Office of Innovative Program Delivery.

This fall, FHWA is hosting five innovation summits to enable more than 1,200 transportation leaders to review the EDC-5 innovations and identify those that fit the needs of their transportation programs. FHWA will establish a technical team for each innovation to support agencies' implementation efforts.

For more information, visit www.fhwa.dot.gov/innovation/everydaycounts.

Thomas Harman is the director of FHWA's Center for Accelerating Innovation.

Self-Enforcing Roadways

Strategic planning and design of rural roads can encourage drivers to choose speeds consistent with the posted limits, reducing the severity of speeding-related crashes.

by Eric Donnell, Kristin Kersavage, and Abdul Zineddin

More than 37,000 fatalities and 2 million injuries occur annually on highways and streets in the United States as a result of traffic crashes. The fatal crash rate in rural areas is 1.84 per 100 million vehicle-miles traveled, which is more than 2.5 times the urban fatal crash rate of 0.71. However, traffic safety improvement programs with strategies for rural areas may be especially successful in reducing crash frequency and severity.

Of particular interest among traffic-related fatalities in the United States are those attributed to speeding, which is approximately 27 percent of the total fatalities annually.

(Above) Self-enforcing roadways is a speed management concept that involves designing roadways that encourage drivers to select operating speeds consistent with the posted speed limit. *Photo: KingWu, Getty Images.*

Speeding-related crashes are those defined as driving too fast for conditions or exceeding the posted speed limit. Among rural traffic fatalities, approximately 28 percent are classified as speeding-related. In 2015, the percentage of speeding-related crashes that occurred on rural roadways with a posted speed limit of 55 miles per hour, mi/h, (88 kilometers per hour, km/h) or higher was 74 percent. Collectively, these data suggest value in effective speed-management programs to reduce speeding-related crashes on moderate- and high-speed, two-lane rural highways.

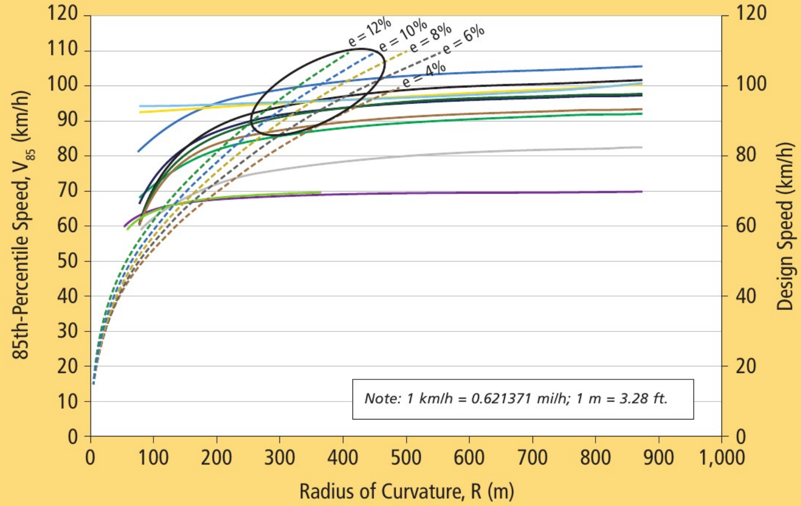
In January 2018, the Federal Highway Administration published a report, *Self-Enforcing Roadways: A Guidance Report* (FHWA-HRT-17-098), which provides details on how to produce "self-enforcing" roadways. A self-enforcing road, also called a self-explaining roadway, is planned and designed to encourage drivers to select operating speeds consistent with the posted speed limit. Engineers can apply the concepts to both planned and existing roadways. This article summarizes several of the concepts that transportation professionals may use to manage speeds on two-lane rural highways; however, many of the concepts may also be applicable to other roadway types.

Speed-Safety Relationships

With regard to crash severity, the operating speed of motor vehicles directly affects the crash outcome. Kinetic energy is directly proportional to the square of the operating speed; thus, higher operating speeds should result in more severe crash outcomes.

Traffic safety research reflects the physics involved. Research published in 2006 by the Transportation Research Board (TRB) determined that speed limit increases were associated with an increase in the probability of fatal injury crash outcomes,

Radius of Curvature Versus 85th-Percentile Speeds and Design Speeds



This graph demonstrates the relationship between different speed measures and a geometric design element. In this example, speeds are plotted relative to the horizontal curve radius on two-lane rural highways. The solid lines were developed using a collection of 85th-percentile operating speed prediction models from published research on the topic. Clear variability exists in the predicted speeds. The dashed lines illustrate the relationship between the designated design speed from the AASHTO Green Book, the maximum rate of superelevation, and the minimum horizontal curve radius. The area approximately within the black oval represents the range in which designated design speeds and predicted operating speeds are similar. For very sharp curves, the geometry of the roadway tends to influence the operating speed of vehicles. Depending on the superelevation of the road, horizontal curvature tends to have little effect on operating speeds on flatter horizontal curves. *Source: FHWA.*

presumably because of increases in vehicle operating speeds. Likewise, a study published by TRB in 2008 found that increases in the posted speed limit were associated with an increased likelihood of a crash resulting in an injury or fatality on rural roads. In addition, a 2016 study by the Insurance Institute for Highway Safety concluded that fatality rates and risk increased as maximum speed limits increased in many regions of the United States.

The relationship between speed and crash frequency is less clear. Separate studies done in the 1960s concluded that as vehicle operating speeds deviated from the average speed of the traffic stream, crash involvement rates increased. Later efforts to replicate the findings were not consistent. In 2002, a study by the University of Minnesota concluded that studies with the familiar U-shaped speed deviation-crash involvement rate relationships were ecological fallacies because individual crash risk based on the speed dispersion among a group of vehicles in the traffic stream does not clearly distinguish between individual and group risk measures.

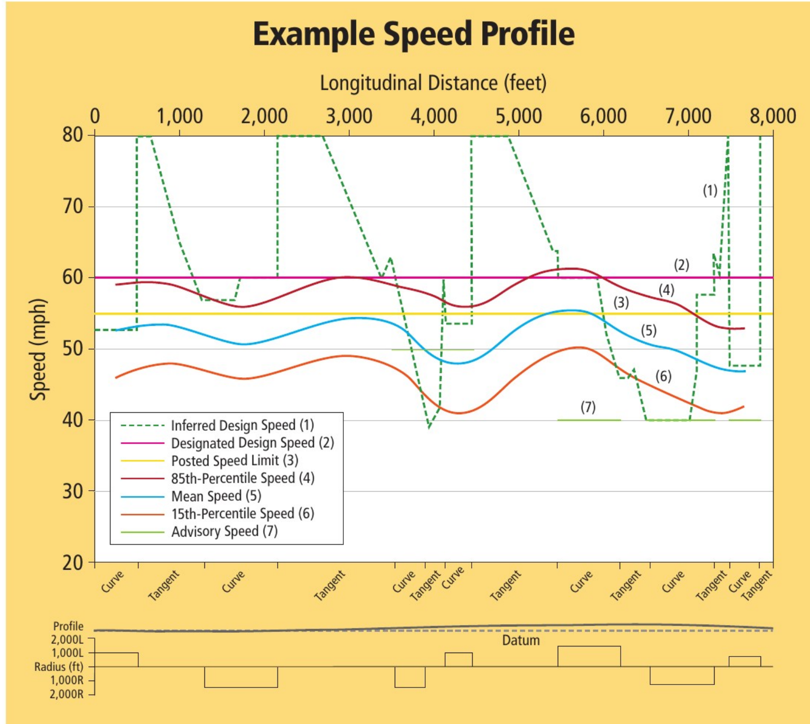
In summary, published research supports the notion that higher operating speeds are associated with more severe crash outcomes. Increasing posted speed limits has shown to increase operating speeds, leading to more severe crash outcomes. However, consistent findings related to the relationship between crash frequency and speed metrics have not been established.

Speed-Geometric Design Relationships

Geometric roadway design practices in the United States rely on design controls and criteria set forth in the American Association of State Highway and Transportation Officials' (AASHTO) *A Policy on Geometric Design of Highways and Streets*, also known as the "Green Book." The design speed (herein referred to as the designated design speed) is defined in the Green Book as "a selected speed used to determine the various geometric design features of the roadway." The Green Book either explicitly or implicitly uses the design speed concept to establish horizontal alignment, vertical alignment, and cross section design elements. Examples include radius of curvature (R), stopping sight distance (SSD), braking distance (db), horizontal sight line offset (HSO), length of vertical curvature (L), maximum superelevation (emax), maximum side friction factor (fmax), and lane and shoulder widths.

The inferred design speed, which FHWA's *Speed Concepts: Informational Guide* (FHWA-SA-10-001) defines as "the maximum speed for which all critical design speed-related criteria are met at a particular location," is equivalent to the designated design speed when either minimum or limiting values of design criteria are used. However, the Green Book recommends using design values that exceed minimum values, and in such cases, the inferred design speed will exceed the designated design speed.

Transportation engineering researchers and practitioners often use operating speed models to assess geometric design consistency, most notably on two-lane rural highways. Many studies have estimated statistical models to predict vehicle operating speeds that may be used to evaluate highway geometric design consistency. In many of the models, transportation researchers and practitioners can input variables such as design features (for example, horizontal curve radius), posted speed limit, and annual average daily traffic into the models to determine the vehicle operating speed under free-flow conditions (for example, vehicle headways of 4 or more seconds). While the most common speed output from these models is the expected 85th-percentile operating speed, statistical models of mean speed and the standard deviation of speed exist. Applying operating speed models may confirm that designated design speeds, posted speed limits, and driver expectations will all be more consistent when the roadway geometry is designed to manage speeds.



This graph depicts an example of a speed profile based on the inferred design speed approach. *Source: FHWA.*

Examples of speed-geometric design relationships are illustrated in *Self-Enforcing Roadways: A Guidance Report*. Among speed-based geometric features, the radius of horizontal curve and horizontal curve spacing have the greatest influence on driver speed choice. For more information, visit www.fhwa.dot.gov/publications/research/safety/17098/17098.pdf.

Self-Enforcing Road Concepts

According to National Cooperative Highway Research Program *Report 504*, "a design process is desired that can produce roadway designs that result in a more harmonious relationship between the desired operating speed, the actual operating speed, and the posted speed limit." While transportation researchers suspect that achieving speed harmony in geometric design affects the safety of a road, the actual effects are unknown, as reported in "Geometric Design, Speed, and Safety," published in Volume 2309 of the *Transportation Research Record: Journal of the Transportation Research Board*. However, when speed harmony exists, the road designs "look and feel" like the intended purpose and may be described as more self-explaining.

When the operating speeds of a roadway are inconsistent with the design speed, speed discord results. Speed discord is a roadway design that produces operating speeds that are higher than the posted speed limit. According to FHWA's *Speed Concepts* guide, speed discord on two-lane rural highways often resulted from the use of above-minimum values of geometric design criteria. In such cases, the 85th-percentile operating speed along a roadway segment often exceeds the posted speed limit and the designated design speed.

"In the year 2017, a total of 1,137 lost their lives on Pennsylvania roadways. Out of the total number of fatalities, 463 were [the result of] speed-related crashes," says Glenn Rowe, P.E., chief of the Pennsylvania Department of Transportation's (PennDOT) Highway Safety and Traffic Operations Division. "When you consider over 40 percent of fatal crashes are related to speed, it's imperative that PennDOT implement cost-effective designs for self-enforcing or self-explaining roadways in order to reach our zero fatalities goal."

Self-Enforcing Roadways: A Guidance Report describes six concepts that may be used individually or in combination to design roadways that produce actual operating speeds consistent with the desired operating speeds. The concepts include: (1) applying the speed feedback loop process, (2) using the inferred design speed approach, (3) applying operating speed models to assess design consistency, (4) utilizing existing geometric design criteria, (5) using a combination of signs and pavement markings, and (6) setting rational speed limits.

What follows is a closer look at the inferred design speed approach, methods for design consistency, and setting rational speed limits.

Inferred Design Speed Approach

The inferred design speed approach applies only to design criteria that are based on the designated design speed. The designated design speed and inferred design speed will differ when using larger-than-minimum values (or lower-than-limiting values) of geometric design criteria. When applying this method, the inferred and designated design speeds are plotted on a two-dimensional graphic (speed versus roadway length) to evaluate design consistency. This graphic can provide information about setting an appropriate regulatory speed limit that is related to the anticipated operating speeds of a roadway. Large differentials between the inferred and designated design speeds will likely produce operating speeds that are higher than anticipated in the design process.

FHWA's guidance report outlines a five-step process to develop an inferred design speed evaluation of an existing or planned roadway. The designated design speed is contained on a set of roadway construction plans, while the inferred design speed is computed using models (for example, stopping sight distance formula, point-mass model for horizontal curve design, and minimum length of crest vertical curve formula) contained in geometric design policy, such as the Green Book. Engineers need the geometric design features of the roadway to

compute the inferred design speed, which is based on speed-based design elements (such as horizontal alignment, vertical alignment, and cross-section). The posted speed limit is based on an engineering field study or local statutes.

Design Consistency Methods

Design consistency methods also may be used to assess the relationship between posted speed limits, designated design speeds, and operating speeds. Operating speed prediction models are needed to apply the methods. A synthesis of these models is available in TRB's 2011 *Transportation Research e-Circular* "Modeling Operating Speed" at http://onlinepubs.trb.org/onlinepubs/circulars/ec151.pdf. Design consistency methods can be evaluated manually using a series of equations, or using an automated method, such as the Design Consistency Module of the FHWA *Interactive Highway Safety Design Model* (IHSDM).

The design consistency method requires detailed geometric design data. These data often are not available in early project planning efforts. However, as the project development progresses, engineers can integrate computer-aided files (or geometric design data) into IHSDM. The Design Consistency Module estimates 85th-percentile operating speeds, including acceleration and deceleration rates approaching and departing curves, and compares operating speeds on successive design elements. It also compares the designated design speed to the predicted 85th-percentile operating speed. Speed differences of less than 6 mi/h (9.6 km/h) are considered good, while speed differences greater than 6 mi/h (9.6 km/hr) are considered fair (if less than or equal to 12 mi/h, 19.3 km/h) and poor (if greater than 12 mi/h, 19.3 km/h).

Self-Enforcing Roadways: A Guidance Report outlines a three-step process to apply the design consistency approach. The steps are:

1. Acquire roadway geometric design criteria (for example, radius of curve, tangent lengths, vertical grade, lane and shoulder widths, and roadside hazard rating).
2. Determine the appropriate operating speed model to apply based on the existing or planned geometry.
3. Set the posted speed at a level consistent with the expected operating speed.

Setting Rational Speed Limits

Another approach to developing self-enforcing or self-explaining roadways is to set speed limits that are reasonable, rational, and consistent with the features of the roadway. FHWA has a Web-based tool, USLIMITS2, which provides guidance regarding appropriate posted speed limits for all road types. USLIMITS2 determines rational speed limits through expert knowledge of speed limits and a series of decision rules and procedures applied to a particular scenario.

The three-step process in *Self-Enforcing Roadways: A Guidance Report* outlines how to apply USLIMITS2. Inputs to the program include operating speed information, traffic volume, terrain, access density, roadside characteristics, the statutory speed limit, presence of onstreet parking, pedestrian and bicycle activity, crash history data, and geometric design information.

Safer Speeds, Safer Roadways

Speeding is cited as a contributory factor in nearly 27 percent of all fatal crashes reported in the United States, and a significant number of these incidents occur on rural roadways with posted speed limits that exceed 40 mi/h (64.3 km/h). As a result, managing speeds on two-lane rural highways is likely to be an effective safety management strategy. Self-enforcing or self-explaining roadways present one possible approach to manage speeds by encouraging drivers to choose a speed that is compliant with the regulatory speed limit.

"Properly designed self-enforcing roadways can be effective in producing speed compliance and less severe crash outcomes," says Monique R. Evans, P.E., director of Eastern Federal Lands Highway Division at FHWA. "And FHWA's *Self-Enforcing Roadways: A Guidance Report* provides guidance to transportation agencies on how to design self-enforcing roadways."

Eric Donnell, Ph.D., P.E., is a professor of civil engineering and director of the Thomas D. Larson Pennsylvania Transportation Institute at Pennsylvania State University. His research and teaching interests include geometric design of highways and streets, speed management, and traffic safety.

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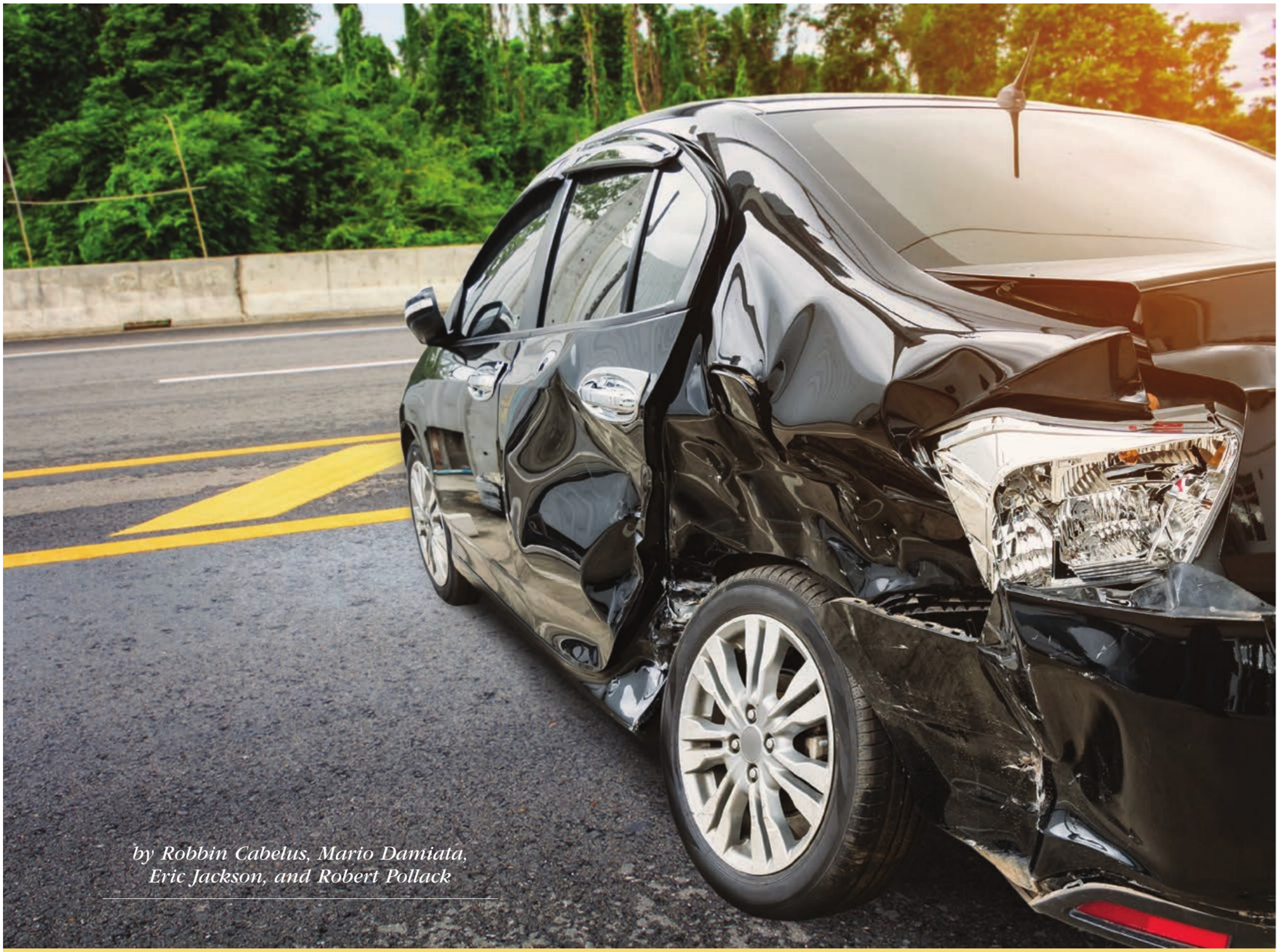
Abdul Zineddin, Ph.D., is a transportation specialist with FHWA's Office of Safety Research and Development at the Turner-Fairbank Highway Research Center. He oversees the speed management research program. Zineddin holds bachelor of science, master of engineering, and doctorate degrees in civil engineering from Pennsylvania State University.

For more information, see www.fhwa.dot.gov/publications/research/safety/17098/17098.pdf or contact Abdul Zineddin at 202–493–3288 or abdul.zineddin@dot.gov.

The fatal crash rate in rural areas is more than 2.5 times the urban fatal crash rate. Speeding is a contributing factor to the significant number of fatalities on rural roads. *Photo: Kevin Mahoney.*



by Robbin Cabelus, Mario Damiata, Eric Jackson, and Robert Pollack

Better Information for Better Roadway Safety

Connecticut's journey to modernize its system for crash data collection, reporting, and analysis could serve as a model for other transportation agencies.

(Above) In 2015, Connecticut launched a complete overhaul of its crash reporting system to improve the quality, accessibility, and usefulness of its crash data. *Photo: © Kwangmoozaa, iStock.*

As demands to more effectively manage resources for improved driver and road safety increase, having a robust system to capture, store, and analyze crash data is a key need for many State departments of transportation. Gone are the days when crash reports were simply filled out by law enforcement officers, filed away, and sent to State agencies and insurance companies without an afterthought.

With the onset of new automotive technologies, increases in risky driver behaviors such as texting, and improvements in engineering, the need to accurately investigate causation factors of crashes has become more important—and more complex.

In 2010, the Connecticut Department of Transportation (CTDOT) was still laboring under a paper-based crash reporting system from 1995 that was outdated and no longer sustainable. With a backlog of more than a year, the system was limiting the State's ability to analyze its crash data, identify major highway safety problems, and efficiently manage its safety resources to address those problems.

At the request of CTDOT, the Federal Highway Administration performed an assessment of Connecticut's crash data system in 2011. As a result, CTDOT developed a business plan for improvement that focused on creating a new vision for crash data management and building the data collection and reporting tools to support that vision. The plan embraced full implementation of a state-of-the-art electronic reporting system that would provide real-time, accurate, complete, and fully accessible data to the highway safety community.

The resulting system is fully compliant with national crash reporting guidelines published by the National Highway Traffic Safety Administration, known as the Model Minimum Uniform Crash Criteria (MMUCC).

Adopting the latest version of the MMUCC, transitioning to electronic crash reporting, and developing a fully MMUCC-compliant crash database to expand the capabilities of an existing Crash Data Repository all at the same time could be intimidating even for the most progressive States. Most of these efforts are typically funded independently and developed incrementally. But Connecticut took a different and more aggressive approach, implementing an agile, multifaceted strategy designed to change not only best practices and technologies but also the State's culture surrounding traffic crash investigation and reporting.

In the process, CTDOT developed a roadmap that other States may want to consider following when revamping their own crash reporting systems.

What Are Model Minimum Uniform Crash Criteria?

In 1998, NHTSA and the Governors Highway Safety Association cooperatively developed a voluntary data collection guideline. The MMUCC guideline identifies a minimum set of motor vehicle crash data elements and their attributes that States should consider collecting and including in their State crash data systems. For more information, see www.nhtsa.gov/mmucc.

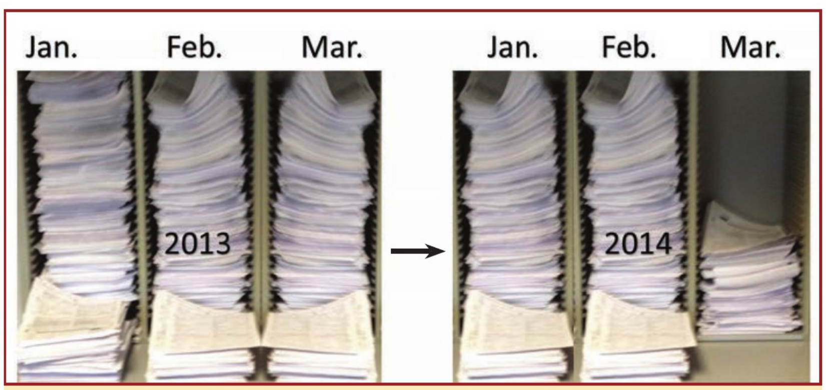
An Antiquated Crash Reporting System

Connecticut is the third smallest State by area but also the fourth most densely populated—resulting in frequently congested roadways and, inevitably, crashes. CTDOT historically did not perceive managing crash data as an important core function, and the crash report form, last revised in 1995, was a simple two-sided document with overlays. Police officers generally filled the forms out in minutes and sent them off to the State primarily to meet the perceived needs of insurance companies, without any understanding of the data's potential importance to CTDOT.

Crash reports were manually coded, processed, and entered into a mainframe database with limited ability to access information. In an attempt to defray costs, CTDOT entered only one-third of the data from each report into the system.

CTDOT received the majority of its 110,000 crash report forms filed annually on paper. A small pilot project with the Connecticut State Police initiated in 2010 included limited electronic submissions. However, the State lacked standards for accepting data electronically, and the reports had to be manually reentered into the CTDOT system.

Over the years, trying to maintain an adequate crash database became increasingly more difficult. By 2012, CTDOT faced a 14-month backlog of crashes needing to be entered into its database. In an attempt



Before the system overhaul, Connecticut faced a 14-month backlog in entering crash data from paper reporting forms. *Photo: CTDOT and CTSRC.*

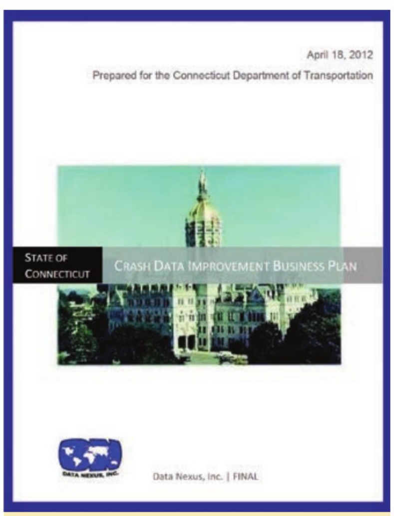
to reduce the backlog, the agency decided to stop entering property damage crashes on local roads for several years. The resultant truncated database barely provided enough information to meet the needs of CTDOT engineers, with little or no regard for potential users outside of CTDOT.

As a result, CTDOT collected very little valuable, relevant, or timely data to support a data-driven highway safety program. The outdated, paper-based system was crumbling under its own weight from years of neglect.

A Business Plan That Makes a Difference

In October 2011, at its own request, CTDOT participated in a Crash Data Improvement Program (CDIP) assessment sponsored by FHWA. A team of subject matter experts assessed all aspects of the State's crash data system and developed a report detailing current practices and making actionable recommendations for improvement.

Connecticut's CDIP report identified a number of challenges, including the aforementioned backlog, outdated crash data collection content, paper-based submissions, and processes that limited data capture. The CDIP also noted the culture of law enforcement officers who lacked an appreciation of the use and importance of the crash data they were providing. The report emphasized the absence of capabilities to facilitate expanded electronic reporting, including a default tool to help low-technology agencies.



Cover of the *State of Connecticut Crash Data Improvement Business Plan.* *Photo: CTDOT.*

Recommendations included establishing a crash database that was MMUCC compliant and capable of capturing all fields from the report form to support safety analyses, and creating a business plan for collection and management of crash data. The report also provided suggestions for improving the timeliness and quality of the data, such as accurate location reporting. The May 2012 final report is available from CTDOT's Crash Initiatives page at www.ct.gov/dot/crashinitiative.

CTDOT recognized the importance of the CDIP's findings and adopted all CDIP strategies for improving its crash data system into its Strategic Highway Safety Plan. CTDOT then independently contracted to develop a business plan to improve its crash data system. The plan identified two major goals: 1) achieving full MMUCC compliance and 2) converting to a completely electronic reporting system by January 1, 2015.

The business plan defined the tasks, milestones, timeframes, and resources needed to fully deploy a new crash reporting system. To implement it, CTDOT established a dedicated multidisciplinary project team that met weekly, led by a project director and facilitated by a "crash data champion" who functioned as a day-to-day project manager. This team consisted of individuals from CTDOT's Offices of Information Systems; Coordination, Modeling, and Crash Data; and Highway Safety; and representatives from the University of Connecticut's Transportation Safety Research Center (CTSRC).

Mike Gracer, the project's chief developer and information technology consultant, says, "I was impressed with the quality, dedication, and makeup of the team, which was allowed to function outside of the traditional organizational processes to give the project the full attention it needed on a day-to-day basis."

Evolution of the Toolbox Strategy

Despite the guidance provided by the new business plan, it was initially not clear to CTDOT how extensive and complex revamping the crash reporting system would become. Early activity focused on continuing to build out a geospatial rendition of the State's road network to support more accurate reporting of crash locations; reducing the paper backlog to manageable levels; designing a user-friendly, MMUCC-compliant crash report; and enhancing the existing Crash Data Repository hosted by the CTSRC by developing a new, MMUCC-compliant database.

While the framework of the business plan was helpful, it became clear that the team needed more flexible and creative methods—what the technology industry calls "agile system development." CTDOT's new approach enabled the evolution of the following strategic elements designed to optimize transparency, communication, customer engagement, and flexibility in technical services and products:

- Weekly guidance provided to the project team by executive leadership.
- A commitment to include law enforcement as partners in all aspects of planning, developing, and implementing the new crash reporting system.
- A strategy to engage the software vendors of police departments' records management systems (RMS) as part of a multiple-solution approach.
- An outreach and marketing plan that provided the tools, training, and technical support necessary to make the transition as easy as possible for law enforcement agencies and their vendors.
- Creation of a full-time position for a crash data liaison to provide day-to-day technical support to individual law enforcement agencies.
- Configuration of the Crash Data Repository to make it a valuable resource for law enforcement and traffic safety planning.

By May 2013, the project team decided on a solution for electronic report submission involving multiple RMS vendors, complemented by a default electronic, PDF-based crash report form that participating law enforcement agencies could access free of charge. In addition, CTDOT began developing a system to import and validate crash reports, creating a formal training program

Connecticut's MMUCC Best Practice Toolbox

The toolbox consisted of eight key components, which helped the State to successfully overhaul its reporting system. *Photo: CTDOT.*

for law enforcement, implementing a field coordinator team to oversee the training, and developing a more rigorous process for existing CTDOT coders to assess data quality.

The cumulative framework of all of these strategies came to be known as the MMUCC Best Practice Toolbox. The toolbox consists of the eight core essential activities and strategies that had evolved over time to achieve a successful outcome: setting clear goals and timeframes, designating a crash data champion, establishing partnerships and outreach, creating a fillable PDF, developing the MMUCC Crash Form and training, identifying information technology solutions, improving data quality, and developing a Crash Data Repository.

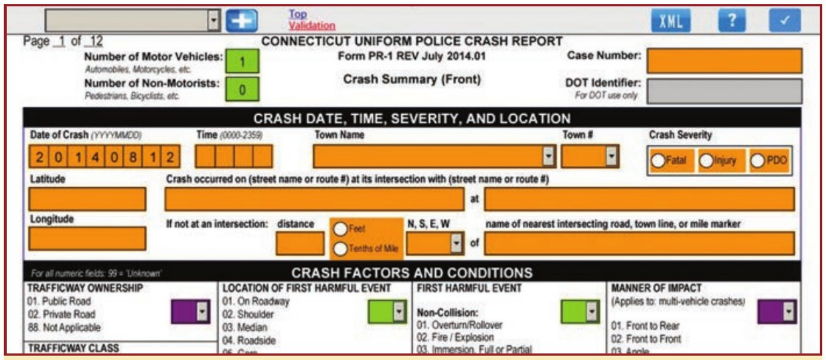
"The toolbox was as much a commitment to a coherent and systematic way of doing business as it was a composite mix of strategies that evolved based on experience," says Chuck Grasso, a retired sergeant with the Enfield, CT, police department and a crash data liaison for CTSRC. "All of these strategies, as well as the data collection, validation, and documentation, are easily transferable for replication in other States."

Early Toolbox Strategies

The toolbox's early strategies laid the groundwork for success by creating a robust environment that can support collaborative and coordinated planning.

Setting clear goals and timeframes. Based on the results of the CDIP, the team focused on two overarching goals: achieving total compliance with national MMUCC guidelines and implementing fully electronic crash reporting by all law enforcement agencies. These two goals served as the major drivers for all planning tasks related to improving the quality, timeliness, and completeness of crash data.

Early in 2013, CTDOT decided that any change in the crash form needed to take effect on January 1, 2015. This would ensure all required annual reporting would be conducted on data elements and definitions that did not change during that reporting period. A 2-year timeline for an overhaul of the crash system did not seem overly ambitious at the time, but the team soon realized how difficult this could be to achieve. However, CTDOT remained committed to the deadline and employed creative and innovative solutions as necessary. Setting and adhering to clear goals provided the necessary targets, timeframes, and motivation to sustain the project and achieve success regardless of any setbacks.


Top
Validation
XML
Page 1 of 12
CONNECTICUT UNIFORM POLICE CRASH REPORT
Form PR-1 REV July 2014.01
Crash Summary (Front)
Number of Motor Vehicles: 1
Automobiles, Motorcycles, etc.
Number of Non-Motorists: 0
Pedestrians, Bicyclists, etc.
Case Number:
DOT Identifier:
For DOT use only
CRASH DATE, TIME, SEVERITY, AND LOCATION
Date of Crash (YYYYMMDD) 2 0 1 4 0 8 1 2
Time (0000-2359)
Town Name
Town #
Crash Severity
Fatal Injury PDO
Latitude
Crash occurred on (street name or route #) at its intersection with (street name or route #)
at
Longitude
If not at an intersection: distance
Feet
Tenths of Mile
N, S, E, W
of
name of nearest intersecting road, town line, or mile marker
For all numeric fields: 99 = 'Unknown'
CRASH FACTORS AND CONDITIONS
TRAFFICWAY OWNERSHIP
01. Public Road
02. Private Road
88. Not Applicable
TRAFFICWAY CLASS
LOCATION OF FIRST HARMFUL EVENT
01. On Roadway
02. Shoulder
03. Median
04. Roadside
FIRST HARMFUL EVENT
Non-Collision:
01. Overturn/Rollover
02. Fire / Explosion
03. Immersion, Full or Partial
MANNER OF IMPACT
(Applies to: multi-vehicle crashes)
01. Front to Rear
02. Front to Front

CTDOT developed a fillable PDF of the revised crash reporting form, part of which is shown here, to enable law enforcement agencies without access to a fully electronic system to easily submit reports electronically. *Photo: CTDOT.*

Designating a crash data champion. The CDIP assessment introduced the concept of recruiting a crash data champion. CTDOT tasked this individual with bringing together the many disparate groups and elements and facilitating the development and monitoring of a cohesive strategy. A champion whose primary focus and responsibility was system planning and implementation was essential to the process. For Connecticut's effort, a staff member of the CTSRC served as the champion and worked onsite at CTDOT as an integral part of the team.

The position of crash data champion was dynamic, and the responsibilities evolved over time. The champion wore multiple hats, serving as project manager, meeting facilitator, internal advocate, and broker in negotiating both internal consensus and agreements with law enforcement and vendor partners. Most importantly, the champion functioned as the bridge between technology providers, law enforcement, crash program managers, and RMS vendors.

Team member Maribeth Wojenski, the chief supervisor of crash management operations at CTDOT at the time of the project, says, "Without this dedicated position, the probability of delivering the project on time and within resource limitations would have been significantly diminished."

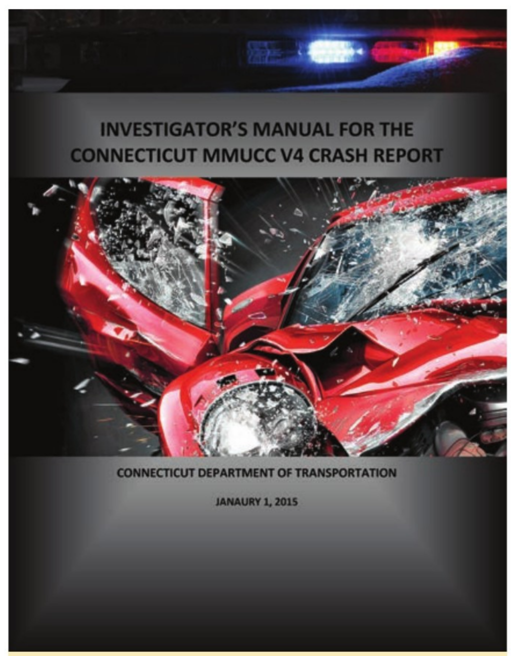
Establishing partnerships and outreach. The project's partnership efforts went through several developmental phases. Early activities focused on building general awareness of the project and creating credibility with the law enforcement community. These activities included monthly briefings to CTDOT's Traffic Records Coordinating Committee and a vendor summit sponsored by the University of Connecticut to showcase software applications and respond to questions regarding the project. The project team then began direct engagement by writing an open letter to local officials and police chiefs, distributing brochures and posters to the law enforcement community, and posting a program video on the CTSRC website that explained the project.

The project team further strengthened its partnerships by hosting law enforcement workshops designed to solicit input on a new crash report as well as functionality for the electronic PDF. "Law enforcement was brought in early in the process to assure buy-in by the 'boots on the ground' who would ultimately determine the success or failure of the project," says Sergeant Andy Gallagher with the Stamford, CT, police department. "Early train-the-trainer sessions where the electronic report was demonstrated were vital in ensuring the project's success."

This phase included outreach to law enforcement agencies' RMS vendors. CTDOT also offered seed funding to interested RMS vendors to modify their systems to enable electronic capture and reporting of crash data.

The intensive final phase of partnering included a classroom-based MMUCC training course followed by technical support in the field on a daily basis. Crucial to the improvement effort was the collaborative and trusting relationship built and sustained with law enforcement and the vendor community.

Setting goals and timelines, designating a champion, and having strong partnerships proved critical for the expedited overhaul of the crash reporting system. Connecticut's model relied on a firm commitment to the project launch date, incentives, technical assistance, continuous and constant communication and feedback to partners, and a sense of inclusiveness that left no agency behind. This collaborative model enabled CTDOT and its partners to achieve their goals without the need for further regulatory authority.



CTDOT developed a comprehensive manual for crash investigators on how to use the new report. *Photo: CTDOT.*

CTDOT partnered closely with law enforcement agencies, including holding workshops for officers to provide input on the development of the new crash reporting form. *Photo: Chris LaRosa, University of Connecticut.*

Toolbox Strategies for Law Enforcement

The CTDOT project team decided early on to actively engage its law enforcement partners in the process to update its 20-year-old crash reporting form. The University of Connecticut hosted three sequential workshops for law enforcement to provide input on the new crash report form. Each workshop resulted in significant edits to the crash report. At the end of the workshop series, CTDOT finalized the form in July 2014 and then began developing the data collection system and tools with which to implement the new form.

Creating a fillable PDF. During the workshops, it became apparent that not all local law enforcement agencies would be able to participate immediately in the electronic submission process. To provide a "safety net" for agencies without participating records management vendors, or whose vendors would not be ready at launch, the project team developed a universal, low-cost tool: a fillable PDF version of the crash report that could be used in the field.

CTDOT received feedback on the functionality of this tool from workshop participants. The resulting "smart" form includes extensive use of dropdown menus and clickable elements to streamline data entry, compliance with the overall requirements for electronic submission to ensure consistent and valid data, and a table of contents for quick navigation through the form. The developers included built-in support for 123 edit rules, context-sensitive help, and error-checking functionality.

The project team's efforts were so successful that the schema, or organizational blueprint, developed by Connecticut for MMUCC 4th Edition (current at the time) served as the basis for the MMUCC 5th Edition schema recently released by NHTSA.

Creating and delivering a training curriculum. The team then began the process of training law enforcement officers on MMUCC terms and concepts. Prior to this, most officers in Connecticut received only minimal instruction in completing the actual crash report as new recruits in the academy. Limited emphasis was placed on the value of the crash report to the highway safety community. To aid in the development of the course, the project team incorporated Connecticut-specific MMUCC guidelines, case study scenarios, and an appreciation of the value of new data elements.

With that foundation, CTDOT developed a comprehensive, 6-hour classroom course that covers all MMUCC data elements and attributes and includes training videos, visual examples, workgroup exercises, and a period of open discussion. The CTSRC used animation and humor in the production of its videos to keep officers engaged. Incentives to participate in the training course include offering law enforcement credits for inservice training. Material from the MMUCC course is now used for all recruit training, and the course is available on request for refresher training. Training content and videos also are available on the CTSRC website at https://ctsrc.uconn.edu.

Almost every police agency in the State received an onsite visit as the project moved closer to the launch date. To assist with delivering the training, the CTSRC relied on a cadre of trained law enforcement instructors and crash investigation experts to facilitate effective communication with active-duty officers and law enforcement agencies. Three part-time law enforcement officers with significant crash investigation expertise conducted followup training.

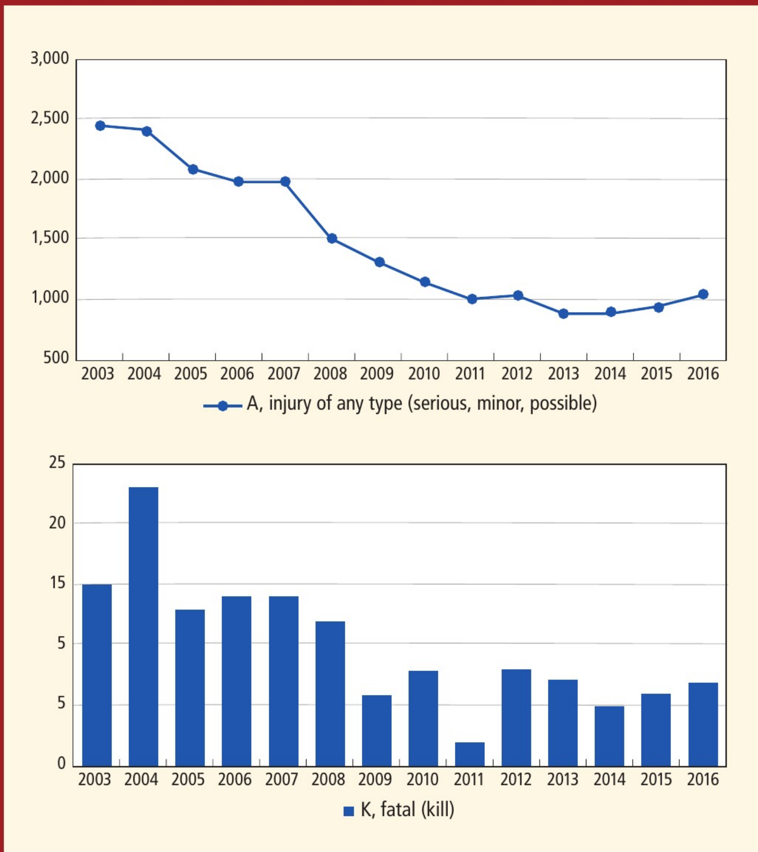
After the project launched, the CTSRC hired two full-time law enforcement field coordinators to provide technical advice, troubleshoot submission issues, and produce weekly newsletters and podcasts addressing common MMUCC issues.

Toolbox Strategies for Electronic Reporting

By partnering with law enforcement agencies and their RMS vendors, CTDOT's team realized it needed to develop tools to enable the seamless transmission of electronic crash data from a variety of users to the comprehensive database. In addition, having all reports submitted electronically for the first time necessitated a change in protocols at CTDOT for validating and editing the data.

Identifying technology solutions. The team first developed a schema

Year by Year: Crash Severity Comparisons



These graphs generated from the Crash Data Repository show the trend of injury (line graph) and fatal (bar graph) crashes in Connecticut for 16- and 17-year-old drivers since 2003. In 2008, the State implemented a legislative change to its graduated drivers licensing law, reflected in the drop in crashes for the following years. *Source: CTDOT.*

to establish the formatting requirements for data transmission. This was captured in the *State of Connecticut's Crash Data Guidelines,* a major element of the toolkit, which defined data elements and attributes, their values, and edit and validation rules to ensure data quality. CTDOT added the rules to the State's file transfer website to validate crashes at the time of submission from law enforcement agencies.

The team also incorporated data validation and edit rules into the fillable PDF to ensure compatibility and required software vendors to incorporate them into their software. To help, CTDOT created the Testing and Certification Guide. This guide provided crash scenarios that vendors had to enter into their systems before submitting their software to CTDOT for certification.

CTDOT also developed a Crash Uploader tool for easy transmission of the fillable PDF. By providing the tool at no cost to local agencies, the team prevented barriers to submitting crash reports electronically. CTDOT also purchased licenses for crash diagramming software and provided them for free to all law enforcement agencies in the State.

Improving crash data quality. One byproduct of the new crash reporting system was the change in validation and editing protocols at CTDOT. Under the old paper reporting system, technicians needed to enter data for every field, review the crash diagram, and locate the crash based on the best information available. The new system provides built-in validations and edits within the fillable PDF or the local agency's electronic system. To make it even more robust, the team implemented those same validations and edit checks within the CTDOT system that receives crash reports.

Technicians can now spend the majority of their time reviewing advisory edits, checking for inconsistencies, and easily locating the crash based on required GPS data in the crash report. As a result of the new protocols, high-quality crash data are now available within 30 days of receipt of the crash report.

Toolbox Strategies for Data Accessibility and Analysis

Key to gaining support for the project from law enforcement agencies—without a mandate—was making timely crash data easily accessible to the agencies by using innovative data visualizations. These types of tools were not previously available from CTDOT. Law enforcement agencies relied on their own software and staff for crash data analysis.

Developing a Crash Data Repository. The collection of accurate, timely, and complete data led to the expansion and enhancement of the Connecticut Crash Data Repository hosted at the University of Connecticut. This public-facing website at www.ctcrash.uconn.edu enables users to query, display, and analyze more than 20 years of crash data from across the State. Registration for the site is free and open to the public. Users may view summaries, run and save queries, view data from individual reports and diagrams, map crashes, generate summary tables, and download raw crash data for further analysis. All personal and private information has been removed from the crash data to protect the privacy of those involved in the crashes.

A key enhancement to the repository is a series of dashboards, which provide the ability to explore data summaries. The team designed the dashboards to enable users to quickly filter the data and then generate a PDF report of facts and

figures. Users can save queries and export the resulting crash data to conduct analysis in a statistics package of their choosing.

The repository can assist law enforcement agencies in identifying problem areas in their jurisdictions, applying for CTDOT grants for enforcement activities, and planning high-visibility enforcement in high-crash locations to help prevent crashes from occurring in the future. Advanced tools enable users to query crash data on almost every data element on the crash report form and produce maps and graphics to visually represent the data. Users can then align policy changes with changes in crash frequencies.

For example, the repository can produce maps with color-coded pushpins representing the severity of each crash, which can easily be converted to heat maps indicating where crash densities are the heaviest. Law enforcement can use these maps to help determine where to target education or enforcement activities. Users also may choose to display aerial maps or Google Street View maps. These can help engineers identify problems with the roadway environment or design.

Connecticut's Crash Data Repository is constantly evolving as CTDOT identifies and adds new features. It has become the primary resource for analyzing crash data for a range of users—from law enforcement to the media—and serves to support highway safety grants, the State's annual Highway Safety Plan and its Strategic Highway Safety Plan, new legislation, educational and public awareness programs, and roadway and engineering improvements.

A Roadmap to Project Success

CTDOT implemented its new crash reporting system on January 1, 2015, as planned. The project's success was made possible because of the full commitment of CTDOT management to move forward aggressively, manage interim challenges creatively, offer startup tools and resources, and maintain open communications and accountability.

Despite a lack of authority to mandate that local agencies participate, the project team achieved full voluntary participation of all agencies by creating a culture of inclusiveness and collaboration. The resources and partnership opportunities offered by the project, including financial incentives, technical assistance, training, and tools, won over law enforcement and vendors alike. The toolbox formula combined with a philosophy of agile system development effectively achieved full participation and commitment in a way that a regulatory approach would not have accomplished.

Connecticut's path can serve as a roadmap for other States, which can adapt CTDOT's state-of-the-art tools and training materials to their own needs. All of the tools and materials developed in the project, including software, are available to other States upon request.

Thanks to its success, the project received national recognition. The Association of Transportation Safety Information Professionals gave the project its Best Practices in Traffic Records award in 2015 and the Governors Highway Safety Association recognized it with a Special Achievement Award in 2016. In addition, Harvard University's Kennedy School of Government recognized the CTSRC with its prestigious Innovations in American Government Award for the data sharing capabilities of the repository.

Connecticut now enjoys the distinction of having one of the Nation's most comprehensive and timely crash reporting systems. "By embracing a proactive, partnership-driven, and innovative approach to modernizing our system, we were able to effect serious systemic change in record time," says Wojenski. "I am truly grateful to the multidisciplinary team of professionals that guided the way as well as the law enforcement community and others that stayed with the effort to make it happen. It was truly a collective win for all of us."

Program Accomplishments

- Attained 99.3 percent MMUCC compliance for data collected at crash scenes.
- Achieved full voluntary participation of all local agencies.
- Changed Connecticut's crash reporting culture.
- Produced state-of-the-art training materials that can be adapted by any State.
- Developed cutting-edge tools to facilitate crash reporting.
- Demonstrated a successful DOT/university partnership model for a multidisciplinary project.

Robbin Cabelus is the director of Transportation Planning and Highway Safety for CTDOT. She holds a B.S. in civil engineering from the University of Connecticut.

Mario Damiata served over 40 years as a highway safety specialist with NHTSA with specialties in driver behavior and traffic records management programs. He is currently serving as the roadway safety consultant and "data champion" to CTDOT. He has a B.A. in English from Georgetown University and has done graduate work in Public Policy and Public Administration at American University.

Eric Jackson, Ph.D., is an associate research professor at the University of Connecticut and is the director of the CTSRC. Dr. Jackson earned his B.S. degree in civil engineering from the University of Kentucky and his master's degree and Ph.D. in transportation systems from the University of Connecticut.

Robert Pollack is a transportation specialist with the FHWA's Office of Safety, where he leads a roadway data technical assistance program. He has both bachelor's and master's degrees in psychology from Illinois State University.

For more information, see www.ct.gov/dot/crashinitiative or contact Eric Jackson at 860–486–8426 or eric.d.jackson@uconn.edu.

20 Years of Creative Problem Solving

If you have a challenge, the FHWA Resource Center has a team of experts to help you tackle it.

by Clark Merrefield and Judith Johnson

The FHWA Resource Center can help State and local agencies implement solutions for a wide range of transportation issues. Here, Alaska DOT staff take part in one of the specialized ADA training classes provided by civil rights experts from the Resource Center, Designing Pedestrian Facilities for Accessibility. Class participants were provided with first-hand experience navigating Juneau, AK, streets blindfolded and using canes, to better understand the challenges faced by disabled users.

Today's transportation challenges are complex and rapidly evolving—from deploying vehicle automation technology to combating distracted driving. To address them, the Federal Highway Administration's Resource Center turns to more than 100 experts across 10 teams to deploy new technologies and innovations. The center's work helps to keep roads safer, operating efficiently, and contributing to the Nation's economy. Transportation agencies at all levels of government rely on the Resource Center's creative workforce to help tackle challenges in 18 disciplines such as infrastructure design, realty, finance, and project management.

The Resource Center offers what it calls "just-in-time training and technical assistance." Recognized disciplinary experts train transportation professionals at State departments of transportation, other Federal agencies, metropolitan planning organizations, local public agencies, Tribal governments, highway associations, private industry, and academia. Technical specialists across the Resource Center teams bring new ideas, solve problems, facilitate meetings, mediate disputes, deliver courses, promote innovation, and champion change.

In 2016, the Resource Center trained more than 51,000 customers—28,000 in person and 23,000 virtually—through courses its staff developed and taught, often partnering with the National Highway Institute, an affiliate unit in the FHWA Office of Technical Services.

The Resource Center was founded in 1998 to support and advise FHWA division offices in delivering programs to State departments of transportation, metropolitan planning organizations, and other partners. The center was originally four separate, regional centers, which merged in 2003, making it more efficient. Experts address issues from a corporate perspective and respond to customer needs regardless of location. Over the past two decades, the center has earned the confidence of transportation professionals by making valuable contributions to advancing transportation technologies and solutions.

Keys to Success: Service and Expertise

Patrick Hasson, who has been with the Resource Center since it was founded, remembers the center's early doubters. "It was a big change, this new organization within FHWA," says Hasson, who leads the Resource

Center Safety and Design team. "The Resource Center was far different from anything we had done, and I had many people say I would be out of a job in a year. The big thing that's lived on is the focus on customer service. That has become our culture and it drives a lot of the way we approach things."

Each year, Resource Center team members respond to thousands of service requests from across the country. Transportation professionals looking for knowledge beyond currently available training contact the center's team managers with specific challenges.

"We're here to help deliver programs and solve challenges," says Lisa Randall, Resource Center Freight and Transportation Performance Management team manager. "That divisions and States and localities feel willing to call us—I think shows, more than almost anything, the success of the center."

When the Resource Center receives a request for assistance, technical team managers assemble the right team of experts, collaborate to design solutions based on proven or emerging practices, work with customers to deploy solutions, and provide ongoing technical assistance and training to guarantee long-term success.

"We're knowledge brokers," says Amy Lucero, FHWA's chief technical services officer, who oversees the Office of Technical Services, including the Resource Center. "In many cases, we're the ones transferring expert knowledge to States that have complex projects, and in support of our division offices. We have that hands-on expertise, and you get expert folks throughout the country."

The Resource Center has survived for two decades in part because its experts have worked to build relationships with FHWA division staff and with State and local agencies.

Resource Center specialist Brian Betlyon delivers a transportation performance management (TPM) course on target setting. The TPM, Asset Management, and Freight team serves as FHWA's overall coordination point for all TPM activities, as well as the lead within the Resource Center on cross-cutting TPM topics and requirements.

Resource Center staff are in a unique position to step back and apply deep technical knowledge with a holistic view, explains Grant Zammit, Resource Center Operations team manager. "It's understanding the context of the challenge a client is facing," Zammit says. "It's understanding conflicting challenges, but still trying to figure out how to meet requirements and satisfy external forces. Isolated with those challenges you might choose to take one path, but when you look at the whole, how do you navigate a complex landscape? Those are the solutions we provide."

Contributing to National Successes

Resource Center teams have contributed to numerous initiatives to improve road safety and efficiency, including Every Day Counts (EDC) and the Second Strategic Highway Research Program (SHRP2). Resource Center teams collaborated with the National Fire Academy to conduct workshops on traffic incident management—training first responders. Resource Center teams have also sponsored multiple events, showcases, peer exchanges, and training courses in safety, operations, structures, geotechnical engineering, pavements and materials, construction project management, environment, and other disciplines to advance EDC implementation and SHRP2 products.

Starting in 2010 and then ramping up as part of the first EDC rollout in 2011, Resource Center staff worked with FHWA Headquarters offices to develop a strategic implementation and deployment plan for Safety Edge℠ technology. Safety Edge creates a gradual, 30-degree angled edge on the side of the road that can help vehicles that leave the roadway to return safely. The Resource Center focused its educational outreach on showing State DOT staff and paving contractors how to apply Safety Edge and why it works. Safety Edge is now used for road paving in nearly every State. From 2005 to 2015, FHWA evaluated the effectiveness of Safety Edge and found it is associated with a 34.5-percent reduction in dropoff-related crashes on the 1,321 miles

Kathryn Weisner, a specialist on the Resource Center's Construction and Project Management team, uses a tablet to enter inspection data and photos in a daily report from a bridge construction site in York, PA. The Resource Center offers training and technical assistance across a wide variety of disciplines.

Resource Center Teams and Topics

Expertise Team	How the Resource Center Can Help
Civil Rights	Disadvantaged Business Enterprise; Americans with Disabilities Act/Section 504; Title VI/Nondiscrimination Program; and Contractor Compliance and On-the-Job Training Program
Finance Services	Financial or Project Management Systems; Indirect Cost Allocation Plan; Financial Management Process Review; and Reporting and Data Analysis
Construction and Project Management	Alternative Contract Management; Federal-aid Project Delivery; e-Construction; Program and Project Management; Construction Inspection; Claims Avoidance Techniques and Strategies; and Advanced Data Collection Methods
Environment, Air Quality, and Realty	National Environmental Policy Act; Section 4(f) of the DOT Act; Cultural Resources; Environmental Justice; Endangered Species; Wetlands and Water Resources; and Roadside Vegetation Transportation Conformity; Air Quality Modeling; and Noise Modeling Acquisition; Relocation; and Appraisals
Safety and Design	Intersection Control Evaluation; Roundabouts; Road Safety Audits for Law Enforcement; Performance-Based Practical Design; Local Road Safety Plans; Roadside Safety; Roadside Design; *Highway Safety Manual*; Pedestrian and Bicycle Safety; and Performance-Based Intersection Design and Operations
Geotechnical and Hydraulic Engineering	Structure Foundations; Retaining Structures; Slope Stability; Geology; Ground Modification Methods; Geosynthetics; Earthquake Engineering; Instrumentation; and Asset, Risk, and Performance Management Hydrologic Analysis; Stream Stability Assessment; Hydraulic Modeling of Floodplains, Channels, and Structures; Bridge Scour Analysis; Scour Countermeasure Design; Culvert Design, Inspection, and Rehabilitation; Aquatic Organism Passage Design; and Pavement Drainage Design
Pavement and Materials	Quality Assurance; Profiler and High-Speed Surface Characteristic Certification Site Assessment and Assistance; Infrared and Ground Penetrating Radar; Data Management Quality Plans and Pavement Management; and Pavement Preservation
Operations	Work Zone Program and Project Assessments; Traffic Operations Analysis; *Manual on Uniform Traffic Control Devices* (MUTCD); Cybersecurity for Intelligent Transportation Systems; Engineering, Planning, and Organizing for Operations; Traffic Signal Management and Operations, Performance Evaluation Managed Lane/HOT Lane Project and Program Development; and Automated Vehicle Basics
Structures	Bridge Design, Construction, Inspection, Management, and Preservation: Project, Process, and Program Reviews; Customized Training, such as: Element Level Bridge Inspection, Seismic Analysis and Retrofits, and High Strength Bolting
Transportation Performance Management, Asset Management, and Freight	Asset Management; Scenario Planning/Strategic Visioning; Target Setting; Planning and Project Level Analysis; Travel and Land Use Analysis and Forecasting; Transportation Data; Analytical Tools and Methods; Monitoring and Evaluation; Performance-Based Planning and Programming; Federal Transportation Performance Management Requirements; Freight Planning and Project Development; Truck Size and Weight; Truck Parking; and Freight Performance Management and Freight Operations

(2,126 kilometers) of rural two-lane highways that were studied.

Resource Center teams also have contributed to other high-impact projects. To support the rollout of Jason's Law—named for trucker Jason Rivenburg who was murdered while resting at an abandoned gas station—staff explored supply chain issues that cause truckers to have to stop at odd hours. They then convened working groups and roundtables to find solutions. For example, one potential solution they proposed is a phone app to tell truck drivers if their rig will fit into parking spaces at particular stops.

In addition, the Resource Center mobilized to help with evacuation coordination and routing during hurricanes Harvey, Irma, and Nate in 2017. Resource Center teams stationed in Atlanta, GA, contributed traffic management expertise at the Federal Emergency Management Agency's (FEMA) regional coordination center. They worked with their FHWA division and State DOT counterparts throughout the southern region to assess traffic flow volumes, traveler information systems, and road closure information. The teams provided on-call assistance and staffed emergency support positions at FEMA facilities.

"We are always ready to respond," says National Resource Center Director Bernetta Collins. "If there is a crisis or an unexpected incident, we want to be the first call for assistance. We pride ourselves on having the ability to respond quickly when transportation is affected. We are confident we have the resources and organizational

Safety specialist Craig Allred demonstrates speed monitoring to an employee of the Florida Department of Transportation as part of a road safety audit and assessment.

structure to support such events with the highest level of expertise."

Support at the State Level

Resource Center staff also contribute at the State level. For example, they offered technical expertise to California on intersection control evaluation, which uses quantitative safety analysis to inform intersection design—including alternative intersection types, like roundabouts. In Florida, Resource Center staff are training State troopers to identify road engineering issues. Because law enforcement officers spend the bulk of their time on the road, they can be valuable contributors to identifying and reporting issues.

The FHWA Indiana Division Office and Resource Center teams have worked closely for more than 2 years on several major projects. These include $1.45 billion for nine new interchanges and several overpasses along I–69. For the project, specialists from the Resource Center use safety analyses and simulation modeling to deliver services in planning, air quality, operations, safety, design, environment, and realty. Preliminary engineering has been completed, and construction is expected to begin in the summer of 2019.

In March 2018, Resource Center staff performed training in Juneau, AK, for Alaska DOT staff regarding compliance with the Americans with Disabilities Act. The staff from Alaska DOT rode in wheelchairs, walked blindfolded while using a cane, and used low-vision goggles to get first-hand experience of what it is like for disabled people to navigate Juneau's streets. The exercise showed how design decisions can affect the pedestrian environment and directly impact mobility for people with disabilities. Alaska DOT staff now regularly reference the provided training materials for clarity on best designs for infrastructure such as curb ramps, sidewalks, and pedestrian signals.

Embracing Flexibility, Change, and Innovation

The Resource Center continues to support customer needs, to bring new technologies to the field, and to adapt to a changing transportation environment.

In 2015, the Resource Center's office in Baltimore, MD, began a yearlong pilot allowing technical specialists to work from home. The pilot was successful and cost-effective, and the Resource Center has extended full-time remote work to technical specialists in all office locations. Remote work enables Resource Center experts to bring their far-reaching insights to challenges nearly anywhere, anytime—and represents a sneak peek into how the center may continue to evolve.

"In the next 20 years, I hope the Resource Center is recognized simply as just that—a center for the resources the transportation industry needs," Collins says. "We want to build on our cross-functional, cross-disciplinary approach in all we do. We are addressing challenges with our whole team—environment, structures, safety, and all our other disciplines—so that we are immediately thought of as bringing a holistic approach for any issue."

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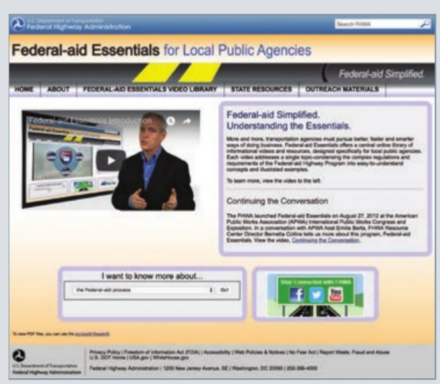
Judith Johnson is the marketing and communications manager for the FHWA Resource Center. She has a B.A. in English from Fisk University and an executive certificate in marketing management from Emory University. She completed graduate studies in journalism at the University of Missouri-Columbia.

For more information, see www.fhwa.dot.gov/resourcecenter or contact Clark Merrefield at clark.merrefield@dot.gov.

Federal-aid Essentials

Do you work at a local public agency? Want to know how to navigate the Federal-aid Highway Program? The FHWA Resource Center created the Federal-aid Essentials website in 2012 for busy local agency staff who want straightforward answers to questions about Federal-aid policies, procedures, and practices. Over time, State agencies have expanded the use of Federal-aid Essentials for employee orientations, refresher courses, and certification training programs. There are videos, State contacts, and outreach materials. Visit www.fhwa.dot.gov/federal-aidessentials.



Boosting Pavement Resilience

by Heather Dylla and Rob Hyman

Design considerations can help mitigate the toll that changing environmental factors like temperature and precipitation may take on infrastructure.

(Right) In Alaska, this shoulder rotation occurred along the Dalton Highway as a result of permafrost thaw.

Temperature can affect pavement performance. Most drivers have driven on roads with blowups, buckling, or rutting of pavements. These pavement distresses may necessitate emergency repairs or require State highway agencies to issue advisories cautioning drivers.

Data from the Federal Highway Administration's Long-Term Pavement Performance program show that 36 percent of the total damage to flexible pavements and 24 percent of the total damage to rigid pavements studied is caused by environmental factors.

Blowups, buckling, and rutting are just a few ways that weather and climate impact pavement structural and functional performance. Pavements are designed based on typical historic climatic conditions, reflecting local temperature ranges and precipitation levels. However, warming trends, changing precipitation patterns, and changes in the frequency and severity of extreme weather events are all projected for the coming decades. As a result, the assumption that historic climatic conditions are a good proxy for future environmental conditions may no longer hold true, threatening pavement performance, road users' safety, and investments in transportation infrastructure.

To mitigate this threat, FHWA has created a methodology to assess the vulnerability of various transportation assets to changing temperatures and precipitation patterns, and identified some best practices to designing pavements for these changing conditions.

Climate Impacts On Pavements

Environmental factors that may impact pavement performance include temperatures, precipitation, and sea-level rise. As a result, many pavement distresses are a function of climate parameters.

Pavement blowups are not the only distress caused by environmental conditions: shoulder rotation, thermal cracking, rutting, shoving, and corrugation are all affected by temperature; corrugation, frost heave, deflection, cracking, and reduced load-bearing capacity are all affected by subsurface moisture; and pumping is affected by precipitation. Many of these distresses (for example, rutting and thermal cracking) are also impacted by other factors such as material properties and traffic.

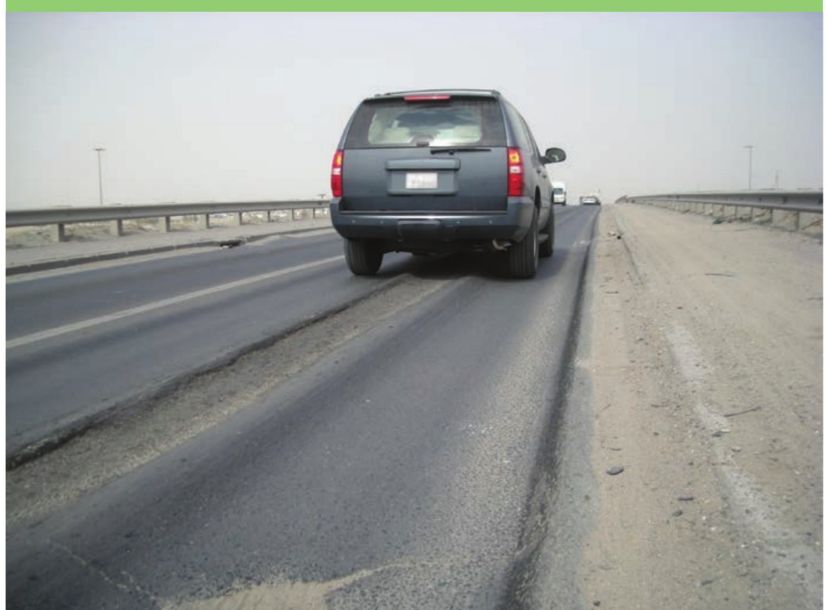
Although engineers often assume stationarity (i.e. that the mean, variance, and other statistical properties of a time series are constant over time) as a matter of practicality, in reality climate-related environmental conditions have never been truly constant. In fact, the Intergovernmental Panel on Climate Change predicts that environmental conditions will change at an increasing rate over the coming decades. While the magnitude and speed of projected change are uncertain, even the most optimistic scenarios project substantial change to temperature, precipitation, and related parameters over the next century.

Some of the future trends most significant to pavement performance include:

- Temperature impacts such as general increase in temperature, higher extreme temperatures, increase in the frequency and duration of extreme temperatures, and fewer freezing days.
- Precipitation impacts such as changes in average annual precipitation, with some regions seeing more precipitation while others see less, generally wetter winters and drier summers, and increased precipitation intensity.
- Sea-level rise including flooding and rising ground water, and saltwater encroachment.

Climate parameters have other impacts on pavement performance such as pavement safety and load carrying limits. For example, many

The photograph is an example of a concrete blowup near the joint of a rigid pavement. Pieces of the concrete are missing along the joint. *Photo: Archie Miller, Manitoba Infrastructure.*



Here, a vehicle travels on a flexible pavement that has severe rutting in the asphalt pavement. The pavement is located in a desert climate outside of the United States, but clearly demonstrates deformation.

Examples of Temperature-Affected Components

Climate Change Impact	Affected Components and Strategies
Higher Average Temperatures	**Flexible Pavement** • Increased maximum pavement temperature increases the potential for rutting and shoving, requiring more rut-resistant asphalt mixtures —May require raising high-temperature asphalt binder grade and/or increasing the use of binder polymerization and/or improved aggregate structure in asphalt mixes —Increased use of rut-resistant designs including thin, rut-resistant surfaces • Increased age hardening of asphalt binder —Use binders that age more slowly —Expanded use of asphalt pavement preservation techniques to address binder aging **Rigid Pavement** • Increased potential for concrete temperature-related curling (and associated stresses) and moisture warping —Greater consideration of concrete coefficient of thermal expansion and drying shrinkage —Incorporation of design elements to reduce damage from thermal effects including shorter joint spacing, thicker slabs, less rigid support, and enhanced load transfer
Higher Extreme Maximum Temperature	In addition to strategies listed above: • Higher extreme temperature may impact construction scheduling, requiring work to more often be conducted at night • If accompanied by drought, increased potential for subgrade shrinkage **Flexible Pavement** • Increased potential for asphalt rutting and shoving during extreme heat waves —See strategies above, but recognizing that the historical basis for selecting binder grades may no longer be valid **Rigid Pavement** • Increased risk of concrete pavement blowups due to excessive slab expansion —Use shorter joint spacing in new design —Keep joints clean and in extreme cases, install expansion joints in existing pavements

States that have long, cold winters take advantage of the additional strength of pavements under frozen conditions by increasing the allowable axle load limits during wintertime pavement subgrade hardening. Then, during the spring thaw period when the pavement structure and subgrade (as well as the layer interfaces) may be subjected to significant amounts of melt water, which greatly weakens the load capacity of the pavements, the States put vehicle weight limits into place. Earlier spring melt will likely reduce the period of these winter weight premiums.

A case study by FHWA found that the Maine Department of Transportation's seasonal policies for truckload restrictions may be vulnerable to anticipated warming trends. Over the coming decades, shorter freezing seasons will lead to shorter seasons for the winter weight premium, and smaller premiums as well. This may have a significant economic impact on the trucking industry in Maine, requiring either pavement strengthening measures across the network of trucking routes or replanning the freight networks.

Current Pavement Design Methods

When designing pavements—whether it is the mixture design or the structural design—pavement design and material engineers must consider traffic loads, subgrade properties, and environmental conditions. For example, in asphalt mix designs, Superpave® (SUperior PERforming Asphalt PAVEments) asphalt binder performance grades are based on expected pavement temperature extremes, while the freeze-thaw cycles are important for specifying minimum entrained air content for concrete mix designs. Further, in pavement design key environmental parameters include temperature, moisture, and frost actions. The *Mechanistic-Empirical Pavement Design Guide* (MEPDG) requires five weather-related parameters for the entire design life: (1) hourly air temperature, (2) hourly precipitation, (3) hourly wind speed, (4) hourly percentage of sunshine, and (5) hourly relative humidity.

Unlike the treatment of traffic conditions, which considers future traffic loads in the design of pavements, these environmental conditions are assumed stationary and are based on historical climate data. Because of this assumption, pavements constructed today may not be realistic for future climate conditions in some cases. As a result, future pavement performance may be vulnerable to distresses ranging from thermal cracking to weakening from frost heave and thaw.

"Including climate change considerations is an important aspect for DelDOT's [Delaware Department of Transportation] long-term planning, design, construction, and maintenance of the State's critically important infrastructure," says Jim Pappas, P.E., deputy director of Transportation Solutions at DelDOT. "To ensure we can be as knowledgeable as possible, the department is investing significant resources into understanding these impacts and working closely with other interested stakeholders across the State, region, and country to increase the knowledge base and adapt and implement best practices as changes occur."

Designing for Changing Conditions

Because current pavement design and analysis tools such as the MEPDG generally use historical climate data sources, a number of new steps are required in the design process to use these tools with future climate parameters. First, practitioners need to make decisions on which and how many future climate scenarios to use to adequately bracket the range of potential futures. Then, practitioners need to translate temperature and precipitation projections into

Examples of Precipitation-Affected Components

Climate Change Impact	Affected Components and Strategies
More Extreme Rainfall Events	• Increased need for surface friction meaning potentially more focus on surface texture and maintaining adequate skid resistance —Maintain positive cross slope to facilitate flow of water from surface —Increase resistance to rutting —Reduce splashing/spray through porous surface mixtures • Increased need for surface drainage to prevent flooding —Increase ditch and culvert capacity —More frequent use of elevated pavement section • Increased need for functioning subdrainage —Ensure adequacy of design, installation, and maintenance of subdrainage • Need to improve visibility and pavement marking demarcation • High levels of precipitation may threaten embankment stability • Reduction in structural capacity of unbound bases and subgrade when pavements are submerged —Develop a better understanding of how submergence affects pavement layer structural capacity and strategies to address it
Higher Average Annual Precipitation	• Reduction in pavement structural capacity due to increased levels of saturation —Reduce moisture susceptibility of unbound base/subgrade materials through stabilization —Ensure resistance to moisture susceptibility of asphalt mixes • Improved surface and subsurface pavement drainage —Use strategies mentioned previously • Will likely negatively impact construction scheduling —Investigate construction processes that are less susceptible to weather-related delays

project-level parameters, such as the pavement temperatures and moisture conditions, using downscaled global climate model results (which are available online, for example, at https://gdo-dcp.ucllnl.org/downscaled_cmip_projections/dcpInterface.html and www.narccap.ucar.edu).

The empirical models used to predict pavement performance (such as ride quality, rutting, fatigue cracking, slab cracking, faulting, and punchouts) also need to be calibrated to reflect how pavement designs and materials interact in a changing environment. Sometimes the data required and data available are mismatched. For instance, the American Association of State Highway and Transportation Officials' AASHTOWare Pavement ME Design methodology requires hourly records of five climate inputs: (1) temperature, (2) precipitation, (3) wind speed, (4) cloud cover or percent sunshine, and (5) relative humidity. However, future climate models are not designed to provide hourly records at acceptable levels of data accuracy. Often, only daily results are available.

In addition to structural design, practitioners may need to make improvements to the foundation to ensure the pavements are more resistant to flooded conditions as well as extreme weather events.

Climate Projections In Texas

Although climate model projections are not "plug and play" with current pavement design and analysis tools, practitioners can develop workarounds frequently. For example, FHWA partnered with the Texas Department of Transportation (TxDOT) to study how to incorporate future climate into possible pavement designs for the proposed State Highway 170 (SH–170). Because SH–170 has not yet been fully designed and built, the study of these items provides an opportunity to help influence the eventual design. The study evaluated the potential impacts of projected temperature and precipitation changes on pavement performance. FHWA obtained climate projections from the U.S. Bureau of Reclamation, which provided peer-reviewed, statistically downscaled data of the World Climate Research Programme's Coupled Model Intercomparison Project (CMIP) Phase 5. Over a 50-year analysis period, the climate projections indicated a steady increase in ambient temperature and, possibly, aridity. These changes in turn impact secondary climate variables such as relative humidity and soil moisture, and consequently could affect the performance of pavement materials and subgrade.

To study the impact of the projected temperatures and precipitation on the pavement, FHWA considered both flexible and rigid pavement designs. The future climatic conditions were used in MEPDG and other performance models to analyze the impact on the pavement performance. For example, the researchers used simplified versions of the AASHTOWare Pavement ME Design analytical models to determine the percent change in design parameters for crack width, crack spacing, and punchouts for continuously reinforced concrete pavement. For these analyses, relative humidity is a critical value needed. However, this information is not readily available from climate models, so FHWA used empirical models relating temperature and humidity at the site to develop estimates of future relative humidity based on temperature projections.

The results of the study showed both beneficial and detrimental effects on the performance of both the flexible and rigid pavement design options. The decreased precipitation increases the subgrade support and reduces the soil shrink-swell cycles, improving the pavement smoothness. However, the increased temperature increases the potential for cracking and rutting, reducing the overall pavement performance.

To address these challenges, FHWA researchers identified potential adaptation strategies: use a stiffer binder in the case of flexible pavement design and use additional steel for rigid pavement design. TxDOT has not started design and construction of the pavements; however, if it incorporates these recommendations into its design it could implement the adaptation measures gradually. The recommended materials are widely available, reasonable in cost, and already in use in some places.

Key Pavement Indicators to Monitor

Asphalt Pavement Indicators	Concrete Pavement Indicators
Rutting of asphalt surface	Blowups (JPCP)
Low temperature (transverse) cracking	Slab cracking
Block cracking	Punchouts (CRCP)
Raveling	Joint spalling
Fatigue cracking and pot holes	Freeze-thaw durability
Rutting of subgrade and unbound base	Faulting, pumping, and corner breaks
Stripping	Slab warping punchouts (CRCP)

Note: JPCP = jointed plain concrete pavement, CRCP = continuously reinforced concrete pavement.

Because the adaptation measures do not require complex redesign or development of engineering innovations, TxDOT can avoid significant obstacles (such as a learning curve for a new technology) and the recommendations may prove economically beneficial over a longer term. Adaptation measures also may be appropriate on a larger scale because all roadways in the area may be exposed to the same climate factors.

Monitor Pavement Performance and Trends

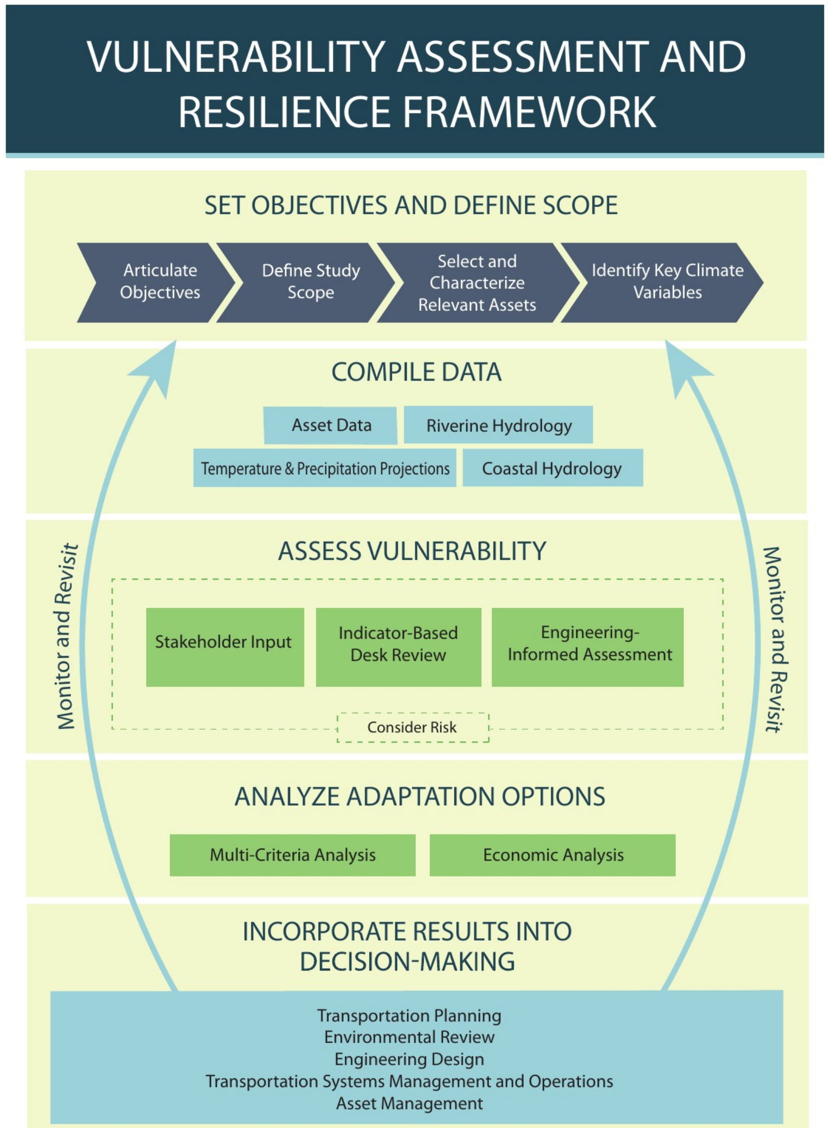
Most predicted changes to environmental variables are projected to occur relatively slowly in relation to a typical pavement life cycle—think changes on the scale of decades—allowing agencies to monitor trends and implement adjustments to their practices when appropriate. Pavement designers can compare current weather and climate values used in design to projected values over the life cycle of the existing or proposed pavement. Where these values differ significantly, the engineers can consider ways to update the climate-related design inputs with data reflecting future climate projections.

In some cases where trends are slow enough or pavement rehabilitation cycles quick enough, a simpler approach is to ensure that the historical data used in analyses are up to date (including data from the past decade). Similarly, another approach is to monitor key pavement performance parameters to see if they are exhibiting trends that suggest the need for revised practices. These indicators can help agencies understand if and when to modify current design and maintenance practices.

In cases where the trends differ, agencies should consider taking the next step of evaluating the vulnerability of their pavement network to future climate impacts by conducting an analysis of the network or specific projects.

Assess Vulnerability Of Pavement

State agencies can evaluate where weaknesses exist in the transportation system to improve pavement performance, optimize funding, and increase the health and longevity



FHWA's *Vulnerability Assessment and Adaptation Framework* provides guidance for transportation agencies to conduct their own assessments. *Source: FHWA.*

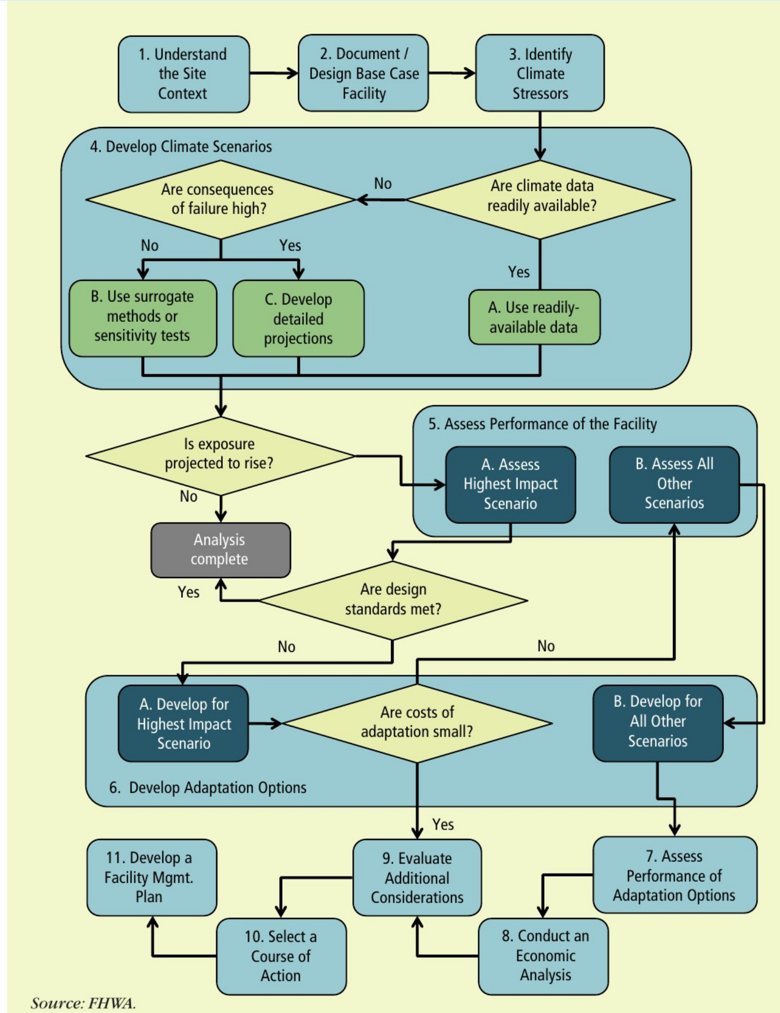
of the Nation's highways. FHWA has developed several tools to help with this type of assessment.

A starting point is FHWA's *Vulnerability Assessment and Adaptation Framework* (FHWA-HEP-18-020), a guide to analyzing the impacts of extreme weather and changing environmental conditions on transportation infrastructure. The framework aids agencies by providing a structured process for conducting an assessment and identifying key considerations, questions, examples, and resources for the major tasks involved. The framework is available at www.fhwa.dot.gov/environment/sustainability/resilience/adaptation_framework/index.cfm.

Transportation engineers often are unfamiliar with sources of climate data projections. To provide easy access to download and synthesize the types of data used in the case studies described previously, FHWA developed the CMIP Climate Data Processing Tool. This large Microsoft® Excel®-based tool processes raw climate projection data, downloaded from a U.S. Bureau of Reclamation data portal website. The tool's outputs are projected temperature and precipitation changes in a local area. The tool provides a relatively quick and easy way for users to determine the potential magnitude of future changes in their area. The tool is available at www.fhwa.dot.gov/environment/sustainability/resilience/tools.

Finally, the Vulnerability Assessment Scoring Tool enables users to design and structure an indicator-based vulnerability assessment. Users must input local asset data and then the tool provides a flexible framework for creating a relative vulnerability score for each asset evaluated, enabling a structured prioritization of potential vulnerabilities. This tool is available at www.fhwa.dot.gov/environment/sustainability/resilience/tools.

DECISION TREE OF THE ADAP STEPS



Source: FHWA.

More Resilient Pavement Design Strategies

As aging infrastructure is rebuilt or upgraded, opportunities exist for State highway agencies to plan and design infrastructure to meet future environmental conditions. FHWA's Adaptation Decision-Making Assessment Process (ADAP) is a risk-based approach for planners, designers, or engineers to account for the increasing role of future climate impacts in transportation projects, focused on the project or engineering level. The process aids decisionmakers in determining which project alternative makes the most sense in terms of life-cycle cost, resilience, regulatory, and political settings. The framework lays out specific steps, but some situations may warrant adjustments within the general confines of the framework. The process can be tailored to meet an agency's specific requirements. In addition to being used for designing more resilient infrastructure projects, planners, designers, and engineers can use the ADAP to assess existing assets' sensitivity to projected climate trends.

Not all steps of the ADAP are required in all situations. The process is designed to be flexible to minimize the level of effort needed in the analysis where the consequences of asset failure are low or the cost of adapting to future climate trends is relatively small.

Adaptation strategies depend on pavement type and the project climate parameters. Core adaptation strategies for pavements to compensate for potential increases in pavement distress as a result of higher temperatures or changing precipitation patterns may include:

- Adjusting the pavement binder and mix design specifications to better match expected future environmental conditions.

Sources for More Information

Impact of Environmental Factors on Pavement Performance in the Absence of Heavy Loads (FHWA-HRT-16-078)
www.fhwa.dot.gov/publications/research/infrastructure/pavements/ltpp/16078/16078.pdf

Climate Change Adaptation for Pavements (FHWA-HIF-15-015)
www.fhwa.dot.gov/pavement/sustainability/hif15015.pdf

Vulnerability Assessment and Adaptation Framework, Third Edition (FHWA-HEP-18-020)
www.fhwa.dot.gov/environment/sustainability/resilience/adaptation_framework

Adaptation Decision-Making Assessment Process (ADAP) (FHWA-HEP-17-004)
www.fhwa.dot.gov/environment/sustainability/resilience/ongoing_and_current_research/teacr/adap

Synthesis of Approaches for Addressing Resilience in Project Development (FHWA-HEP-17-082)
www.fhwa.dot.gov/environment/sustainability/resilience/ongoing_and_current_research/teacr/synthesis

For example, by moving to a stiffer asphalt grade suited to higher temperatures.

- Adjusting the pavement structural design. For example, for concrete pavements, robust designs that limit moisture damage and shrinkage are a good alternative. Stabilized subbases and base materials may be a good alternative to unbound bases especially in areas where the ground water table may rise or precipitation is increasing.

Often, because of the long timeframes of these future trends and the uncertainty in the exact magnitude of future changes, phased adaptation options provide a useful way to address potential changes without incurring unnecessary upfront costs. For instance, one strategy for asphalt pavements is to design a thick asphalt layer with multiple layers of varying levels of stiffness (also known as a perpetual pavement). The surface layer, which is most severely impacted by temperature, can easily be rehabilitated when needed through micromilling and replaced with a new surface layer to accommodate changes resulting from climate impacts over time.

The Iowa Department of Transportation uses perpetual pavements as an overall strategy to reduce life-cycle cost and increase system sustainability. In situ testing on the agency's most recent project on Iowa Highway 100 in Linn County has shown minimum strain levels and can be expected to yield nearly infinite fatigue life of the lower layers. The agency should be able to respond to surface distresses caused by environmental factors during future rehabilitation efforts. The project recently won the Perpetual Pavement Award from the Asphalt Pavement Alliance and the pavement is performing well.

In many cases, adaptation options will increase project costs by a relatively small amount. For example, the Texas and Maine case studies discussed in this article found project cost increases ranging from 2 to 13 percent over the next three decades. Although a 2 percent project cost increase may seem minimal with regard to the total project funds, for network level strategies, implementation of these strategies cost increases may be a significant financial concern.

Closing the Gaps

Current approaches to improving pavement's resilience to future climate and weather conditions have many gaps including developments to improve pavement foundation designs to withstand flooding and other changes.

Pavement design models and national temperature-based design maps need to be updated with information that is available from existing climate models. For instance, the engineering tools used to aid in the selection of asphalt binder grade, such as the Long-Term Pavement Performance Bind (LTPPBind) 3.1 software, use nationwide mapping of design temperatures based on historical weather data. FHWA recently improved the data in this tool by incorporating the National Aeronautics and Space Administration's Modern-Era Retrospective Analysis for Research and Applications (MERRA) data for a more complete historical climate dataset. FHWA presented the data findings and advantages to AASHTO and AASHTO plans to incorporate the MERRA data into the AASHTOWare PavementME design software tool. Further incorporating future climate parameters into the data and design methodologies would provide practitioners with the flexibility to work with a range of possibilities using both historical and forecasted data.

Nonetheless, the approaches available today can help agencies monitor trends in climate-related pavement performance, assess vulnerability to present and future changes in environmental conditions, and design more resilient pavements. Together, these strategies can help to reduce long-term costs by ensuring the resilience and durability of the Nation's pavements.

"Preparing for the future climate and incorporating designs or treatments now that are more resilient is an important way to preserve the state of good repair of the transportation system," says Carol Lee Roalkvam, environmental policy branch manager with the Washington State Department of Transportation's Environmental Services Office. "Agencies can take steps now to be better prepared for future climate conditions."

Heather Dylla, Ph.D., is a sustainable pavement engineer on FHWA's Pavement Materials Design and Performance Team. Dylla holds a doctorate and a master's degree in engineering science from Louisiana State University and B.S. in civil engineering from Bradley University.

Rob Hyman is an environmental protection specialist on FHWA's Sustainable Transportation and Resilience Team. Hyman holds master's degrees in civil and environmental engineering and also in technology and policy from the Massachusetts Institute of Technology and a bachelor's degree in earth and planetary sciences from Harvard University.

For more information, contact Heather Dylla at heather.dylla@dot.gov, or Rob Hyman at robert.hyman@dot.gov.

Along the Road

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

Public Information and Information Exchange

FHWA Updates Transportation Planning Resource

FHWA's Transportation Planning Capacity Building Program has updated *The Transportation Planning Process Briefing Book: Key Issues for Transportation Decisionmakers, Officials, and Staff* (FHWA-HEP-18-005). The briefing book provides an overview of transportation planning for government officials, decisionmakers, planning board members, transportation service providers, interested stakeholders, and the public. The updated publication replaces the 2015 version of the same name and reflects recent changes in Federal legislation concerning transportation at the metropolitan, State, and nongovernmental levels.

Effective transportation planning affects environmental resource consumption, social equity, land use, economic development, safety, and security. The report covers the basics and key concepts of metropolitan and statewide transportation planning, along with references for additional information. Part I provides a broad introduction to the planning process while discussing transportation planning and its relationship to decisionmaking. Part II presents short descriptions of key products of the transportation planning process.

The publication, along with a collection of related resources, is available electronically.

For more information, visit www.planning.dot.gov.

Supporting Active Transportation for National Parks and Partners

Traveling to or exploring national parks by foot, bicycle, or other nonmotorized mode provides visitors with opportunities to experience natural, cultural, and historical places in new ways. The National Park Service (NPS) recently published a new resource, the *NPS Active Transportation Guidebook*, which aims to assist and inspire parks and their partners to identify and pursue opportunities that enhance active transportation to and within national parks.

Infrastructure and programs to support active transportation modes offer a broad range of benefits to parks and surrounding communities, including helping to better manage vehicle congestion, promoting resource preservation, supporting economic development in gateway communities, and accommodating current and increased visitation by providing alternatives to driving.

The NPS developed the guidebook with technical support from the USDOT's Volpe National Transportation Systems Center, and in collaboration with FHWA and bicycle and pedestrian professionals, transportation

Volpe Center

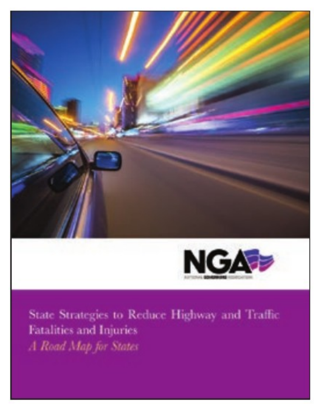
Bicyclists traverse the Natchez Trace Parkway, part of the National Park Service, which extends 444 miles (715 kilometers) from Mississippi to Tennessee.

experts, park staff, and other partners. The guidebook covers a number of topics and strategies to support walking and biking in national parks and surrounding communities, from planning and deploying infrastructure such as pedestrian pathways and bike lanes, to evaluating and improving safety for active transportation modes, to offering activities and programs that provide park visitors the opportunity to bike or walk.

While the guidebook is geared toward national parks and their partners, the information, examples, and resources presented may also help representatives at State and local agencies and other organizations think creatively about expanding active transportation in their communities.

For more information, visit www.nps.gov/subjects/transportation/bikeped.htm.

NGA Issues Road Map for Curbing Crashes



In 2016, 39 States reported an increase in traffic fatalities. Nationwide, there were 37,461 traffic-related deaths, the highest number since 2008 and a 5.6-percent increase from 2015. Crashes in 2016 resulted in an estimated 4.6 million injuries and economic losses of more than $430 billion.

In early 2018, the National Governors Association (NGA) released a report with strategies aimed at trying to help States curb roadway crashes, deaths, and injuries. The report emphasizes the need for States to improve how they address safety issues across various agencies that build roads, police the highways, and respond to crashes.

State Strategies to Reduce Highway and Traffic Fatalities and Injuries: A Road Map for States highlights steps governors can take to improve coordination

and strengthen existing efforts across State agencies, for example, in areas ranging from automated speed enforcement in school and work zones to post-crash emergency response.

NGA developed the road map through research and consultation with senior State officials and other national experts and partners, including the Governors Highway Safety Association and the National Safety Council, and with the support of the Centers for Disease Control and Prevention. The report helps States identify and implement proven countermeasures to reduce crashes and injuries. The report notes that States face challenges in reducing traffic fatalities and injuries as well as identifying the causes of nonfatal injuries. "To address these challenges," the report says, "States must coordinate State highway safety planning; enforce State policies and laws on traffic safety; and pursue cost-effective, evidence-based, data-driven safety interventions."

For more information, visit www.nga.org/center/publications/state-strategies-to-reduce-highway-and-traffic-fatalities-and-injuries-a-road-map-for-states.

National Governors Association

USDOT Runs Safety Campaign for Railroad Crossings

In early 2018, the Federal Railroad Administration and the National Highway Traffic Safety Administration ran a national railroad grade crossing safety campaign, "Stop. Trains Can't." The campaign was part of USDOT's ongoing effort to increase public awareness around railroad tracks and reduce crossing deaths and injuries. Campaign tactics included Web banner advertisements, radio spots, and infographics, as well as sample social media posts and press releases.

The campaign, which ran for 5 weeks from February 26 to April 1, 2018, is the latest in a 3-year focused effort to reverse the uptick in railroad crossing fatalities. Although overall rail incidents have been on the decline for the past 10 years, railroad-crossing fatalities have spiked in recent years. In 2016 alone, 266 people died at railroad crossings, a 16-percent increase from 2015.

Railroad crossing incidents and fatalities are a long-standing problem, but they are easily avoidable. Trains cannot swerve, stop quickly, or change direction to avert collisions, so motorists must be prepared to stop at crossings and proceed cautiously. It can take a freight train traveling 55 miles (89 kilometers) per hour about the length of 18 football fields to come to a complete stop after emergency brakes are applied. In addition, by law, trains have the right of way.

For more information on the "Stop. Trains Can't." campaign, visit www.transportation.gov/stop-trains-cant. For safety tips for motorists and pedestrians at railroad crossings with and without warning signals, visit www.fra.dot.gov/Page/P0843.

Creating Inclusive Safe Routes to School

Students with disabilities are a key group to include when developing and implementing a Safe Routes to School program. On average, one out of every seven students has some type of disability.

To help schools plan and develop a program that considers and meets the needs of students with disabilities, the Safe Routes to School National Partnership released *Engaging Students with Disabilities in Safe Routes to School*. The publication describes the benefits of Safe Routes to School for students with disabilities, strategies for including students with disabilities, important components of inclusive Safe Routes to School programming, considerations for students with different kinds of disabilities, and ways to partner and build resources.

In Eugene, OR, the city's recreation program provides a variety of adapted bikes to school districts for bike education programs that include students of all abilities.

Safe Routes to School National Partnership

Students with disabilities can benefit greatly from Safe Routes to School programs, which provide invaluable tools that support healthy lifestyles, bolster physical activity, and promote independence. Developing a program that is welcoming for students with disabilities broadens a program's reach, ensures all students can receive the benefits of the program, and enables students with and without disabilities to enjoy each other's company and learn safe and healthy habits together.

For more information, visit www.saferoutespartnership.org/resources/fact-sheet/engaging-students-disabilities-safe-routes.

Safe Routes to School National Partnership

United States Postal Service Statement of Ownership, Management, and Circulation

1. Publication Title: PUBLIC ROADS
2. Publication Number: 0033-3735
3. Filing Date: September 5, 2018
4. Issue Frequency: Quarterly
5. Number of Issues Published Annually: Four
6. Annual Subscription Price: $21.00 (Domestic), $29.40 (Foreign)
7. Complete mailing address of known office of publication: Federal Highway Administration, 6300 Georgetown Pike, Room F–204, McLean, VA 22101
8. Complete mailing address of headquarters or general business office of publisher: Federal Highway Administration, 1200 New Jersey Avenue, SE, Washington, DC 20590
9. Full names and complete mailing addresses of publisher, editor, and managing editor:
   Publisher: Federal Highway Administration, 1200 New Jersey Avenue, SE, Washington, DC 20590
   Editor: Alicia Sindlinger, ICF, 9300 Lee Highway, Fairfax, VA 22031
   Managing Editor: Allison Simmons-Jacobi, Arch Street Communications, 31 Mamaroneck Avenue, White Plains, NY 10601
10. Owner: U.S. Department of Transportation, 1200 New Jersey Avenue, SE, Washington, DC 20590
11. Known bondholders, mortgagees, and other security holders owning or holding 1 percent or more of total amount of bonds, mortgages, or other securities: N/A U.S. Government Publication
12. Tax Status: Has not changed during preceding 12 months
13. Publication Title: PUBLIC ROADS
14. Issue Date for Circulation Data Below: Summer 2018
15. Extent and Nature of Circulation
    A. Total Number of Copies (Net press run):
       Average no. copies each issue during preceding 12 months: 5,000
       No. copies of single issue published nearest to filing date: 5,000
    B. Paid Circulation (By Mail and Outside the Mail)
       (1) Mailed Outside-County Paid Subscriptions Stated on PS Form 3541 (Include paid distribution above nominal rate, advertiser's proof copies, and exchange copies)
       Average no. copies each issue during preceding 12 months: 1,413
       No. copies of single issue published nearest to filing date: 237
       (2) Mailed In-County Paid Subscriptions Stated on PS Form 3541 (Include paid distribution above nominal rate, advertiser's proof copies, and exchange copies)
       Average no. copies each issue during preceding 12 months: 1
       No. copies of single issue published nearest to filing date: 0
       (3) Paid Distribution Outside the Mails Including Sales Through Dealers and Carriers, Street Vendors, Counter Sales, and Other Paid Distribution Outside USPS®
       Average no. copies each issue during preceding 12 months: 2,877
       No. copies of single issue published nearest to filing date: 4,763
       (4) Paid Distribution by Other Classes of Mail Through the USPS (e.g., First-Class Mail®)
       Average no. copies each issue during preceding 12 months: 108
       No. copies of single issue published nearest to filing date: 0
    C. Total Paid Distribution:
       Average no. copies each issue during preceding 12 months: 4,400
       No. copies of single issue published nearest to filing date: 5,000
    D. Free or Nominal Rate Distribution (By Mail and Outside the Mail):
       (1) Free or Nominal Rate Outside-County Copies Included on PS Form 3541
       Average no. copies each issue during preceding 12 months: 0
       No. copies of single issue published nearest to filing date: 0
       (2) Free or Nominal Rate In-County Copies Included on PS Form 3541
       Average no. copies each issue during preceding 12 months: 0
       No. copies of single issue published nearest to filing date: 0
       (3) Free or Nominal Rate Copies Mailed at Other Classes Through the USPS (e.g., First-Class Mail)
       Average no. copies each issue during preceding 12 months: 0
       No. copies of single issue published nearest to filing date: 0
       (4) Free or Nominal Rate Distribution Outside the Mail (Carriers or other means)
       Average no. copies each issue during preceding 12 months: 0
       No. copies of single issue published nearest to filing date: 0
    E. Total Free or Nominal Rate Distribution:
       Average no. copies each issue during preceding 12 months: 0
       No. copies of single issue published nearest to filing date: 0
    F. Total Distribution:
       Average no. copies each issue during preceding 12 months: 4,400
       No. copies of single issue published nearest to filing date: 5,000
    G. Copies Not Distributed:
       Average no. copies each issue during preceding 12 months: 0
       No. copies of single issue published nearest to filing date: 0
    H. Total:
       Average no. copies each issue during preceding 12 months: 4,400
       No. copies of single issue published nearest to filing date: 5,000
    I. Percent Paid:
       Average no. copies each issue during preceding 12 months: 100
       No. copies of single issue published nearest to filing date: 100
16. Total circulation includes electronic copies. Report circulation on PS Form 3526-X worksheet: N/A
17. Publication of Statement of Ownership: Will be printed in the Autumn 2018 issue of this publication.
18. Signature and Title of Editor, Publisher, Business Manager, or Owner:

I certify that all information furnished on this form is true and complete. I understand that anyone who furnishes false or misleading information on this form or who omits material or information requested on the form may be subject to criminal sanctions (including fines and imprisonment) and/or civil sanctions (including civil penalties).

Maria Romstedt, Editor-in-Chief September 5, 2018

Internet Watch

by Jim Hunt

Selecting the Right Tools To Optimize Planning

Transportation planners have a challenging job. They must balance competing priorities and needs against an anticipated but not necessarily known future. Planners must answer complex questions: Will congestion decrease if we invest in a particular strategy? How might travel patterns change and where will we see the worst congestion in the future?

The use of analysis tools in planning for operations helps answer questions like these. Planning for operations is a joint effort between transportation planners and operators to integrate transportation systems management and operations strategies into the planning process to improve system safety, efficiency, and reliability. A fundamental aspect of achieving this goal is using the right analysis tools and methodologies.

To help, the Federal Highway Administration's Traffic Analysis Tools Program offers a series of online resources to facilitate the deployment and use of existing tools and to support the development of new, improved tools. The resources include almost 20 publications, links to training and workshops available through the National Highway Institute, overviews of a variety of types of tools, and videos from four local agencies in New Mexico, Minnesota, and Texas about using analysis tools to support transportation planning and decisionmaking. These resources are available on the Traffic Analysis Tools website at https://ops.fhwa.dot.gov/trafficanalysistools/index.htm.

Analysis Tools to Support Operations Planning

No single analytical tool can solve every problem. Using an overly sophisticated tool may result in poor use of resources, and using a tool that is too basic may produce insufficient results. Analysis tools fall into the following five general categories:

Archived operations data are used for documenting baseline operational conditions, monitoring and evaluating system performance, and identifying and reporting performance issues and needs.

Regional travel demand models are widely used for estimating changes in mode choice and traffic patterns or volumes resulting from changes in development levels, demographics, and the transportation system itself.

Sketch planning tools provide quick order of magnitude estimates with minimal input data in support of preliminary screening assessments. They are most useful early in the planning process, while planners are still screening potential strategies.

Analytic/deterministic methods help planners analyze the performance of isolated or small-scale transportation facilities and the impacts of strategies under various demand conditions. They enable planners to predict capacity, density, speed, delay, and queuing on transportation facilities.

Simulation tools use a variety of formulas and algorithms to simulate travel behavior. They help evaluate a range of improvements and strategies at isolated locations, in corridors, or areawide.

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FHWA's Traffic Analysis Tools Program provides resources to help transportation planners select the right analysis tools for projects to improve system safety, efficiency, and reliability.

Methods for Operations Assessments

Industry vendors and FHWA-supported research have led to the development of a number of new methods to better assess the changeable nature of transportation operations.

Activity-based models typically focus on individual person-trips, representing how individuals travel throughout the entire day. They offer higher accuracy on travel patterns and provide detailed performance measures.

Dynamic traffic assignment methods are emerging as a practical tool for numerous planning and operations applications, including simulating the impact of incidents, evaluating operational strategies that may shift traffic patterns, and estimating travel behavior from various demand changes and interactions.

Multi-scenario methods enable planners to assess impacts under varying conditions, including nontypical days (nonrecurring events). Tools of this type can help planners refine project scope or design to optimize benefits.

Visualization methods help planners present transportation performance data and information in a visual format, such as annotated maps, graphs, photos, illustrations, and videos. These methods are most useful in communicating transportation needs to leaders who prioritize budgets and to the public.

Finding the Keys to Success

Matching the methods or tools to planning objectives, budget, and resource requirements is essential to project success. FHWA's Traffic Analysis Tools website can help transportation planning and operations professionals select the right options.

Analysis tools are important components in linking planning and operations, and in promoting the optimal performance of the transportation system through operational strategies. Linking the two fields using appropriate tools, methods, and performance measures can answer transportation planners' questions and help them convey understandable information to decisionmakers, stakeholders, and the public.

For more information, contact John Halkias at john.halkias@dot.gov or 202-366-2183.

Jim Hunt, P.E., is a transportation operations program manager on the Organizing and Planning for Operations team of the FHWA Office of Operations.

NATIONAL HIGHWAY INSTITUTE

Training Update

by Marisa Beck

Guidance for Changing Federal-Aid Regulations

The planning and finance staff of State departments of transportation and metropolitan planning organizations face myriad regulations and requirements for expending and administering Federal-aid planning funds. Indepth knowledge of these regulations is vital to ensuring sound administration and management of funds.

The establishment of uniform administrative requirements for Federal awards and enactment of new legislation and regulations under the Moving Ahead for Progress in the 21st Century (MAP-21) and the Fixing America's Surface Transportation Acts introduced changes to the requirements for administering and managing Federal Highway Administration planning and research grants. To help familiarize transportation professionals with the details of these requirements, the National Highway Institute (NHI) has updated its Web-based training series on FHWA Planning and Research Grants with three introductory-level courses.

Planning and Research Program Administration

NHI's three-part series provides a comprehensive overview of the management of FHWA planning grants, including key concepts and terminology. The first of the three courses, FHWA Planning and Research Grants: Program Administration (23 CFR Part 420) (course number 151057), introduces participants to the series and focuses on program administration. Learners gain familiarity with terms and general concepts around grants. They also learn the requirements of 23 CFR Part 420—the regulation that implements the Federal-aid highway planning program outlined in Title 23 and contains the specific FHWA grant policies and procedures.

This Web-based training uses an interactive format. On every screen that discusses a regulation, users can click directly on a link to visit the full text of the regulation in question. The interface also features an interactive glossary where users can review the definitions of unfamiliar terms.

The Uniform Guidance

The second and third courses in the series dive into the requirements of 2 CFR Part 200, Uniform Guidance. The second course, FHWA Planning and Research Grants: The Uniform Guidance (2 CFR Part 200) – Part 1 (course number 151058), begins with a brief history of the Uniform Guidance and addresses the responsibilities of the States and the flow of requirements to State and local governments. It finishes with detailed reviews of subparts A through D of the regulation, which cover definitions, general provisions, and pre- and post-award requirements.

In the third and final course of the series, FHWA Planning and Research Grants: The Uniform Guidance (2 CFR Part 200) – Part 2 (course number 151059), learners explore the last two subparts of the Uniform Guidance: subpart E on cost principles and subpart F on audit requirements. The review of subpart E includes detailed discussion on which costs are allowable and which are unallowable. The lessons on subpart F cover key terms, basic requirements, and roles and responsibilities associated with the audit of Federal awards. Entities that expend more than $750,000 in Federal funds during their fiscal year are subject to audit of their handling of the funds.

"It took me about a year as a participant of FHWA's Professional Development Program to compile and comprehend all of this information separately. This series puts everything in one place and will be invaluable for new employees," says Vontra Giles, a community planner in FHWA's Alabama Division. "It's really helpful to have hyperlinked references to the CFR and other resources sprinkled throughout the course. It's interactive and engaging, and it closed a lot of knowledge gaps I had prior to completing the series."

NHI's Web-based planning and administration course 151057 introduces participants to the grant funding process by walking through the steps and explaining key terms and concepts.

This training series is highly recommended for staff, including planning, engineering, and finance professionals from FHWA, the Federal Transit Administration, State departments of transportation, metropolitan planning organizations, and other agencies who expend or administer Federal-aid planning funds. The training series does not have any prerequisites and is suitable for beginners.

Each portion of the series is available for $25 per participant. The entire series can be completed in 5.5 hours, and participants can earn up to 0.6 continuing education units for successful completion of the entire series. To register for these courses, visit www.nhi.fhwa.dot.gov.

Marisa Beck is a contracted instructional designer for NHI.

Communication Product Updates

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

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

When ordering from NTIS, include the NTIS publication number (PB number) and the publication title. You also may visit the NTIS 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
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Email: customerservice@ntis.gov

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

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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).

State of the Practice for Traveler Information During Nonrecurring Events
Publication Number: FHWA-HRT-17-014

This report identifies and reviews literature and synthesizes the best practices on efforts to understand traveler information needs and related decisionmaking processes within the context of nonrecurring events—planned or unplanned—that impact traffic conditions. Unplanned events may include traffic incidents, severe weather, and other emergencies. Planned events may include road work, sporting events, planned protests, concerts, and holiday celebrations, among others.

This report provides a comprehensive review of current challenges and a look forward at anticipated trends and advances as the landscape of information on nonrecurring events evolves.

The intended audience for this report includes transportation agencies interested in implementing or managing a traveler information system that includes information for nonrecurring events as well as researchers investigating traveler needs and behaviors related to nonrecurring event information.

The document is available at www.fhwa.dot.gov/publications/research/safety/17014/index.cfm.

Summary Report: Cooperative Adaptive Cruise Control Human Factors Study
Publication Number: FHWA-HRT-17-025

This report presents the results of human factors research to examine the effects of cooperative adaptive cruise control (CACC) on driver performance in a variety of situations. CACC is an automated vehicle application that complements the capabilities of the vehicle operator without altering the vehicle operator's alertness and attention.

CACC combines three driver assist systems: (1) conventional cruise control, which automatically maintains the speed a driver has set, (2) adaptive cruise control, which uses radar or light detection and ranging sensors to automatically maintain a gap the driver has selected between the driver's vehicle and a vehicle ahead, and (3) dedicated short-range communications to transmit and receive data with surrounding vehicles so that the cruise control system can more quickly respond to changes in speed and location of other CACC vehicles, even vehicles that the driver cannot see.

FHWA conducted four experiments using a driving simulator as part of this CACC human factors study. The first experiment compared driving with CACC in a string of four or five vehicles with manual control of the following distance. The second experiment examined driver performance when merging into a string of CACC vehicles. The third experiment looked closer at the role of automated braking and auditory alerts in collision avoidance, and the fourth experiment explored the effect of a driver's preferred following distance on performance and workload.

The research in this report suggests that CACC can reduce driver workload while enhancing safety. However, CACC is only one of many vehicle automation technologies in development or early deployment. The role of the driver will be in flux for many years as known safety and convenience automation technologies advance. Human factors research will need to focus on the ever-changing role of the driver and the resulting effects on the performance of these driver-vehicle systems.

The document is available at www.fhwa.dot.gov/publications/research/safety/17025/index.cfm.

Safety Evaluation of Horizontal Curve Realignment on Rural, Two-Lane Roads Publication Number: FHWA-HRT-17-066

This evaluation, conducted as part of FHWA's Evaluation of Low-Cost Safety Improvements Pooled Fund Study, examines the safety effectiveness of horizontal curve realignment by increasing the radius of curved roadway segments on two-lane rural roads. One objective of this strategy is to reduce lane departure crashes, especially run-off-road crashes.

The results of the evaluation showed a substantial and significant reduction in crashes. The economic analysis revealed that increasing the radius of a horizontally curved roadway segment on two-lane, rural roads is a cost-effective safety improvement for reducing all types of crashes.

The researchers determined the crash modification factors associated with curve realignment using the empirical Bayes method and compared the results from existing crash modification factors from cross-sectional studies. This evaluation used data from rural, two-lane roads in California, North Carolina, and Ohio. The evaluation revealed a 68-percent reduction in total crashes, a 74-percent reduction in injury and fatal crashes, a 78-percent reduction in run-off-road and fixed object crashes, a 42-percent reduction in nighttime or reduced-light crashes, and an 80-percent reduction in wet crashes.

This document is intended for safety engineers, highway designers, planners, and practitioners at State and local agencies involved with implementing strategic highway safety plans.

The document is available at www.fhwa.dot.gov/publications/research/safety/17066/index.cfm.

Corrosion Forecasting and Failure Projection of Post-Tension Tendons in Deficient Cementitious Grout Publication Number: FHWA-HRT-17-074

Bridge tendons can be more susceptible to corrosion than conventional reinforcement with no indication that corrosion is taking place. Failures from deficient grout-induced corrosion have been reported as early as 2 years after construction. FHWA conducted research to provide bridge engineers with a practical methodology for predicting corrosion-induced, post-tensioned tendon failures caused by a grout deficiency or deficiencies.

The goals were twofold: first, to present results from phase two of an experimental study and, second, to develop a methodology to forecast the onset and subsequent rate of wire and strand fractures and tendon failures, given information regarding the extent of grout deficiency or deficiencies.

The study's results indicate an initiation period for fractures and failures during which corrosion progresses at an increasing rate up to a point, after which the rate of corrosion moderates. The research team investigated other variables including level of prestress, wire strength, number of tendons, tendon length, and fracture and failure rates subsequent to initial occurrence. The report presents equations for bridge engineers to forecast the onset of fractures and failures based on statistics of either localized wire corrosion wastage or grout chloride concentration.

The document is available at www.fhwa.dot.gov/publications/research/infrastructure/bridge/17074/index.cfm.

Alternative Contracting Method Performance in U.S. Highway Construction Publication Number: FHWA-HRT-17-100

This TechBrief presents findings based on empirical data from FHWA's national study, "Quantification of Cost, Benefits and Risk Associated with Alternative Contracting Methods and Accelerated Performance Specifications." The study includes documented lessons learned related to two alternative contracting methods: construction manager/general contractor and design-build.

The study collected a first-of-its-kind dataset from 291 completed highway projects. Together, the data form the largest empirical database of project information exclusive to highway construction. The findings provide guidance for State departments of transportation to assist in determining when to use alternative contracting methods to maximize project objectives related to cost, schedule, and intensity performance metrics.

This publication presents the state of the practice in the use of alternative contracting methods and discusses the characteristics of projects for which agencies are using these methods. It also provides information on how alternative methods affect cost certainty, cost growth, project delivery speed, schedule growth, and production rates or project intensity.

The document is available at www.fhwa.dot.gov/publications/research/infrastructure/17100/index.cfm.

Identification of High Pedestrian Crash Locations Publication Number: FHWA-HRT-17-107

The overall goal of FHWA's Pedestrian and Bicycle Safety Research Program is to improve safety and mobility for pedestrians and bicyclists. This report documents the research into developing a process to identify locations with high rates of crashes involving pedestrians.

FHWA contacted several cities and States to establish the criteria used to identify and rank locations with high pedestrian crash rates. In all cases, researchers used crash data. In some cases, researchers considered other

variables as well, especially when developing the list of sites for treatments. For example, Los Angeles uses a score that considers the age of the pedestrian and a health and equity index in addition to the number of injury crashes and the number of fatal crashes. Several cities create unique lists for intersections, facilities, and areas, recognizing that treatment selection would be different for these element types.

The methods used to identify and evaluate sites with a high crash frequency have evolved in recent decades. For example, the availability of geographic coordinates (latitude and longitude) for crashes has resulted in regular use of geographic information system (GIS) platforms for displaying the locations and density of crashes on maps.

The objective of this FHWA research was to document methods used to identify or prioritize high pedestrian crash sites or areas. Using the information gathered as part of this research, the research team produced the *Guidebook on Identification of High Pedestrian Crash Locations* (FHWA-HRT-17-106) with best practices and a five-step process to identify locations.

The report is available at www.fhwa.dot.gov/publications/research/safety/17107/index.cfm. The guidebook is available at www.fhwa.dot.gov/publications/research/safety/17106/index.cfm.

Eco-Drive Experiment on Rolling Terrain for Fuel Consumption Optimization (Summary Report)
Publication Number: FHWA-HRT-18-037

This summary report presents a research project sponsored by FHWA's Office of Operations Research and Development to evaluate the ability of eco-drive, a longitudinal control algorithm, to improve the fuel economy of a vehicle on rolling terrain. The promising results provide justification for the implementation of vehicle-to-infrastructure technology that would appeal to roadway owners, roadway users, and original equipment manufacturers.

Eco-drive is one of many theoretical concepts developed to increase vehicle fuel efficiency and improve the sustainability of the entire transportation system. This study proposes an eco-drive algorithm for optimizing vehicle fuel consumption on rolling terrains, which frequently cause additional fuel waste because of inefficient transformation between kinetic and potential energy.

The study aimed to test and verify the newly developed algorithm on an innovative connected and automated vehicle platform and to quantify the fuel-saving benefits of eco-drive. Researchers compared the proposed eco-drive system to conventional constant-speed cruise control on a total of seven road segments over 47 miles (76 kilometers). Experimental data show that up to 20 percent of fuel consumption can be avoided on certain rolling terrains.

This conclusion can enable a rough estimate of fuel-saving potential on given roadways and help State departments of transportation identify roadways where eco-drive could be effectively implemented. The algorithm and experiment can also support original equipment manufacturers in developing and marketing this technology to reduce fuel consumption and emissions in the future.

The document is available at www.fhwa.dot.gov/publications/research/operations/18037/index.cfm.

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NATIONAL DIALOGUE ON HIGHWAY AUTOMATION

Automated vehicles may significantly transform the Nation's roadways. They offer potential safety benefits but also introduce a learning curve for the many public agencies responsible for the planning, design, construction, operation, and maintenance of the roadway infrastructure.

The Federal Highway Administration is initiating a national conversation with State and local agencies, industry, associations, the public, its partners, and stakeholders to gather input on key issues regarding automated vehicles and the highway community.

Major Topics for Discussion

Planning and Policy

Digital Infrastructure and Data

Freight

Operations

Infrastructure Design and Safety

The National Dialogue on Highway Automation is a series of interactive workshops to facilitate collaboration and support the transportation community to safely and efficiently integrate automated vehicles into the road network. Input received during the National Dialogue will help inform FHWA research, policies, and programs.

The National Dialogue is designed to achieve the following objectives:

- **Listen:** Gather detailed input from a diverse group of stakeholders regarding opportunities and challenges on highway automation.
- **Engage:** Facilitate information sharing among industry, public agencies, and others to understand the current state of automated vehicle technologies.
- **Inform:** Raise awareness of FHWA and USDOT initatives in automation, serving as a resource for the transportation community.
- **Evolve:** Update existing institutions for working with stakeholders to develop new partnerships and strengthen coordination channels.

The National Dialogue workshops are being held in various locations across the country.
For more information, please visit https://ops.fhwa.dot.gov/automationdialogue.

U.S. Department of Transportation
Federal Highway Administration

Office of Operations
Federal Highway Administration

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Transportation agencies today must pursue better, faster, smarter ways of doing business. Federal-aid Essentials for Local Public Agencies offers a central online library of informational videos and resources that are readily accessible and available to all. Each video addresses a single topic—condensing the complex regulations and requirements of the Federal-aid Highway Program into easy-to-understand concepts and illustrated examples.

Visit Federal-aid Essentials at www.fhwa.dot.gov/federal-aidessentials.

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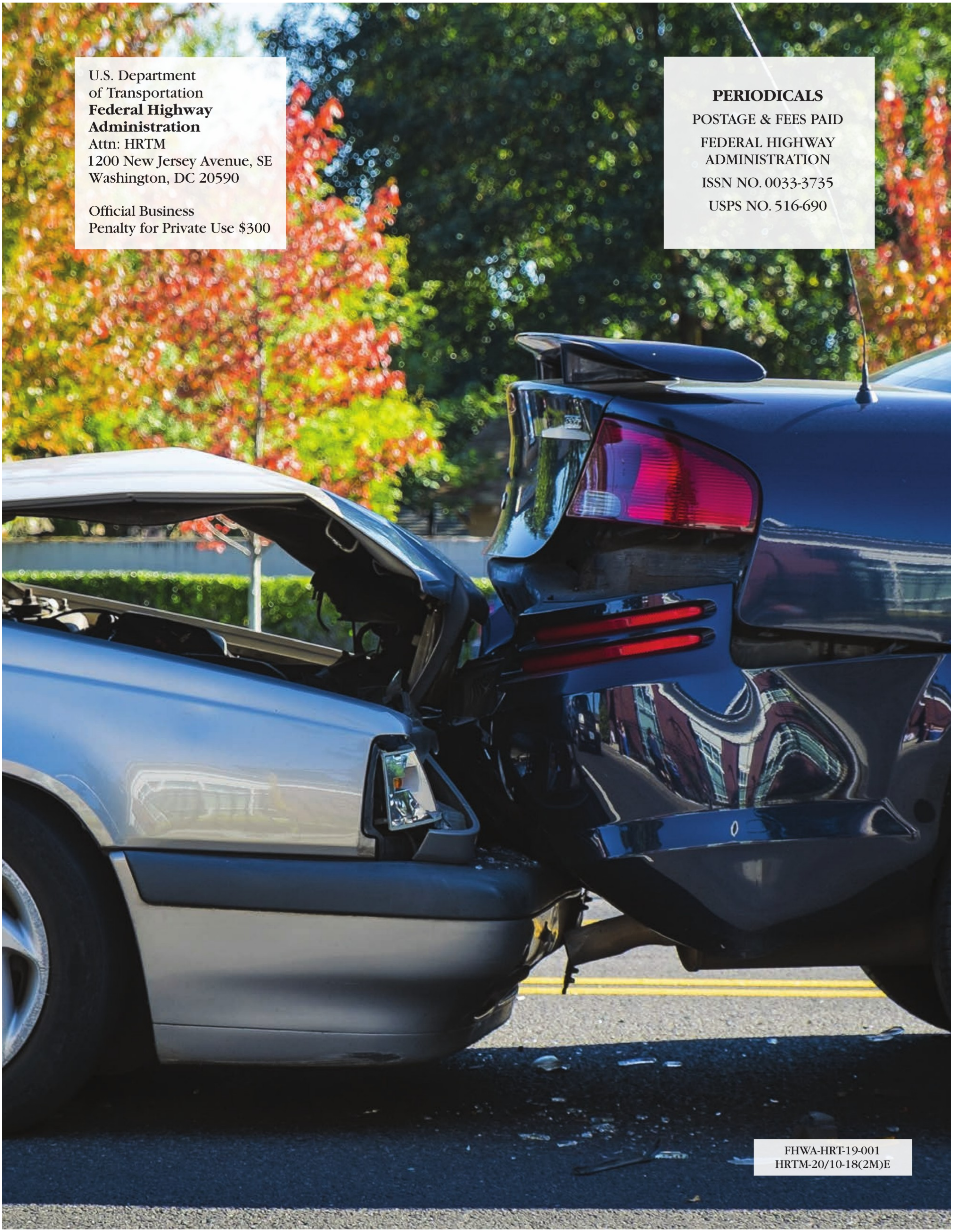

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FEDERAL HIGHWAY
ADMINISTRATION
ISSN NO. 0033-3735
USPS NO. 516-690

FHWA-HRT-19-001
HRTM-20/10-18(2M)E