Public Roads

www.fhwa.dot.gov

January/February 2011

University Partnerships

Managing Road Weather

Bridge Aerodynamics

U.S. Department of Transportation

Federal Highway Administration

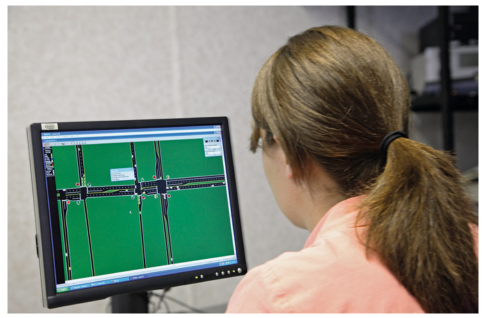
Public Roads

January/February 2011 www.fhwa.dot.gov Vol. 74, No. 4

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

Articles

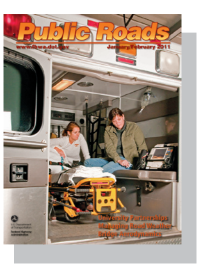
Page 14



Page 30

Page 36

Departments



Front cover—Montana State University (MSU) Assistant Professor Laura M. Stanley (left) and graduate student Jessica Mueller are studying the use of seatbelts by emergency medical personnel. The MSU Western Transportation Institute, which is one of 59 University Transportation Centers (UTCs) across the country, is helping fund Stanley's research and providing valuable real-world experience for students planning to enter the field of transportation engineering. For more about UTCs, see "Pooling Talent and Technologies" on page 36 in this issue of PUBLIC ROADS. *Photo: Neil Hetherington, Western Transportation Institute.*

Back cover—Neal Hawkins, a researcher at the Center for Transportation Research and Education at Iowa State University, is finishing painting "SLOW" and a white arrow on the pavement ahead of a horizontal curve on a county road north of Burlington, IA. Pavement markings are an example of a low-cost treatment that can help reduce speed and crashes at horizontal curves on two-lane rural roads. For more information, see "Twisting Roads Still Spell Trouble" on page 8. *Photo: Shauna L. Hallmark, Iowa State University.*

U.S. Department of Transportation
Federal Highway Administration

U.S. Department of Transportation
Ray H. LaHood, *Secretary*

Federal Highway Administration
Victor Mendez, *Administrator*

Office of Research, Development, and Technology
Michael Trentacoste, *Associate Administrator*

Paula Magoulas, *Editor-in-Chief*

Paula Magoulas, *Publication Manager, Creative Director*

Norah Davis, *Editor*

John J. Sullivan IV, *Associate Editor*

Paula Magoulas, *Distribution Manager*

Public Roads (ISSN 0033-3735; USPS 516-690) is published bimonthly by the Office of Research, Development, and Technology, Federal Highway Administration (FHWA), 1200 New Jersey Avenue, SE, Washington, DC 20590. Periodicals postage paid at Washington, DC, and additional mailing offices.

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

The editorial office of *Public Roads* is located at the McLean address above.
Phone: 202–493–3398. Fax: 202–493–3475.
Email: paula.magoulas@dot.gov.

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

New Foundation for Transportation Operations of the Future

In the past, the Federal Highway Administration's (FHWA) Office of Operations Research and Development (R&D) focused on developing technology in an evolutionary fashion. But today, and in the future, technologies combined with appropriate policies can facilitate revolutionary changes that could reduce highway fatalities to near zero and dramatically relieve stop-and-go traffic. Accomplishing these changes is possible only by broadening researchers' perspectives beyond highways to include the entire transportation infrastructure (transit, rail, airports, and seaports) and beyond drivers to include pedestrians, bicyclists, public transportation passengers, and truckers.

Research advances today are turning microelectronics into nanoelectronics, telecommunications into telepresence, and information processing into thinking machines. To take advantage of these advances, FHWA works with its transportation partners in conducting exploratory research that includes operations R&D. (See "Pooling Talent and Technologies" on page 36 of this issue of PUBLIC ROADS.)

FHWA also is building a new foundation for the future—the multimodal Transportation Operations Laboratory (TOL) at the Turner-Fairbank Highway Research Center. The TOL will consist of test beds for developing data resources, transportation concepts and analysis, and cooperative vehicle-highway interfaces.

The data resources test bed will create a framework for organizing a variety of transportation-related data, collecting high-quality datasets, and creating a Web portal for users to access well-documented data for producing their own innovative solutions.

The concepts and analysis test bed will use the new datasets to conduct "what-if" simulations to see how innovative technologies and policies will change the performance of the Nation's transportation system. The article "Traffic Simulation Runs: How Many Needed?" on page 30, for example, shares insights regarding issues faced in a modeling and simulation environment. "Managing Traffic Operations During Adverse Weather Events," on page 2, uses modeling and simulation tools to examine the impact of weather on traffic operations and safety.

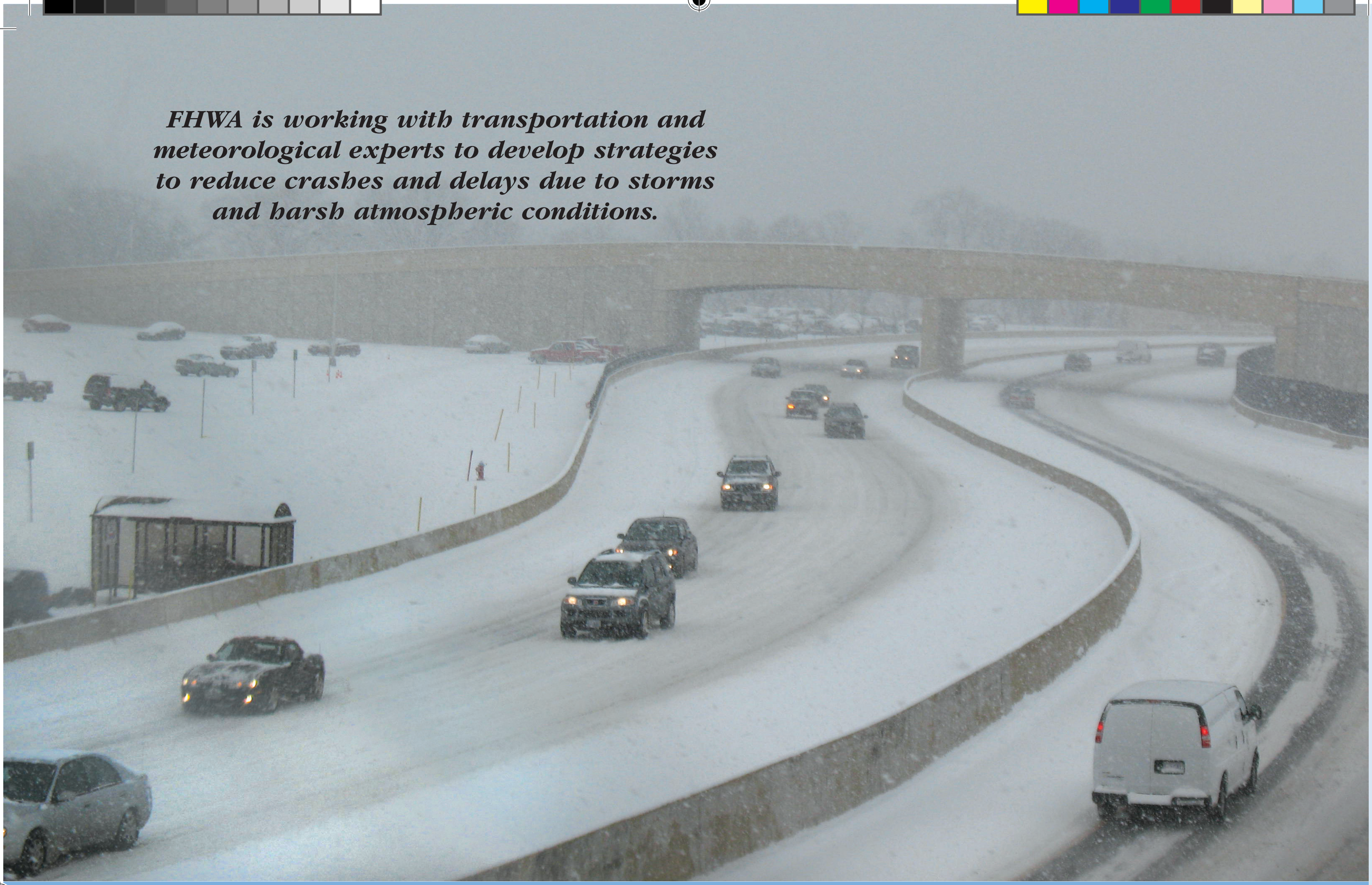
The cooperative vehicle-highway test bed will take the best concepts from simulations, apply advanced communications and sensor technologies, and test them before deployment in wider scale field tests. The article "Using GPR to Unearth Sensor Malfunctions," on page 24, presents test results related to a new technology that holds promise for efficiently and effectively detecting broken sensor loops embedded in roads.

A powerful example of the TOL's utility involves communication among vehicles, infrastructure, and mobile devices. Traffic signals can communicate their phases and timing to vehicles and pedestrians carrying mobile devices. The vehicles anonymously transmit their positions, travel times, and other data to traffic management centers, which in turn communicate advisory messages to drivers through dynamic messaging on road signs or inside the vehicles via warning tones. Traffic signals will "talk" to cars and mobile devices, and cars will "talk" to other cars and traffic signals about where they are and how fast they are going. This concept could lead to revolutionary decreases in delays and a reduction in the number of crashes that occur during stop-and-go traffic.

As new sensors, electronics, communications, and information processing technologies continue to advance at phenomenal rates, the field of transportation management and operations increasingly looks toward these and other new technologies to solve problems like congestion. Here at FHWA, the TOL provides a new home for conducting related state-of-the-art research and technology development and promises benefits for all stakeholders.

Joseph I. Peters

Joseph I. Peters, Ph.D.
Director, Office of Operations Research and Development
Federal Highway Administration



Managing Traffic Operations During Adverse Weather Events

by Roemer M. Alfelor and C. Y. David Yang

(Above) Adverse weather substantially reduces speeds and increases travel times on U.S. roads. FHWA's Road Weather Management Program aims to find ways to improve safety and mobility during weather events, such as the February 2010 snowstorm shown here with accumulation on Route 110 near the Pentagon in Arlington, VA. *Photo: John J. Sullivan IV.*

Weather affects the performance of the Nation's highway system every day. Rain, snow, ice, and the like are partly or fully responsible for more than 1.5 million highway crashes and more than 600,000 injuries and 7,000 fatalities on U.S. roads every year.

Further, motorists waste about 1 billion hours a year stuck in traffic related to adverse weather. In fact, weather is the second leading cause of nonrecurring highway congestion, accounting for about 25 percent of delays. Recent studies by the Federal Highway Administration (FHWA) estimate that adverse weather increases average travel times by 14 percent in the Washington, DC, area and 21 percent in Seattle, WA. During peak periods, travel time in Washington, DC, can increase by as much as 24 percent in the presence of rain or snow.

Despite the documented impacts of adverse weather on transportation, researchers do not fully understand the links between weather and traffic flow. However, through FHWA's Road Weather Management Program, partners from the transportation and meteorological communities are rising to the challenge. By studying, developing, and implementing weather responsive traffic management (WRTM) solutions, researchers are taking steps to improve traffic flow and operations during inclement weather, with the ultimate goal of minimizing delays and crashes.

Accurate and timely road and weather data are critical because they enable State and local departments of transportation (DOTs) to manage infrastructure in real time in response to existing and impending weather conditions and to warn motorists about changes in weather and road conditions. Advancements in intelligent transportation systems (ITS), road weather information systems, weather and traffic data collection, and forecasting technologies present new opportunities for better understanding how drivers behave in adverse weather and how their decisions affect traffic flow. Ultimately, these technologies can support WRTM strategies such as real-time modification of traffic signal and ramp meter timing, operation of automated deicing systems, and setting of variable speed limits.

FHWA recently conducted research to identify relevant datasets, including domestic and international sources, and analyzed the gaps between research needs and data availability. In addition, an effort is underway to develop applications using data culled from weather stations and the U.S. Department of Transportation's (USDOT) IntelliDrive[SM] initiative, which aims to enable safe, interoperable, and networked wireless communications among vehicles, infrastructure, and passengers' personal communications devices.

Weather Responsive Traffic Management

FHWA established the seeds of the Road Weather Management Program more than a decade ago to research, develop, and deploy strategies and tools to help road managers respond more effectively to inclement weather. In 2005, the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users directed FHWA and its partners to (1) maximize use of available road weather information and technologies; (2) expand road weather research and development efforts to enhance roadway safety, capacity, and efficiency while minimizing environmental impacts; and (3) promote technology transfer of effective scientific and technological advances.

The goal is to provide State DOTs with the knowledge and tools to address road weather in three key ways:

Advisory. Disseminate road weather information to the public through tools such as the 5-1-1 traveler information telephone services, variable message signs, and highway advisory radio.

Control. Regulate or optimize traffic flow in response to weather, such as through signal timing, ramp metering, and road closure.

Treatment. Clear roads of weather-related obstructions, as in snow removal and dust and fog control.

The end result is better decision-making by DOTs and motorists, resulting in improved reliability, safety, and mobility on the transportation system during adverse weather.

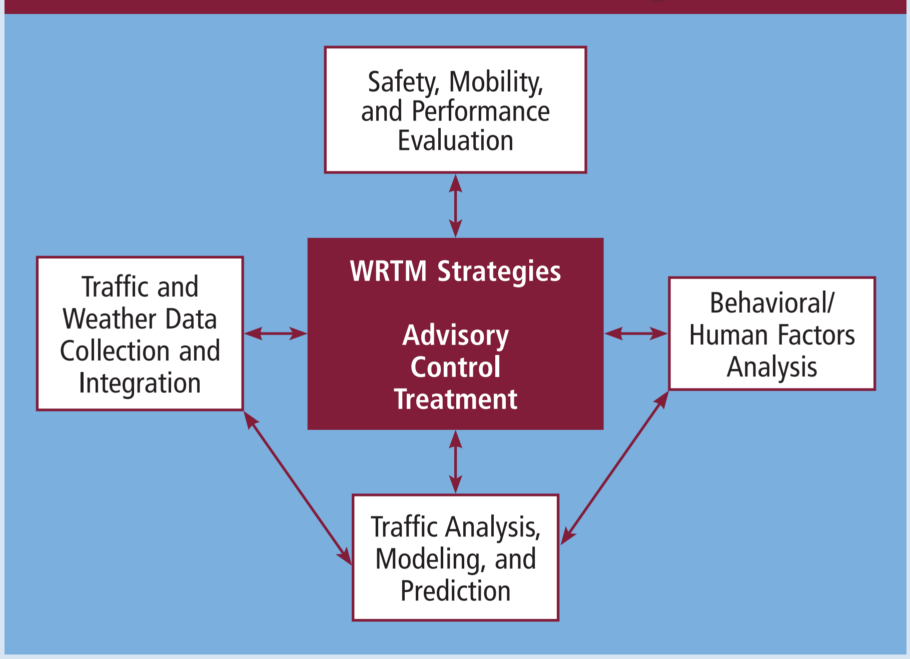
The FHWA Road Weather Management Program continues to review current practices, document the benefits of existing approaches, and identify needs, such as strategies applicable for use on arterials and freeways. Ongoing research will evaluate how weather and traffic information can improve traffic operations by enabling system managers to reset traffic signals and ramp meters; display advisory and warning messages; and make decisions on traffic control, maintenance, routing and diversion, and other operations.

Traffic Analysis And Modeling

Historically, road managers pulled weather and traffic data from static and fixed devices such as video cameras, traffic counters, loop detectors, airport weather stations, and environmental sensor stations. More recently, USDOT's IntelliDrive initiative has spawned a variety of approaches to capture traffic and weather information using moving vehicles. Making both static and dynamic information available requires active involvement by a range of participants in the transportation and weather communities.

Through the Road Weather Management Program, FHWA recently analyzed the effects of adverse weather on macroscopic (aggregate, big picture) traffic flow and quantified changes in traffic speed, capacity, and density. The researchers used data from traffic management centers (TMCs) in Baltimore, MD, Minneapolis–St. Paul, MN, Seattle,

Framework for the WRTM Program



FHWA's framework for weather responsive traffic management includes four core research areas that feed into three key strategies—advisory, control, and treatment—that DOTs can implement to improve the performance of highway systems in adverse weather. *Source: FHWA.*

Researchers at the Virginia Tech Transportation Institute (VTTI) used data culled from video stills like these from intersections near Blacksburg, VA, to develop weather-sensitive gap acceptance models. *Source: VTTI for FHWA.*

WA, and the National Weather Service stations at those cities' airports.

As reported in *Empirical Studies on Traffic Flow in Inclement Weather* (FHWA-HOP-07-073), published in 2006, the research revealed that precipitation (rain or snow) did not affect the density of the traffic stream, but it did affect traffic free-flow speed, speed-at-capacity, and capacity. Most of those parameters varied with precipitation intensity. Although capacity reductions of 12–20 percent occurred in snowy conditions, the reduction in capacity did not appear to be a function of the intensity of the snow (or rate of snowfall).

For the researchers, one of the more interesting findings was that the Twin Cities saw greater reductions (19 percent) in traffic stream free-flow speed and speed-at-capacity in snow than did Baltimore (5 percent). Those relative figures might seem counterintuitive considering the Twin Cities have higher annual snow totals than Baltimore. A possible explanation is that drivers who are more accustomed to snow are more aware of its dangers—and slow down. This theory also might explain the higher reductions observed in a Canadian study, as reported in the 1994 article "Effect of Adverse Weather Conditions on Speed-Flow-Occupancy Relationships" in the *Transportation Research Record*.

A 2009 followup study, *Microscopic Analysis of Traffic Flow in Inclement Weather* (FHWA-JPO-09-066), analyzed the impacts of adverse weather on microscopic traffic behavior. Microscopic analysis describes individual driver responses to weather conditions, such as changing lanes, merging onto a freeway, making a left turn across traffic at an intersection, or adjusting the distance behind a lead vehicle. Studies that videotaped individual vehicle movements at intersections or freeway merge locations provided a rich source of data for analysis.

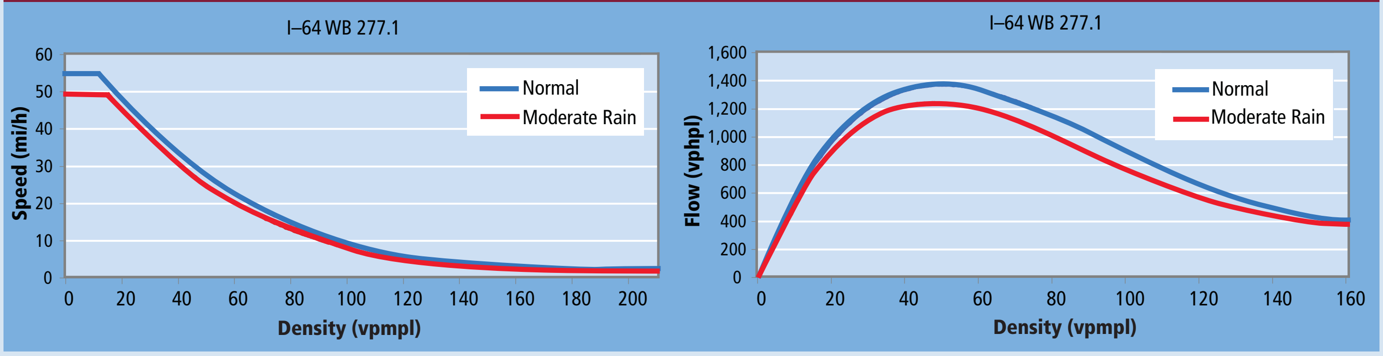
The video-recorded data helped provide a better understanding of how drivers respond to adverse weather, focusing on three types of driving behaviors—car following, gap acceptance, and lane changing. The video data also helped the FHWA researchers incorporate microscopic models into existing microsimulation tools to help model and evaluate WRTM strategies.

In one of the studies, the FHWA researchers used video data collected at several intersections near Blacksburg, VA, to determine whether drivers alter their gap acceptance behavior in rainy weather. The findings indicate a more cautious approach to left-turn gap acceptance in the rain (such as higher critical gaps), which could influence the effectiveness of intersection signal timing plans.

FHWA also conducted research on car-following behavior using a dataset that consists of observations of individual drivers as they navigate an icy test track in Japan. The goal of the research is to analyze how the vehicle speeds and distances between vehicles are affected by the icy road conditions. Research also is underway to collect and analyze detailed information on gap acceptance behavior at intersections in snowy conditions.

"The impact of weather on traffic flow isn't simple and straightforward," says Dave Kinnecom, a traffic management engineer with

Calibrated TrEPS Speed Model



FHWA researchers created these graphs by calibrating the Traffic Estimation and Prediction Systems (TrEPS) model for an interstate highway (westbound I–64, milepost 277.1) in Hampton Roads, VA, using available observations of traffic and user behavior. The graphs show how traffic speeds (in miles per hour) and flows (in vehicles per hour per lane) decrease in the presence of moderate rain under various traffic densities (measured in vehicles per mile per lane). *Source: Northwestern University for FHWA.*

the Utah Department of Transportation (UDOT). "The effect on traffic can depend on the timing of the storm, when and how the roads are treated, and the temperature of the pavement. Sometimes, what seems to be a minor snowstorm can have a significant impact on traffic when there are a lot of minor incidents. At other times, moderate snow has had virtually no effect."

Traffic Estimation And Prediction

Another area for expanding use of weather data is in traffic estimation and prediction. Researchers with FHWA's Road Weather Management Program recently incorporated weather factors into existing Traffic Estimation and Prediction Systems (TrEPS). Using TrEPS, researchers can predict where and when drivers will travel on a road network and apply dynamic control and traffic management strategies proactively rather than reactively.

FHWA modified two TrEPS prototypes—DYNASMART-P, a system for transportation planning, and DYNASMART-X, a real-time system for predicting traffic conditions and patterns—to account for weather impacts, improving their traffic estimation and prediction capabilities and overall utility. A 2009 FHWA study, *Incorporating Weather Impacts in Traffic Estimation and Prediction Systems* (FHWA-JPO-09-065), addressed supply and demand aspects of traffic response to adverse weather, including driver response to various weather-specific interventions, such as advisory information (variable message signs) and control actions (variable speed limits).

For this study, researchers with the Road Weather Management Program implemented the weather-related features in DYNASMART and applied the system to a real-world road network. Using DYNASMART, the researchers identified and modeled the supply-side and demand-side elements of TrEPS to account for changing weather conditions and the availability of traveler information systems and WRTM devices. The study provides a direction for future development toward a proactive approach to traffic management under adverse weather that incorporates weather effects in transportation network analysis tools. Consequently, TMCs will be able to implement more effective strategies during severe weather conditions to improve travel safety and mobility.

Further, FHWA is working to translate these advances in traffic estimation and prediction into practice. Specifically, the FHWA researchers are calibrating the model for a variety of local conditions and traffic patterns for implementation and evaluation in the context of regional planning and operations. Also, the researchers are focusing on weather-related traffic management and control measures, and are studying how to interface their deployment and evaluation with the TrEPS decision-support tools.

According to Jack Stickel, manager of transportation data services with the Alaska Department of Transportation & Public Facilities, degradation of road surface conditions is highly correlated to expanded segment travel time. "Measuring the changes in traffic speed and thus segment travel time can go a long way in estimating the impacts of precipitation, sudden warming that melts snow and ice on the road surface, or increasing winds that require additional driving safeguards," Stickel says. "Segment travel time can be used as a proxy for changes in the road weather environment."

Traffic and Weather Data Collection and Integration

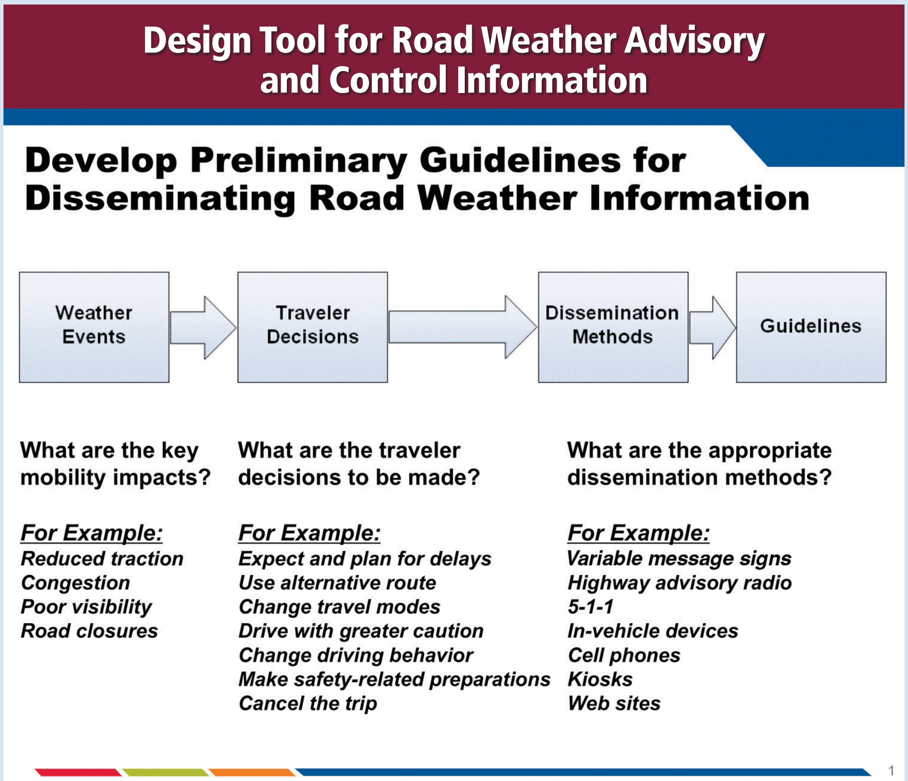
A TMC usually serves as the hub of a regional transportation system and communicates traffic information to motorists and the public. Integrating weather information and decision-support functions in TMC operations supports a transportation agency's ability to manage traffic, dispatch maintenance forces, and respond to weather-related problems and other emergencies.

To support TMCs and their activities, FHWA is working to define a framework for the types of weather and traffic data needed and how to integrate them to support effective operational strategies. The Road Weather Management Program is looking at the types and characteristics of data, the sources and procedures used to gather them, and how transportation agencies and motorists use this information in making decisions. For example, some motorist decisions affected by weather and traffic conditions include whether to make the trip, when to make the trip, what routes to take, and what modes of travel to use. Timely, accurate, and relevant weather and traffic information requires effective methods for data collection, integration, and dissemination.

In 2008, FHWA published *Integration of Weather Information in Transportation Management Center Operations: Self-Evaluation and Planning Guide* (FHWA-JPO-08-057) to help TMCs identify their weather information needs and develop plans to better integrate the information in their daily operations. The guide stemmed from recommendations in

KCScout.com

The Kansas City Scout TMC, shown here, used FHWA's *Weather Integration in TMC Operations: A Self-Evaluation and Planning Guide* to develop a plan for improving its operations during adverse weather conditions.



This flowchart shows the structure and sequence of the design tool for road weather advisory and control information. *Source: Battelle for FHWA.*

a 2006 FHWA study, *Integration of Emergency and Weather Elements Into Transportation Management Centers* (FHWA-HOP-06-090).

This self-evaluation guide is designed to help a TMC integrate weather information and technologies into its daily operations. The first step is to identify the relevant weather events in a TMC's jurisdiction, their impacts on traffic operations and infrastructure, and processes for responding to those events. From there, the guide walks road managers through the process of prioritizing identified needs for the application and integration of weather information, and identifying strategies and solutions best suited to meeting the TMC's needs. In addition, the guide summarizes how to develop a plan for integrating weather information and includes a list of strategies to help TMCs fill information gaps.

Since the guide's publication, TMCs in Cheyenne, WY, Colorado Springs, CO, Kansas City, MO, Milwaukee, WI, Sacramento, CA, and four more in Louisiana have conducted their own self-evaluations. Most of them have developed plans for integrating weather information. The Sacramento TMC developed a weather alert system that automatically generates adverse weather warnings and alerts to help TMC operators post appropriate messages and advisory information for travelers.

"The FHWA weather integration self-evaluation process has had numerous benefits for the Wyoming Department of Transportation [WYDOT]," says Vince Garcia, GIS/ITS program manager at WYDOT. "The guide was very simple to use and it focused our attention on best practices. Such focus enabled us to concentrate our efforts and lend credence to our ITS requests when pursuing funding opportunities with WYDOT's executive staff."

Human Factors and Road Weather Information

To be effective, the content, format, and timing of weather information needs to be consistent with what travelers need, want, and will use. Toward that end, in March 2010, FHWA published the *Human Factors Analysis of Road Weather Advisory and Control Information: Final Report* (FHWA-JPO-10-053). The goals of the study were to evaluate the current state of the practice in communicating weather-related traffic advisory and control information, and to recommend ways to improve those practices. The research derived a preliminary set of guidelines for communicating and presenting road weather information that meet the needs of drivers and travelers under various weather conditions and travel scenarios.

The guidelines are contained in a decision/design document that enables traffic managers to work through a series of questions to identify appropriate road weather messages and dissemination methods based on the type of weather event, anticipated mobility impacts, and the types of traveler decisions that could be made. For example, a transportation agency can use the design guide to identify the specific content, format, and delivery mechanisms for warnings and advisory messages to travelers who will be driving on a highway corridor that is experiencing adverse weather such as heavy snow, rain, or fog.

"Utah has focused on improved traveler information," says UDOT's Kinnecom. "We want to inform the traveler of not just the weather but current and projected road conditions. We have put a 'Road Weather' page on our 'Commuterlink' Web site that features forecasted road conditions out to 18 hours. We have an emergency alert feature on the Web site that advises users of road closures, chain or four-wheel drive restrictions, and expected driving conditions. UDOT also uses 5-1-1 to advise travelers of both forecasted weather and road conditions."

The TMC in Colorado Springs, CO, uses both Twitter™ and dynamic message signs [DMSs] to provide information on forecasts of adverse weather, including snow, heavy rain, and fog. "Most of the information at present tends to be regional, although the conditions from neighborhood to neighborhood can vary greatly during adverse conditions," says Robert Helt, principal traffic engineer with the city of Colorado Springs. "With the addition of small DMSs at various signal locations, the conditions reported become more relevant to each neighborhood."

Future Studies

Although these and other activities across the industry have significantly advanced the state of the practice in weather responsive traffic management, a few gaps still remain. Recent advances in mobile sensing and data collection technologies for traffic and weather, including those coming from the IntelliDrive program, can help researchers and practitioners use available data to improve forecasting and decisionmaking, including traffic management. For example, IntelliDrive's Dynamic Mobility Applications capitalize on vehicle-infrastructure connectivity by using data from vehicle probes and other real-time data sources, and enable TMCs to manage mobility between and across modes more effectively while providing information to travelers to support dynamic decisionmaking.

In the near term, FHWA will expand development and deployment of decision-support modules for traffic management similar to its Maintenance Decision Support System (MDSS), which is a decision-support tool for winter road maintenance. MDSS provides maintenance managers with precise forecasts of surface conditions and recommendations for treatments for specific routes. Using MDSS as a model, FHWA developed a concept of operations and established rules of practice for traffic management, some of which are being implemented as part of regional demonstrations associated with *Clarus* (Latin for "clear"), an FHWA research and development initiative to demonstrate and evaluate the value of road weather information to transportation users and operators.

"We cannot change the weather," says Paul Pisano, team leader of the FHWA Road Weather Management Program, "but we can reduce its impacts on highway operations and safety by using weather forecasts, identifying threats to travelers and the highway system, and responding proactively rather than reactively."

Roemer M. Alfelor has more than 20 years of experience in transportation and currently manages the WRTM research for the FHWA Road Weather Management Program. He serves as secretary of the Transportation Research Board's (TRB) Committee on Surface Transportation Weather. He holds a master's degree in transportation from the Massachusetts Institute of Technology and a Ph.D. in civil engineering from Carnegie Mellon University.

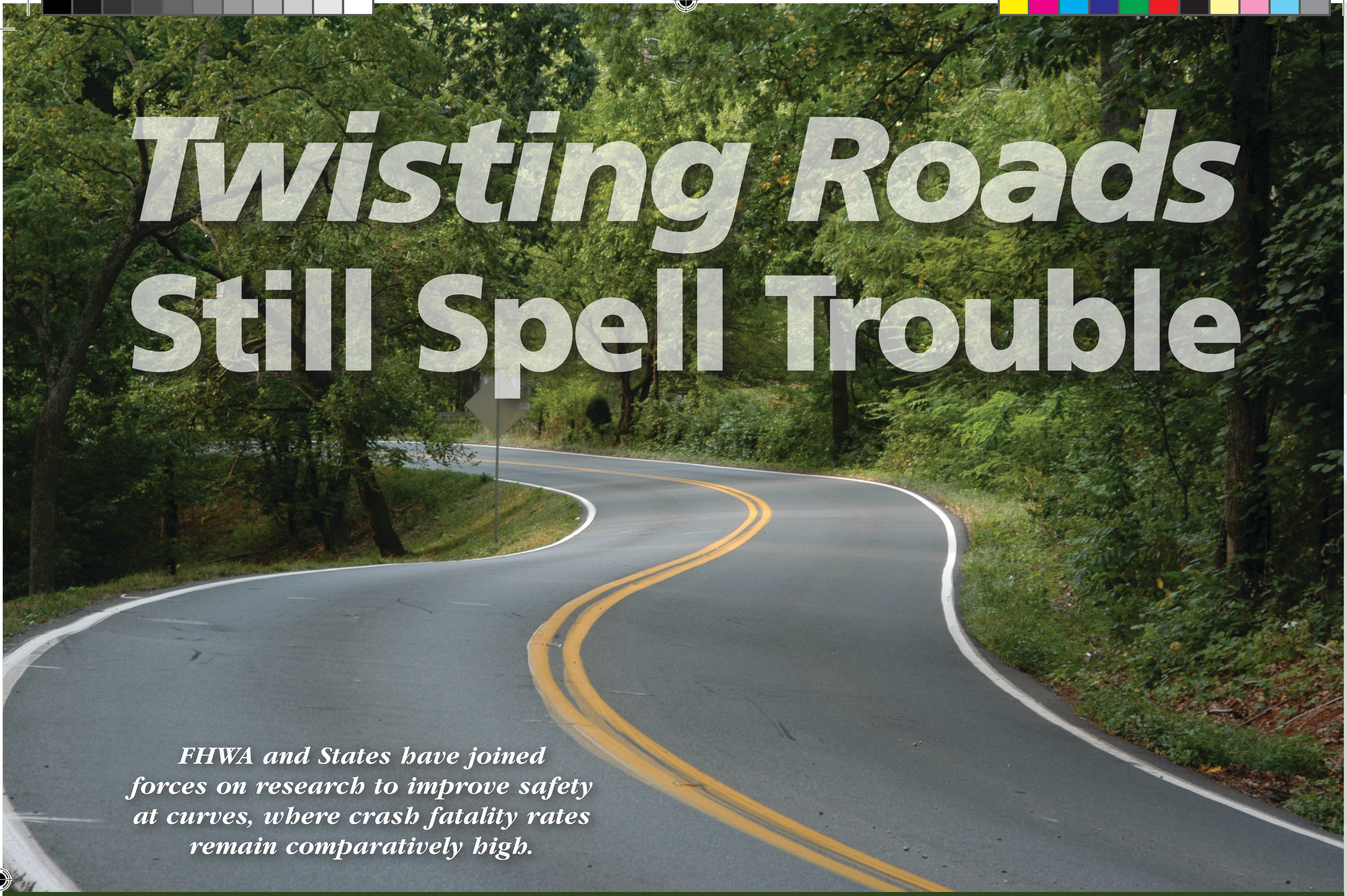
C. Y. David Yang is a research engineer with FHWA's Office of Operations Research and Development. He is responsible for traffic modeling and simulation research at the Turner-Fairbank Highway Research Center. He is chairman of TRB's User Information Systems Committee and serves on the editorial board of the *Journal of Intelligent Transportation Systems: Technology, Planning, and Operations*. He received his bachelor's, master's, and doctoral degrees in civil engineering from Purdue University.

For more information, contact Roemer Alfelor at 202-366-9242 or roemer.alfelor@dot.gov, or David Yang at 202-493-3284 or david.yang@dot.gov.

Variable message signs, like this one on a Minnesota highway, can help TMCs alert motorists about weather, incidents, and traffic ahead.

Minnesota Department of Transportation

Twisting Roads Still Spell Trouble



FHWA and States have joined forces on research to improve safety at curves, where crash fatality rates remain comparatively high.

by Roya Amjadi and Kimberly Eccles

According to the National Highway Traffic Safety Administration's Fatality Analysis Reporting System (FARS), an average of 41,515 people lost their lives on U.S. highways each year during the period between 2004 and 2008. A loss of life of this magnitude is clearly a cause for action. Although resources to address these crashes are limited, transportation professionals can effectively tackle the problem by focusing on high-crash locations, systematically determining the major contributing factors using available crash data and roadway inventory files, and identifying potential safety improvements.

(Above) Fatality rates on curves are increasing, but an ongoing FHWA pooled fund study aims to reveal how rumble stripes, signs, road markings, and other treatments can improve safety on rural roads like this one. *Photo: VHB.*

However, there are limited data on the effectiveness of some types of improvements, particularly more innovative treatments. These data limitations make it difficult to estimate the reduction in crashes that might result from implementing a given safety improvement. As a result, decisions about which safety improvements to make are challenging, and sometimes less-than-optimal decisions are made.

To improve this decisionmaking, in 2005 the Federal Highway Administration (FHWA) launched the Evaluations of Low Cost Safety Improvements Pooled Fund Study (ELCSI-PFS). The study is one of the largest ongoing FHWA safety-related pooled fund studies, with a total of 28 States contributing. The purpose of the study is to develop reliable estimates of the effectiveness of those safety improvements identified in the National Cooperative Highway Research Program (*NCHRP*) *Report 500: Guidance for Implementation of the AASHTO* [American Association of State Highway and Transportation Officials] *Strategic Highway Safety Plan*.

As part of the study, researchers looked at safety improvements that were already implemented at crash sites and conducted retrospective evaluations to determine their effectiveness. They also are looking at safety improvements that were developed by the participating States, as well as improvements derived from research conducted in the driving simulator at the Turner-Fairbank Highway Research Center (TFHRC) in McLean, VA.

Researchers are evaluating these improvements by Empirical Bayes statistical methodology, using before-and-after crash data for evaluations. FHWA anticipates that more than 30 safety improvements will be evaluated over 10 years of the study.

Motivated by the fact that on average 27 percent (11,071) of total fatalities occur on horizontal curves, the participating State departments of transportation (DOTs) selected horizontal curves as a priority for safety improvements. *NCHRP Report 500, Volume 7: A Guide for Reducing Collisions on Horizontal Curves* identifies 13 strategies that have been tried to (1) reduce the likelihood of a vehicle leaving its lane and either crossing the centerline or leaving the roadway and (2) minimize the adverse consequences of vehicles leaving the roadway at horizontal curves. For this study, FHWA and the States are evaluating a selection of these safety improvements for horizontal curves, including curve delineation signage, centerline and edgeline pavement markings, centerline and edgeline rumble strips or stripes, friction treatments for pavement surfaces, as well as other new and innovative strategies. The study is considering how these strategies can be applied both individually and in selected combinations to achieve varying degrees of safety effectiveness. Below is a discussion of how some of the participating States are structuring their evaluations of these safety improvements.

Curve Delineation

One low-cost strategy to enhance safety is improved curve delineation. This study aims to increase drivers' awareness as they approach or navigate through curves by providing more conspicuous signing and more effective lane markings. Improving delineation can be particularly helpful for motorists at night and/or in adverse weather conditions. One option for improving delineation is the use of pavement markings with greater durability, all-weather functionality, and higher retroreflectivity. Other options include post-mounted delineators, chevrons, raised pavement markers, and wider edgelines.

To determine the safety effectiveness of these changes in curve delineation, TFHRC obtained geometric, traffic, and crash data for 89 curves in Connecticut and 139 curves in Washington State that had these treatments. All sites were on two-lane rural roads, but specific treatments varied by site, including new chevrons, horizontal arrows, advance warning signs, improvement of existing signs, and installation of new signs using fluorescent yellow sheeting. Daily traffic volumes at the sites in Connecticut ranged from about 1,000 to 20,000 vehicles. In Washington, the traffic volumes ranged from about 250 to 15,000 vehicles per day.

VHB

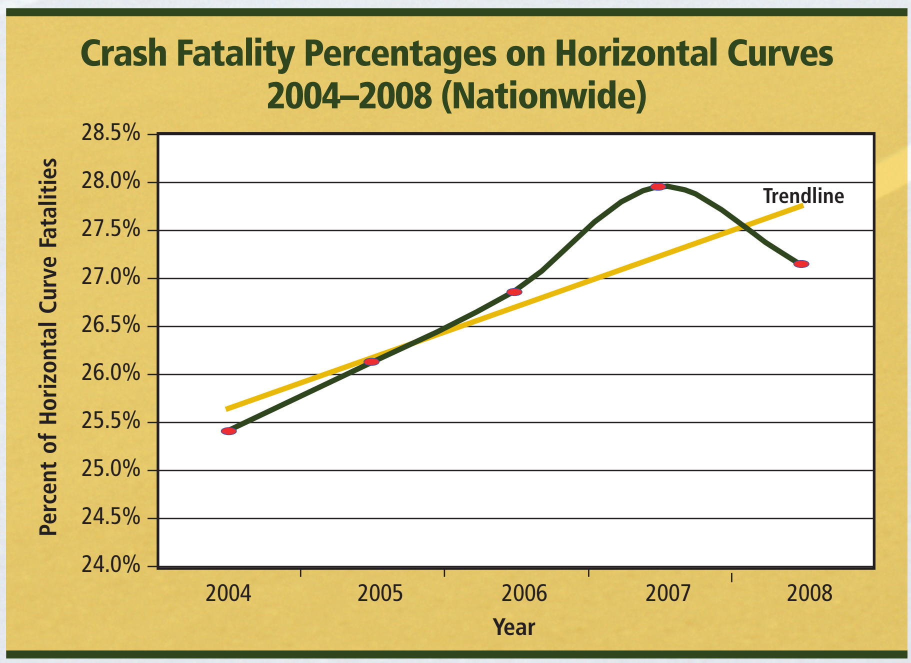
By day, this curve might appear easy enough to navigate, but darkness makes executing the turn much more dangerous. FHWA is helping States find the best options for improving night visibility and safety in general.

The Connecticut Department of Transportation (ConnDOT) used fluorescent yellow sheeting to improve signing at horizontal curves. This included installing new signs or replacing existing ones. Included were warning signs (for example, curve ahead or suggested speed limit) and curve delineation signs (chevrons or horizontal arrows).

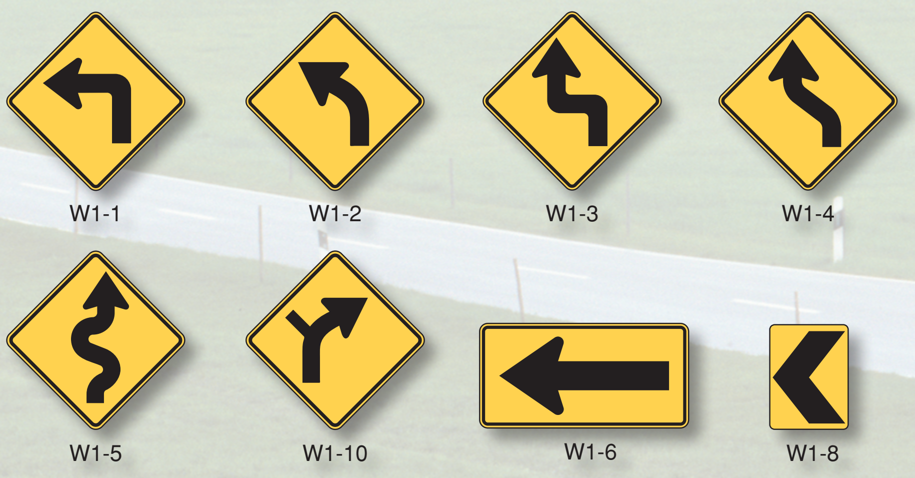
ConnDOT identified candidate locations for treatment through a regular safety program called the Suggested List of Surveillance Study Sites. The list uses crash data, traffic volumes, and roadway characteristics to identify intersections and road segments with higher than expected crash rates. District engineers reviewed the locations to identify those on horizontal curves. The engineers then treated the curves with improved signing. ConnDOT received positive feedback from enforcement officials who asked to have similar improvements at other curves.

Unlike Connecticut, the treatments in Washington involved the State DOT installing only chevrons (W1-8 signs) on horizontal curves, without any other delineation or signing. This treatment included installing chevrons for the first time at some locations and adding additional chevrons to sites that already had a few.

Using the empirical Bayes method, TFHRC investigated the effects of the changes in delineation through aggregate and disaggregate crash analyses (that is, comparing crashes at each site and at groups of sites before and after the strategies were installed). The aggregate analysis revealed an overall 18 percent reduction in injury and fatal crashes, along with a 27.5 percent reduction in total crashes and a 25 percent drop



Despite an overall downward trend in highway fatalities across the United States, the trend of fatalities that occur at horizontal curves is increasing (as shown here), indicating that curves remain treacherous territory. *Source: FHWA.*



Connecticut installed these types of signs, as shown here from FHWA's *Manual on Uniform Traffic Control Devices*, to improve safety on horizontal curves.

in lane-departure crashes in dark conditions. All of the results were statistically significant at the 95 percent confidence level. Total crashes on curves and lane-departure crashes on curves (that is, crashes involving a vehicle leaving its lane) decreased by about 9 percent, but this change was not statistically significant.

A more detailed review revealed that crash reductions were greater at locations with higher traffic volumes, sharper curves (radii less than 492 feet, or 150 meters), and with more hazardous roadsides (roadside hazard rating of 5 or higher, on a scale of 1 to 7, with 7 being the most hazardous). The analysis also indicated greater crash reductions at locations with higher levels of improvement; that is, on curves where the DOTs either added more signs or substituted signs with more retroreflective material.

TFHRC conducted an economic analysis to determine the relative cost effectiveness of curve delineation improvements. Excluding labor, the unit cost of the fluorescent yellow signs used in Connecticut ranged from $30 to $160 depending on the size of the signs. Smaller signs such as chevrons and advisory speed signs were cheaper than larger signs such as curve warning signs. The unit cost of the chevrons in Washington was about $100.

The researchers then computed the average annualized costs of the signs assuming 5-year service lives, and compared them to the estimated annual benefits. They determined that improving curve delineation with signing upgrades is very cost effective, with a benefit-cost ratio exceeding 8:1.

Curve Multistrategy Safety Improvements

Although the pooled fund study is providing some quantitative measures of the safety benefits of enhanced delineation on curves, many other treatments also are promising. The *NCHRP Report 500* series lists treatments and strategies that were experimental and/or had limited use. One critical research need is to evaluate these new options as well as other treatments that emerge. Each strategy needs to be evaluated alone and in combination with others to determine its effectiveness in various situations.

Some previous evaluations during this pooled fund study were retrospective, in that they looked at strategies that had been in place for years. In 2008, however, the study took a different approach to overcome various sample size constraints. Between 2008 and 2010, six States completed installation of safety strategies at various horizontal curve sites for build-to-evaluate or prospective evaluations. The States—Florida, Iowa, Kansas, Kentucky, Missouri, and Virginia—and TFHRC researchers selected the sites and the most appropriate (in terms of constructability within cost constraints) safety strategies by analyzing statewide crash data. The strategies included surface friction treatments on curves (two- and four-lane roads), surface friction treatments on ramps, in-lane pavement markings for curve warnings, larger and brighter chevrons, and edgeline rumble stripes on curves.

The States are installing single treatments at some sites and combinations of treatments at others. In-lane pavement markings and surface friction treatments are two notable experimental strategies: only a handful of agencies nationwide have used these treatments for this type of application. FHWA facilitates communication among the participating States so they can share information on their progress and learn from each other's efforts. In 2013, after 3 years of data collection, TFHRC and the States will evaluate the data and identify any effects of the treatments, comparing data from 3 years before and 3 years after completion of the safety improvements. A summary of the efforts by four of those States follows.

Iowa

For some time, the Iowa Department of Transportation's (Iowa DOT) highway safety improvement program has focused on low-cost but effective safety improvements, including strategies to reduce fatal crashes on curves. According to Tom Welch, a retired State transportation safety

Improving Curve Delineation Through Signing

Crash Type	Reduction in Crashes (Percentage Estimate)	Standard Error
Injury and Fatal Curve Crashes	18.0%	8.6
Nighttime Curve Crashes	27.5%	7.3
Nighttime Lane Departure Crashes on Curves	25.4%	7.8

Source: Safety Evaluation of Improved Curve Delineation *(FHWA-HRT-09-045).*

Summary of Economic Analysis Results

State	Sites	Years	Total Crash Reduction (per year)	Total Crash Reduction (per site-year)	Crash Savings (per site-year)	Range of Benefit-Cost Ratios
All	228	4.58	11.373	0.050	$4,347	12.7 to 67.9
Connecticut	89	3.05	6.686	0.075	$6,546	19.1 to 102.3
Washington	139	6.76	4.687	0.034	$2,938	8.6 to 45.9

Source: Safety Evaluation of Improved Curve Delineation *(FHWA-HRT-09-045).*

engineer for Iowa DOT, a 2004 crash analysis found that 11 percent of all primary highway fatal curve crashes occurred on just 30 curves in Iowa. On those curves, Iowa DOT installed low-cost improvements that included paved shoulders with rumble stripes and larger, brighter chevrons. The agency also removed fixed objects outside the curves. State and county engineers are making low-cost systematic improvements at other curves and accelerating improvements at high-crash curves.

For TFHRC's six-State pooled fund study, Welch says he expects there will be a sufficient sample of each of five strategies, and combinations of them, to conduct a scientific evaluation of their safety effects by 2013. "It is the hope that the results of these evaluations, if positive, will encourage other agencies to implement these strategies," he says.

Kansas

The Kansas Department of Transportation (KDOT) is in the process of selecting curve sites for its part in the pooled fund study. The agency's analysis of rural, two-lane, undivided, nonintersection, nonanimal crashes revealed that more than 20 percent occurred at horizontal curves. KDOT mapped any curves with more than three of this crash type in a 5-year period. Knowing the number of crashes, annual average daily traffic, radius, and length of each curve, KDOT estimated safety performance functions (SPF) and ranked the top 140 curves. "So now we have a strong list of candidate locations," says KDOT Safety Engineer Steven Buckley. About 30 of the identified curves appear in Kansas's "5 percent report" to FHWA, which describes the State's roadway sites with the most pressing safety concerns.

"Many strategies can't or shouldn't be applied systematically—some are cost prohibitive while others are rendered ineffective if overused," Buckley says. "For these reasons, the question becomes which type of strategy to apply where. This question is best answered with real-world research—thus our participation in the build-to-evaluate phase of this pooled fund study."

Kentucky

The Kentucky Transportation Cabinet's (KYTC) contribution to the pooled fund study will include friction treatments, in-lane pavement markings, improved curve warning signs, and edgeline rumble stripes. Many of the candidate locations will be selected from the State's Roadway Departure Safety Implementation Plan (RD Plan), which was developed in cooperation with FHWA and identifies sites with roadway departure crash histories that could be addressed by proven low-cost countermeasures.

KYTC developed a list of the 10 curved ramps that had the highest number of single-vehicle crashes over a recent 3-year period. According to Scott Pedigo, a KYTC safety engineer, 258 of the 286 crashes (about 90 percent) occurred on wet pavement. For the pooled fund study, the agency plans to install a high-friction treatment at several of these ramps. The RD Plan also lists more than 200 other locations on State rural roads where surface friction treatments should be considered.

Further, Kentucky plans to deploy enhanced signs and markings at approximately 23 curves selected because of their crash histories. Enhanced signing likely will include larger signs fabricated with diamond-grade, fluorescent yellow sheeting. The State expects implementation costs to be no higher than $5,000 per curve.

In addition, Kentucky is in the second year of a pilot effort to

ConnDOT

A yellow left curve and chevron signs in New Britain, CT, mark the way for drivers, which can be especially important in low-light or wet weather conditions, such as shown here.

MoDOT

MoDOT

On this two-lane rural road in Stoddard County (left), MoDOT added a paved shoulder, installed edgeline rumble stripes, and placed chevron signs along this curve (right), improving safety for drivers.

install edgeline rumble stripes on two-lane roadways as they are being resurfaced. In the first year, the department installed approximately 47 miles (76 kilometers) of edgeline rumble stripes and planned to install more than 150 miles (240 kilometers) of edgeline rumble stripes in 2010. These sections will be included in the pooled fund study's analysis of edgeline rumble stripes on curves. If these pilot studies are successful, edgeline rumble stripes could be installed on nearly 1,000 miles (1,600 kilometers) of Kentucky's rural roadways in the future, at hazardous locations identified in the RD Plan.

Missouri

The Missouri Department of Transportation (MoDOT) also is paying particular attention to lane-departure crashes. "This crash type is one that MoDOT believes can be reduced in a variety of ways, but especially through engineering improvements," says MoDOT Traffic Safety Engineer John P. Miller. So far, the primary engineering safety improvement has been use of rumble stripes on improved shoulders and chevrons in curves. Generally MoDOT has installed rumble stripes on improved shoulders on Missouri's most traveled roadways, but it also uses this approach, along with chevrons, on high-risk rural roads as a curve improvement.

"In Missouri, a large percentage of run-off-road crashes occurs in curves," says Miller. "Using strategies like rumble stripes on improved shoulders for a system of routes will help reduce severe crashes on these roads overall."

Miller notes that a recently completed project on a high-risk rural road involved both chevron installation and rumble stripes on improved shoulders. The project was fairly inexpensive, about $55,000, and involved a series of curve improvements on the route.

Missouri is just now beginning to see the benefit of its overall lane-departure strategy, as fatalities from this kind of crash on the most traveled roadways went down 41 percent between 2005 and 2009. Because this strategy is successful, Miller says, MoDOT can continue to implement it on more roadways and especially on curves with chevron installations. And, as with the other States, these findings will support the TFHRC pooled fund study.

Improving Nighttime Visibility of Curves

Another aspect of the pooled fund study is to evaluate innovative treatments to improve the nighttime visibility of curves. One component of the study involved experiments using TFHRC's driving simulator. Simulation is beneficial because it can provide objective measures of safety effectiveness without having to physically build the safety improvements at many locations.

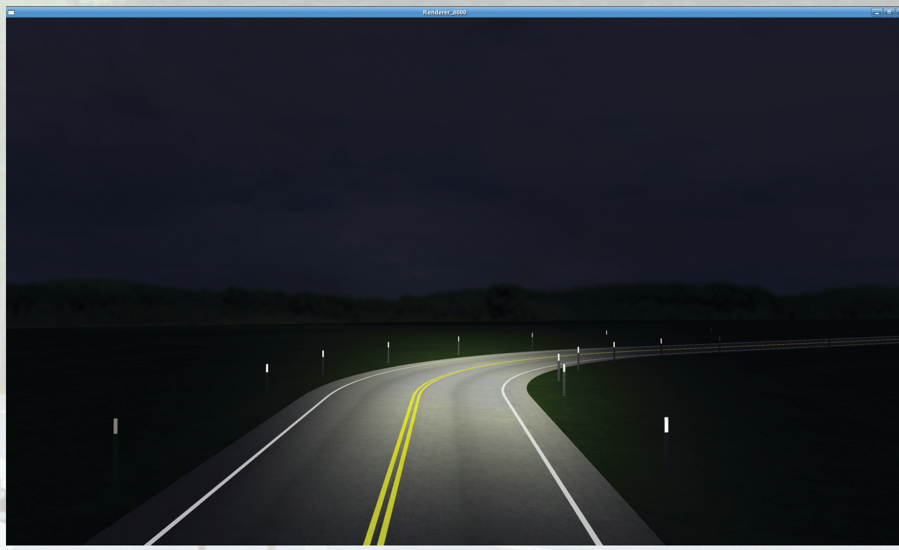
Researchers used the simulator to evaluate two sets of low-cost safety improvements for rural areas. They programmed in the software a set of improvements to enhance the visibility of curves on rural, two-lane, undivided roads at night. The simulated improvements were (1) edgelines and (2) standard reflectorized as well as "streaming" post-mounted delineators. The latter consist of light emitting diodes (LEDs) mounted on posts and programmed with time delays such that the individual LEDs simulate a stream of light traveling around a curve at night, highlighting the curve for motorists.

The results of the experiment indicated that edgelines offered a small potential safety benefit. However, combining standard reflectorized post-mounted delineators with edgelines offered a somewhat greater benefit. This result does not imply that edgelines are not needed; edgelines provide continuous delineation of travel lanes, especially at close

Researchers at TFHRC use this Highway Driving Simulator to evaluate potential low-cost safety improvements that could reduce crashes at horizontal curves on rural roads.

AAI

Here, the TFHRC simulator depicts a two-lane rural road at night with curve delineation and post-mounted delineators on both sides of the road.



AAI

range. Of all the treatments explored, the streaming post-mounted delineators with edgelines offered the most promising potential safety benefit. However, no applications exist for streaming post-mounted delineator on two-lane rural roads, nor are the cost implications of developing such a system known. Therefore, the TFHRC researchers recommend further study including economic analysis and field validation of this potential safety improvement.

Looking to the Future

TFHRC researchers also are looking at the potential safety improvements associated with combining centerline and edgeline rumble stripes on curves with no shoulders or narrow ones. The research is focused on two-lane rural roads in Missouri and Pennsylvania with shoulders less than 4 feet (1.2 meters) wide. All installations are to be completed in 2012.

Also, in 2011, TFHRC will begin an evaluation of the role of pavement performance on curves nationwide. The goal is to identify the extent and severity of a pavement's contribution to curve crashes. The researchers will look at pavement type, age, skid number, and condition. These findings will lead to the identification of applicable low-cost safety countermeasures where pavements are identified as contributors to crashes at curves. This research will be based on the findings of an in-house study involving the FHWA Office of Safety Research & Development and the Highway Safety Information System (HSIS.)

Overcoming Data Challenges

A major barrier to improving safety on horizontal curves is the lack of inventory information about exactly where curves are located and their characteristics. Some agencies have partially overcome this challenge by (1) using crash data to identify crash clusters or (2) using sign inventories to identify locations that are signed with chevrons. Other approaches include (3) visually identifying curves by using geographic information system data or other maps; (4) working with district, county, or other local agency staff to locate curves from memory and local knowledge; and (5) working with enforcement staff to identify hazardous curves based on field observations. Although each of these methods has known weaknesses, in the absence of a comprehensive curve inventory, they do provide some ability to make targeted improvements.

Compiling a horizontal curve inventory would not only make targeted improvements possible in response to crash problems, but it also would make systematic improvements feasible. For example, a curve inventory that contains the location and some characteristics (such as degree of curvature, length of curve, and length of spiral) could help DOTs identify and program systematic improvements at horizontal curves. The agencies could apply strategies used only at some curves to those with similar characteristics. In addition to chevrons and advance curve signs, a DOT could apply lane curve warnings at sharper curves. DOTs also could use inventory and crash data analysis to systematically upgrade all curves in a given jurisdiction.

"If we are going to successfully reduce fatalities by half within 20 years, we will need to learn to do more with less," says KDOT's Buckley. "We're engineers. We're engineered to build things. But why rebuild one curve and address maybe 10 crashes when we can re-sign, mark, or surface 10 curves for the same price and address maybe 100 crashes? That, at its core, is the value of low-cost safety improvements and related research."

Roya Amjadi is a research civil engineer (highway) at TFHRC and has more than 20 years' experience in transportation engineering. She manages the Evaluation of Low Cost Safety Improvements Pooled Fund Study and Rural Safety Innovation Program. She has a B.S. in mechanical engineering from the University of Iowa and an M.S. in civil engineering transportation safety from Cleveland State University. Currently, she is working toward a master's in statistics at George Mason University.

Kimberly Eccles, P.E., is a senior engineer with Vanasse Hangen Brustlin, Inc. (VHB). She has more than 12 years of experience in transportation safety, specializing in safety evaluations, and is the principal investigator for the pooled fund study. She manages the VHB satellite office in Raleigh, NC. Eccles has a B.S. in civil engineering from Michigan State University and an M.S. in civil engineering from North Carolina State University.

For more information, contact Roya Amjadi at 202-493-3383 or roya.amjadi@dot.gov, or Kimberly Eccles at 919-834-3972 or keccles@vhb.com, or visit www.tfhrc.gov/safety/evaluations.

FHWA's Aerodynamics Laboratory is working on a number of research fronts to make bridges more resilient.

Winds, Windstorms, and Hurricanes

by Harold R. Bosch

Over the years, wind-related events, such as hurricanes, tornadoes, and winter storms, have resulted in significant losses of life and property in the United States. Based upon data presented in the 2003 Office of Science and Technology Policy report, *Assessing Federal Research and Development for Hazard Loss Reduction*, the total annualized societal losses attributed to wind events are estimated to be $6.3 billion. The losses exceed those attributed to earthquakes and floods by more than 40 percent and 100 percent respectively.

Furthermore, direct and indirect losses from a *single* extreme wind event can easily surpass $26 billion, as happened in Hurricane Andrew (1992), according to the National Climatic Data Center. These events can damage highway infrastructure and disrupt operations on the Nation's transportation network. Given that highways are vital lifelines in Americans' daily lives and critical to the U.S. economy and security, impacts from wind hazards can have major consequences.

In addition, exposed sections of highways or elevated structures need to be closed periodically due to high winds to ensure the safety of the traveling public. Traffic is rerouted for long periods during the

(Above) A researcher with the FHWA Aerodynamics Laboratory sets up instrumentation for cable vibration tests on the Penobscot Narrows Bridge in Maine. The FHWA wind research program conducts laboratory and field studies to reduce vibration on bridges.

subsequent repairs or replacements, resulting in congestion and delays.

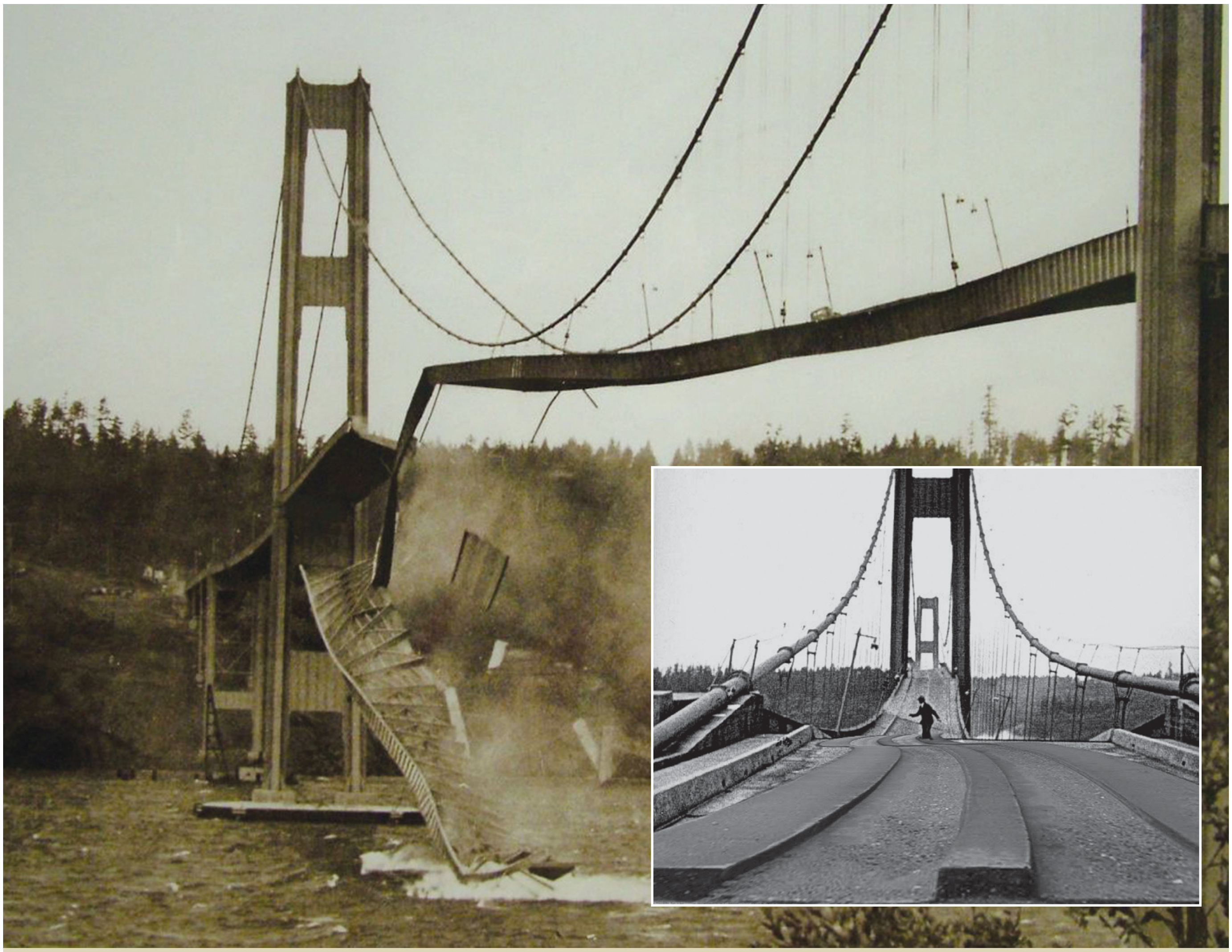
"The Federal Highway Administration's [FHWA] wind research program addresses these problems by conducting laboratory and field studies with the goal of making the Nation's highway bridges more aerodynamically resilient," says Jorge E. Pagán-Ortiz, director of FHWA's Office of Infrastructure Research and Development. "Researchers at the program's laboratory and its partners have conducted basic, applied, and exploratory advanced research leading to new test methods for aerodynamic assessments, tools for predicting structural response to wind, improved design guidance, advances in design codes, and mitigation techniques."

Background

Since the 1836 collapse of the Brighton Chain Pier in England due to oscillations, the effect of wind events on highways, and transportation structures in particular, has concerned engineers. From 1818–1889, windstorms worldwide caused 10 suspension bridges to collapse or suffer major damage, including three in the United States.

In the half century that followed, many larger and lighter structures were constructed without any major wind-related problems—until the fateful collapse of the Tacoma Narrows Bridge in Tacoma, WA, on November 7, 1940. In the 3 years immediately preceding this event, five newly completed bridges exhibited sensitivity to winds and resulting oscillations. As a result, engineering awareness heightened about the potential sensitivity of flexible bridges to winds.

The investigation into the collapse of the Tacoma Narrows Bridge resulted in the 1949 publication of *Aerodynamic Stability of Suspension Bridges* by the University of Washington under the direction of the Washington Toll Bridge Authority in cooperation with FHWA's predecessor, the Bureau of Public Roads (BPR). This report documents one of the first looks into bridge aerodynamics using field observations and testing, mathematical analysis, and wind tunnel testing. Prior to this investigation, the use of wind tunnels in the study of wind effects on ground-based structures was uncommon. However,



On November 7, 1940, the dramatic collapse of the Tacoma Narrows Bridge (shown here) sparked renewed research into the aerodynamics of suspension bridges. The structure was under constant observation during its short 4 months of active life until its collapse in a windstorm. (Inset) This view down the center of the bridge shows the twisting of the spans from the storm.

Estimated Annualized Losses by Hazard

Hazard	Estimated Annualized Loss ($ billions)
Hurricanes	5.0
Winter Storms	0.3
Tornadoes	1.0
Total Wind	6.3
Floods	3.0
Hail	0.7
Extreme Heat	0.1
Extreme Cold	0.5
Total All Weather	10.6
Wildfires	2.0
Earthquakes	4.4

Source: Charles Meade and Megan Abbott, Assessing Federal Research and Development for Hazard Loss Reduction.

Bridges Severely Damaged or Destroyed by Wind

Bridge	Location	Designer	Span (ft)	Failure Date
Dryburgh Abbey	Scotland	John and William Smith	260	1818
Union	England	Sir Samuel Brown	449	1821
Nassau	Germany	Lossen and Wolf	245	1834
Brighton Chain Pier	England	Sir Samuel Brown	255	1836
Montrose	Scotland	Sir Samuel Brown	432	1838
Menai Straits	Wales	Thomas Telford	580	1839
Roche-Bernard	France	Le Blanc	641	1852
Wheeling	USA	Charles Ellet	1,010	1854
Niagara-Lewiston	USA	Edward Serrell	1,041	1864
Niagara-Clifton	USA	Samuel Keefer	1,260	1889
Tacoma Narrows	USA	Leon Moisseiff	2,800	1940

Source: University of Washington.

in the coming decades, they became a well-established, and in many cases essential, tool for this purpose.

Not long after this landmark work, the BPR established the wind research program and the Aerodynamics Laboratory at the Fairbank Highway Research Station, now known as the Turner-Fairbank Highway Research Center (TFHRC), to improve understanding of the effects of wind on transportation structures. To ensure success, BPR, which by then had become FHWA, initiated ongoing collaboration with several other laboratories, such as the National Research Council Canada and Public Works Research Institute of Japan. Today, the program also has a close relationship with various universities and consultants.

Aerodynamics Laboratory Facts

The FHWA Aerodynamics Laboratory features two wind tunnels of varying sizes and functions, along with an array of support equipment. Of the test facilities, the most prominent is a large, low-velocity, open-circuit wind tunnel. With its 6- by 6-foot, ft (1.8- by 1.8-meter, m) test section, this tunnel can generate extremely smooth (laminar) flow at speeds up to 44 feet per second (ft/s), 13.4 meters per second (m/s). Originally designed for testing long-span bridges, the facility can simulate prototype wind speeds up to 150 miles per hour (mi/h), 67 meters per second (m/s), and at large model scales of 1:25. At smaller scales—for example, 1:100—speeds up to 300 mi/h (134 m/s) can be achieved.

For experiments where turbulent flow is desired, the researchers insert an active turbulence generator into the test section between the wind tunnel and the model. To measure wind loads on structures, they place models in a large, dual force balance (a precision sensing system to measure forces, such as lift and drag, on a model) where they can vary the vertical wind attack angle by rotating the model in the flow. Because this is a dual balance system, unbalanced loads on structural components such as tapered cylinders also can be measured. An automated dual three-dimensional (3–D) robot system is available to study flow in the test section and measure flow field details around models.

The second wind tunnel is a higher speed, closed-circuit facility with an open test section measuring 10 by 10 inches, in (25.4 by 25.4 centimeters, cm). Speeds up to 90 mi/h (40 m/s) can be generated. The tunnel is equipped with a fog generator and is well suited for use of particle image velocimetry to visualize flow fields around structures or structural components. This small tunnel also is equipped with a 3–D robot system for detailed flow field measurements, as well as a two-dimensional shaker system for experiments that require forced vibration tests.

In the large, open-circuit wind tunnel (far left) in FHWA's Aerodynamics Laboratory at TFHRC, smooth and turbulent wind conditions are simulated during static and dynamic testing of structural models.

Bridges That Have Oscillated in the Wind

Bridge	Year Built	Span (ft)	Type of Stiffening
Fyksesund (Norway)	1937	750	Rolled I-beam
Golden Gate	1937	4,200	Truss
Thousand Islands	1938	800	Plate Girder
Deer Isle	1939	1,080	Plate Girder
Bronx-Whitestone	1939	2,300	Plate Girder

Source: University of Washington.

Past Research Projects

The FHWA Aerodynamics Laboratory has conducted a number of wind tunnel investigations to develop retrofits for problematic existing bridges and to evaluate the performance of new designs. An example of the latter is proposed designs for the Hale Boggs Memorial Bridge in Louisiana. For this major project, the TFHRC researchers performed a series of wind tunnel tests on four basic design alternatives, including a total of 15 configurations, to determine the configuration with the optimum performance in the expected wind conditions, including hurricanes. The researchers further examined the final configuration at three construction stages to ensure stability during erection.

To evaluate particularly complex problems in structural performance, FHWA sometimes performs full-scale measurements and analytical studies. At the request of the Maine Department of Transportation (MaineDOT), the TFHRC researchers conducted a comprehensive program of measurements, analytical studies, and wind tunnel simulations to evaluate the behavior of MaineDOT's Deer Isle–Sedgwick Bridge. This bridge, built about the same time as the original Tacoma Narrows Bridge and similar in configuration, had been exhibiting a number of wind response problems that resulted in periodic closures and significant damage requiring major repairs.

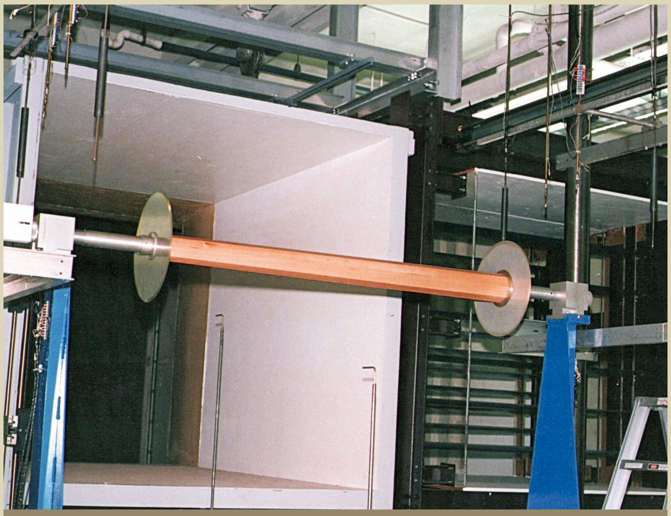
The researchers conducted wind tunnel tests on a 1:25 scale section model of the bridge to assess aerodynamic behavior, evaluate the influence of snow blockage of curb grates (raised open grates along the right edge of each traffic lane), and explore possible mitigation measures. Field measurements and predictions from numerical modeling confirmed observations from the wind tunnel simulations.

Through this work, the researchers developed a retrofit measure consisting of nonstructural fairings, which are streamlining plates that reduce vibrations. MaineDOT implemented the retrofit, and TFHRC researchers are monitoring the bridge's post-retrofit performance.

As part of a major rehabilitation project, a similar aerodynamic retrofit recently has been added to the Bronx-Whitestone Bridge in New York City, another bridge from the same era.

Sometimes, wind can induce vibrations in structural components such as columns, cables, tie beams, and truss members. Two examples

The small, closed-circuit wind tunnel at the lab is shown with a shaker apparatus installed in the test section at the photo's center. A bridge section model is installed in the shaker for forced vibration testing.



This tapered, multisided cylinder model in the wind tunnel test section is mounted in the dual force balance apparatus to measure wind forces at different speeds and attack angles. Researchers can simulate various wind attack angles by rotating the model relative to the wind using the balance.

are vibration problems with the columns of the Perrine Memorial Bridge in Idaho and truss members of the Commodore Barry Bridge, owned by the Delaware River Port Authority.

The Idaho bridge is a large, steel, deck-arch structure that has columns with unsupported lengths ranging from 7 to 160 feet, ft (2.1 to 48.8 meters, m). Moderate daily winds, traveling up and down the Snake River Canyon, were causing visible, and sometimes significant, vibrations in the longer columns. To explore this vibration problem and assist the Idaho Transportation Department, the TFHRC researchers briefly installed instrumentation on the bridge to monitor wind conditions and resulting column behavior. They also performed analytical work to develop a numerical method to assess the stability of long columns with elastic end constraints. As a result of these activities, Idaho designed and installed tuned mass dampers (a weight on a flexible beam tuned to match a structure's vibration frequency) inside the columns to mitigate the vibrations.

The Delaware River Port Authority deployed a similar solution using external tuned mass dampers on the vertical truss members of the Commodore Barry Bridge. Another type of damper solution using both internal and external damping devices on the cables was included in the original design of the Arthur Ravenel Jr. Bridge in South Carolina.

This end view of the Deer Isle–Sedgwick Bridge in Maine is shown following installation of fairings designed in the FHWA Aerodynamics Laboratory. The fairings are triangular in shape and extend over the full length of the suspended portion of the structure.

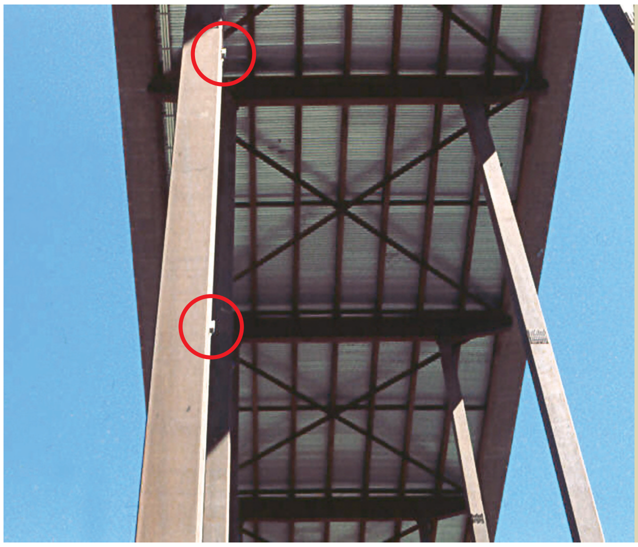
Recent and Ongoing Research

The FHWA Aerodynamics Laboratory recently conducted research on wind loading in five project areas: highway signs and lights, cable-supported structures, full-scale measurements, long-term monitoring, and large amplitude cable vibration. Some of these studies are ongoing.

Signs and lighting. The structural supports for highway signs, luminaries, traffic signals, and high mast lighting often consist of cylindrical members with multisided shapes and tapering along their length for structural efficiency. A number of these structures have collapsed due to fatigue resulting from natural wind loading or gust loading from trucks. To establish the wind loads and pressures for design of these structures, engineers need to know the lift and drag properties of the components. The literature reports considerable research on circular cylinders with uniform diameter, establishing these properties, but for multisided shapes and tapered members, detailed information is much more limited.

With this information gap in mind, researchers at TFHRC designed a series of representative models with various diameters, number of sides, and taper ratios for testing in the wind tunnel. They fabricated a total of 71 models representing circular, hexagonal, and octagonal sections with diameters ranging from 2 to 5 inches, in (5.1 to 12.7 centimeters, cm) and with taper ratios ranging from 0.0 to 0.3 in/ft (0.0 to 2.5 cm/m). Models with a greater number of sides are planned as well. So far, FHWA has conducted static tests on 53 of these models to obtain force coefficients for comparison with American Association of State Highway and Transportation Officials' code values. The researchers also are planning dynamic tests to obtain detailed information regarding wind-induced vibration problems, such as vortex shedding response (response to pressure fluctuations resulting from the shedding of vortices) and galloping (instability of slender structures with a certain shape resulting in large oscillations).

Cable-supported structures. For the most part, design codes do not provide detailed wind load criteria for large cable-supported structures or otherwise complex and unusual structures. Although some uniformity



The rectangular-shaped steel columns of the Perrine Memorial Bridge, which spans the Snake River Canyon in Idaho, rest on a steel arch and support the deck girders above. On the column on the left, vibration sensors (circled) are mounted on the inside face at 25 and 50 percent of the column height.

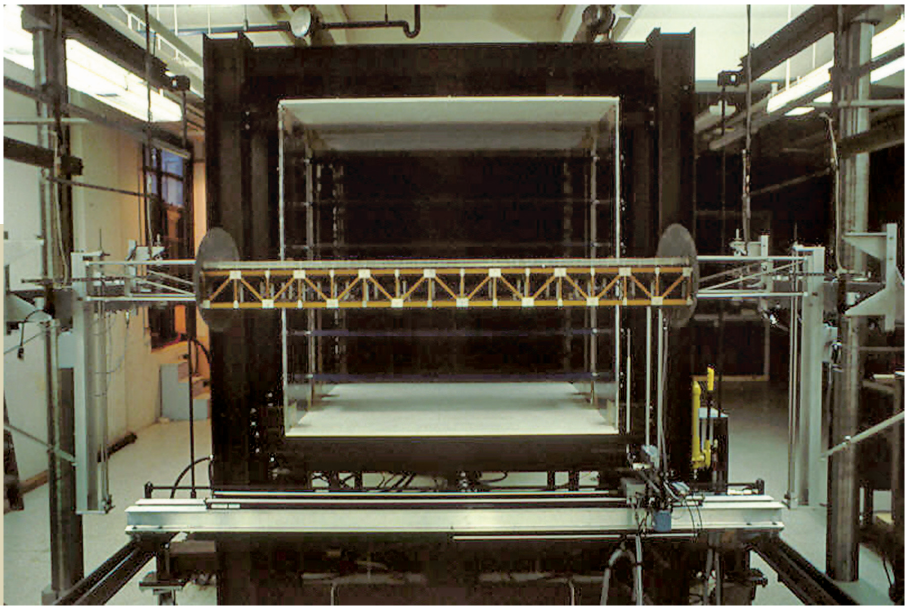
This photo shows one of several types of dampers deployed on the Arthur Ravenel Jr. Bridge in South Carolina to mitigate wind-induced cable vibrations. A trussed support frame is anchored to the deck, and two pairs of viscous dampers are fastened to the top of the frame. The upper ends of the dampers are attached to a collar that is clamped to the outside of the cable.

exists in the general approaches employed to arrive at design criteria for wind conditions, the assumptions, techniques, and procedures employed depend on who is performing the aerodynamic assessment and climatological study. To address the resulting variability, researchers at the FHWA laboratory launched a project to survey and review current approaches and prepare a synthesis report. The research has looked into issues such as selection of recurrence intervals for wind conditions, determination of design wind speeds, influence of directionality and terrain, climate models, and treatment of extreme events. The research will serve as the basis for later development of consistent procedures for establishing design wind loads.

Full-scale measurements. To complement the physical modeling in the Aerodynamics Laboratory, TFHRC researchers maintain a parallel program of full-scale measurements. Such measurements provide detailed information on site wind conditions and structural behavior that is not available from any other source. The measurements aid in the design of laboratory simulations and serve to validate those tests. Full-scale measurements can provide a means to calibrate the results of numerical predictions and computational simulations. They can be used to diagnose wind-related structural problems and to evaluate the effectiveness of aerodynamic retrofits to bridges.

Historically, field tests have consistently been a highly productive way to advance understanding of the interaction of loads with structures. The full-scale measurement program is ongoing and consists of short-term tests to focus on specific structural issues, as well as long-term monitoring to characterize site wind conditions and structural behavior. Currently, researchers are monitoring two long-span bridges for long-term and one bridge for short-term structural issues. The instrumentation systems developed for this task are designed to function autonomously but have remote communication capability so that TFHRC can access data and perform direct system control. To measure the wind and associated structural response, an array of wind, meteorological, vibration, and sometimes displacement sensors are placed strategically on and near the structure.

Long-term monitoring. The long-term monitoring of major bridges under adverse conditions requires



Shown here is a model of California's Golden Gate Bridge in the test section of TFHRC's large wind tunnel. The model is mounted on a spring suspension for study of dynamic response to simulated wind conditions. Behind the model, or upstream, is the laboratory's active turbulence generator for introducing wind gusts into the simulated approach flow.

This schematic shows the design concept for a real-time wind and earthquake monitoring system developed by laboratory staff and proposed for the replacement Tacoma Narrows Bridge. The diagram illustrates placement of wind, vibration, and ground motion sensors. Also shown is the routing of cables and placement of conduits and cabinets. Insets show what the installation details might look like.

robust instrumentation and sensors, sound deployment and maintenance techniques, and comprehensive data management and analysis. TFHRC researchers have developed expertise in all these areas through participation in numerous field projects spanning the past half century. As one example, Aerodynamics Laboratory staff recently assisted the Washington State Department of Transportation and Washington State University by designing a multihazard wind and earthquake monitoring system for the new Tacoma Narrows Bridge and modifications to the existing bridge. The resulting design was cost effective, merging some of the latest technologies with techniques and concepts proven reliable on previous projects. Key features were incorporated into the design, such as expandability, multiple synchronized data hubs (collection points with data acquisition equipment), a blend of wired and wireless technologies, and comprehensive remote access to the system and data via the Internet. While much could be learned from long-term monitoring of these major structures, currently there is no funding or plans for installing this system.

Large amplitude cable vibration. With increasing frequency in recent years, transportation professionals have observed large amplitude vibration of stay cables under conditions of moderate wind, sometimes in conjunction with light rain. This problem is not new; extensive study started in the mid-1980s. But with a growing inventory of cable-stayed bridges in the United States, reports of large amplitude cable vibrations and damage have increased significantly.

To mitigate these vibrations, some structures have been retrofitted. For cable-stayed bridges currently under design or construction, engineers are incorporating dampers, crossties, or aerodynamic surface treatments into the cable system. A national Transportation Pooled Fund research project led by the Missouri Department of Transportation and FHWA, SPR-3(078) Wind Induced Vibration in Cable Stayed Bridges, is underway to investigate this cable vibration

After construction of the Hale Boggs Memorial Bridge in Louisiana, laboratory researchers are performing maintenance on accelerometers mounted on the stay cables. The sensors, installed in small steel enclosures clamped to the outside of each cable, monitor wind-induced vibration.

This photo shows wind-induced damage to a guide pipe of a stay cable on the Fred Hartman Bridge in Texas. As a result of large amplitude cable vibrations, cracks or fractures developed in the stiff steel guide pipes intended to minimize cable rotations in the anchorage areas. For this cable, the guide pipe has broken loose from the anchor box.

problem and develop comprehensive guidelines for both retrofits and new construction. Among other things, the study involves synthesis of existing information, analysis of the mechanics of wind-induced cable vibration, wind tunnel testing to clarify dry cable galloping, and evaluation of mitigation methods.

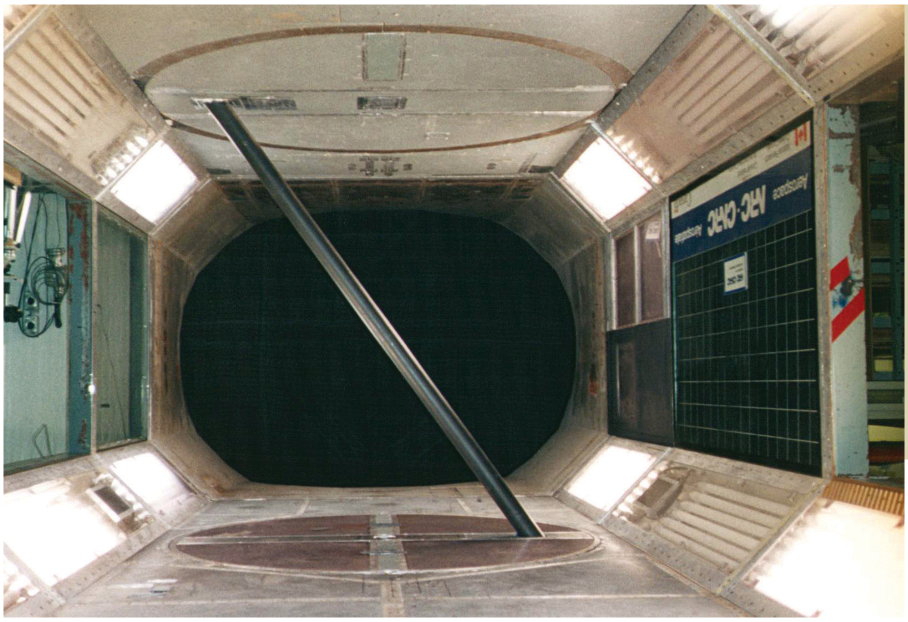
In conjunction with this project, a number of full-scale experimental studies have established the dynamic properties of representative bridge stay cables and performance of various mitigation features. The FHWA researchers have performed tests on new bridges such as the Leonard P. Zakim Bunker Hill Memorial Bridge (Massachusetts), Bill Emerson Memorial Bridge (Missouri), and Penobscot Narrows Bridge (Maine), as well as existing bridges such as the Hale Boggs Memorial Bridge (Louisiana), Sunshine Skyway Bridge (Florida), and U.S. Senator William V. Roth, Jr. Bridge (formerly the C&D Canal Bridge) (Delaware). For the new bridges, the researchers took measurements at various stages of construction to facilitate evaluation of cables with and without grout, dampers, or crossties. They used a small and portable, but robust, instrumentation package to minimize interference with construction activities and traffic operations.

Current Research Projects

Current FHWA research projects include parametric studies, aerodynamic assessments, and measurements of stresses on structural components.

Parametric studies. Japanese researchers have conducted a number of parametric, aerodynamic studies of various deck geometries and details, and they have used the resulting information in the development of their 2008 *Wind Resistant Design Manual for Highway Bridges in Japan*. Building on this Japanese work, a new project is underway by the Aerodynamics Laboratory to investigate a variety of generic geometries, actual bridge sections, and bridge details. The research involves special static and dynamic studies in the laboratory to extract and catalog aerodynamic properties, and will serve as a basis for later development of draft design criteria.

Comprehensive report on aerodynamic assessments. An aerodynamic assessment, usually involving one or several wind tunnel tests, is almost always conducted on any design proposed for long-span bridges. Over the years since the dramatic collapse of the original Tacoma Narrows Bridge, hundreds of such studies have been performed in North America, largely in one of three laboratories in Canada or the FHWA Aerodynamics Laboratory, with a few in other U.S. labs. The results of these investigations represent a wealth of technical information that could advance understanding significantly and serve as an aid for design of future bridges. Unfortunately, many of the results and details remain in the archives of the laboratories conducting the



Shown here is a wind tunnel test by the laboratory's research partners at National Research Council Canada to measure wind pressures on a rigid model of an inclined cylinder representing a bridge stay cable. The researchers measured pressures using taps at several circumferential rings along the length of the model. They varied the yaw angle (horizontal angle between the approaching wind and a vertical plane containing the cable) by rotating the model on a turntable.

work and the design consultants who commissioned the research. The results that are published are limited and scattered in the literature. The TFHRC researchers are working with other laboratories in North America to gain access to the archives to collect, catalog, and synthesize this information. They will compile the results into a comprehensive catalog suitable for use by researchers, designers, and bridge owners.

Stresses in structural components. Bridge designers estimate the expected wind pressures on a structure's vertical and horizontal surfaces and calculate the resulting stresses in structural components. For relatively simple structural shapes and configurations, the codes provide guidance for calculation of wind pressures. But for complex or flexible structures, or structures in complicated settings, establishing pressures through measurements on models in wind tunnels is quite common. Mean forces, such as uplift and drag, or forces integrated over the surfaces of the model typically are measured by installing a scale model in a force balance and placing it in a wind flow with various speeds and attack angles.

As part of FHWA's Exploratory Advanced Research (EAR) Program, researchers at the Aerodynamics Laboratory are investigating a new technology for measuring local pressures, using pressure-sensitive paint or surface-stress film on model surfaces. The objective is to explore, adapt, and deploy a new technology that will be well suited to the measurement of static and dynamic pressures over the surfaces of structural models with high spatial resolution while in low-speed wind flows.

New Research Activities

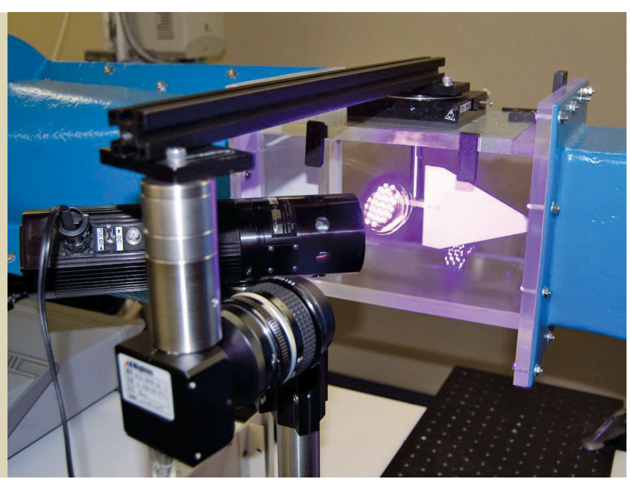
Two new projects will involve optimizing aerodynamic performance and addressing vibration of stay cables.

Optimization of aerodynamic performance. In the structural design of cable-stayed bridges, several road deck cross sections appear to have become favorites among design consultants throughout North America. Although designers have focused considerable effort on producing structurally efficient bridges, they have devoted much less attention to optimization of aerodynamic performance. Generally, cross sections are tested in the later stages of design to assess if they meet the specified aerodynamic design specifications or criteria. If they do not, additional tests are performed to "fix" the design.

The objective of FHWA's new study is to evaluate some of the more popular designs from an aerodynamic standpoint and focus on the significance of geometric details that are key to aerodynamic performance. The researchers will classify the most common road deck cross sections into a few generic shape categories. The Aerodynamics Laboratory will design special benchmark section models that are representative of each category and test them in the wind tunnels. The researchers will design the models so that details can be modified easily or retrofits introduced to explore ways to optimize aerodynamic performance. The researchers then will develop design guidelines.

Vibration of stay cables. Another new project is an extension of activities conducted under Transportation

One of the laboratory's research partners is testing a model treated with pressure-sensitive paint in a small wind tunnel. The light-emitting diode light source is on the center left with the camera on the photo's lower left. The model in the wind tunnel is a delta wing configuration.



Innovative Scientific Solutions, Inc.

Pooled Fund study SPR-3(078) to address the problem of wind-induced large amplitude vibration of bridge stay cables. Although research conducted under the pooled-fund study has increased understanding and led to development of draft guidelines, a number of significant knowledge gaps remain. For example, little or no information is available in the literature regarding the performance of aerodynamic surface treatments. In addition, the limited design criteria regarding galloping was removed recently from the Post-Tensioning Institute's *Recommendations for Stay Cable Design, Testing and Installation*, and proposed new criteria were not approved due to insufficient supportive evidence. The objective of the FHWA project is to fill some of these gaps in order to prepare a more complete guidelines document. The TFHRC researchers will perform wind tunnel tests to provide information regarding surface treatments and specific cable instability issues. The laboratory will complement the physical modeling with numerical modeling of cable responses to various wind or wind-and-rain loading conditions and by computational fluid dynamics (CFD) simulations as appropriate.

National Windstorm Impact Reduction Program

Introduced in the U.S. House of Representatives as H.R. 3980, the National Windstorm Impact Reduction Program legislation was later added to H.R. 2608, which reauthorized the National Earthquake Hazards Reduction Program. The legislation passed in the Senate and was signed into law as Public Law 108-360 on October 25, 2004. The program's goals are to achieve major measurable reductions in losses of life and property from windstorms through a coordinated Federal effort, in cooperation with other levels of government, academia, and the private sector. The aim is to improve understanding of windstorms and their impacts and develop and encourage implementation of cost-effective mitigation measures to reduce those impacts.

The Subcommittee on Disaster Reduction (SDR) under the National Science and Technology Council coordinates the program. (For more about the SDR, see "Taking a Key Role in Reducing Disaster Risks" in PUBLIC ROADS May/June 2010.) The law required the formation of an interagency working group consisting of representatives from four primary agencies (National Oceanic and Atmospheric Administration, National Institute of Standards and Technology, National Science Foundation, and Federal Emergency Management Agency) and other Federal agencies as appropriate. The working group prepared the *Windstorm Impact Reduction Implementation Plan* in 2006 and two biennial progress reports for Congress in fiscal years 2005–2006 and 2007–2008.

Concluding Remarks

"The FHWA wind research program will continue to conduct applied and advanced research using physical experiments, full-scale tests, and analytical studies to assess the impacts and reduce the risks of winds, windstorms, and hurricanes on the highway infrastructure," says FHWA's Pagán-Ortiz.

In the early days of the program, building the research infrastructure was necessary before the hazards could be investigated. Now that the laboratory is well established, enhancing and extending these resources will continue through automation of facilities, implementation of new simulation techniques, development of new sensors, and establishment of new test procedures.

The program will assess and incorporate developments in instrumentation as they become available, such as wireless data hubs, self-powered sensors, and miniaturized sensors. The laboratory will continue to develop and improve numerical tools for the prediction and evaluation of structural performance in response to wind loading. Although TFHRC researchers have performed some development work and computer simulations in the past using CFD, these activities will intensify in the coming years, taking advantage of the growth in computing power. For some of the more complex problem areas involving fluid-structure interactions, researchers will explore the use of computational multiphysics mechanics.

The laboratory will continue to assess the aerodynamic stability and performance of new designs and develop retrofit measures for inservice structures. The laboratory will work with the American Association for Wind Engineering, the International Association for Wind Engineering, and others to disseminate new information and procedures and to work toward international alignment of design codes for wind resistance.

Until recently, no comprehensive or coordinated program at the national level has addressed wind hazards to the built environment. Although several Federal agencies, such as FHWA and the National Oceanic and Atmospheric Administration, National Institute of Standards and Technology, and Federal Emergency Management Agency, have conducted studies addressing wind issues, their work has represented relatively small parts of much larger missions. The result has been a fragmented approach and slow progress. In 2004, however, the National Windstorm Impact Reduction Program was signed into law to address wind hazards through a coordinated Federal effort. Researchers at TFHRC serve on the interagency working group leading this program and will continue to be involved to ensure that FHWA's research provides maximum benefit to the public and the Nation's highway infrastructure.

Harold Bosch is a wind research program manager in the FHWA Office of Infrastructure Research and Development. He coordinates wind research activities with State and local agencies, academia, and various partners and customers, and he manages the Aerodynamics Laboratory. He received his B.S. in civil engineering from The University of New Mexico and has completed numerous graduate courses in advanced fluid mechanics, wind engineering, analysis of complex structures, structural design, and vibrations. He has 40 years of experience in construction, bridge design, and structural research.

For more information, contact Harold Bosch at 202-493-3031 or harold.bosch@dot.gov.

by James A. Arnold, David R. P. Gibson, Milton K. "Pete" Mills, Michael Scott, and Jack Youtcheff

Using GPR to Unearth Sensor Malfunctions

Ground-penetrating radar assesses loop detectors to determine necessary repairs so that all vehicles, including motorcycles, will be able to trigger traffic signals.

It's probably happened to nearly every motorist at one time or another. You stop for a red light, perhaps at night, when few or no other vehicles are on the road. You wait, and wait, and wait some more, but the signal does not change to green. The problem? It could be a malfunctioning loop wire sensor.

Inductive loop wire sensors embedded in the roadway surface are devices that indicate the presence or passage of vehicles and provide information that supports traffic management applications such as signal control, freeway mainline and ramp control, incident detection, and gathering of vehicle volume and classification data to meet State and Federal reporting requirements. Gray sealant that fills cut lines on roadways indicates the location of the loop wire part of the sensors in the pavement.

Malfunctioning in-roadway loop sensors can prevent traffic signals from sensing the presence of vehicles, a problem that can be particularly frustrating and even dangerous for smaller vehicles, such as motorcycles and bicycles. Malfunction rates for loop detectors can run as high as 14 percent, according to a Transportation Research Board paper, "Malfunction Detection and Data Repair for Induction-Loop Sensors Using I–880 Data Base," by H. J. Payne and S. Thompson. Anecdotal evidence puts malfunction rates as high as 25 percent.

The extent to which malfunctioning is attributable to the loop sensors versus the communications systems that link sensors to the central traffic management system is unknown. But informal discussions with traffic researchers identify installation errors and utility trenchers cutting the wires as the main sources of hardware malfunction.

The Indiana Department of Transportation (INDOT), for example,

(Below) This motorcycle is crossing a functioning traffic sensor loop, which notifies the traffic signal controller of the vehicle's presence and triggers a signal change. FHWA researchers are applying ground-penetrating radar as a means to detect malfunctioning sensors.

was able to reduce its malfunction rate by requiring, first, that installations be done as preformed loops during pavement resurfacing. Second, INDOT recommends that the splices attaching the loop wires and the lead-in wires from the controller cabinets be made inside large junction boxes (also called pull boxes) at the side of the road where they are protected from moisture and are readily accessible for repairs.

To address sensor malfunction, the Federal Highway Administration (FHWA) in 2006 initiated a Small Business Innovation Research (SBIR) project, 06FH2 "Step-Frequency Ground Penetrating Radar for Location and Evaluation of In-Roadway Sensors" to develop a nondestructive evaluation (NDE) method employing ground-penetrating radar (GPR) for detecting and assessing in-roadway inductive loop sensors.

"The project staff also addressed issues such as the evaluation of sensor sensitivity, the state of the art for NDE technology prior to the project, how the research improved NDE technology, and why evaluation of pavement condition is important both for sensor evaluation and for pavement design and maintenance," says Joe Peters, director of FHWA's Office of Operations Research and Development (R&D).

How the Project Started

To assess whether the physical structure of a loop system is at fault when a malfunction occurs, a detailed examination of the sensor is necessary. Previously, destructive sawcutting and removal of a portion of the loop were required to conduct that physical assessment.

In 2004, FHWA staff members from the offices of Infrastructure R&D, Safety R&D, and Operations R&D participated in an Exploratory Advanced Research team review of GPR. When examining an NDE GPR intensity mapping of a roadway, they noticed long lines on the graph that turned out to be a water pipe and conduits. This observation initiated a discussion about just how small a feature could be detected with NDE GPR and its lower detection limits.

The NDE staff at FHWA soon determined that the then-state-of-the-art GPR and acoustics systems could not measure features as small as loop wires, much less cracks in a wire or other potential problems such as moisture in pavement, sawcuts, or loop sealant. This finding led to discussion of whether researchers could make improvements in the hardware and software so that GPR and acoustics systems could detect loop wires and loop wire defects. As a result of this discussion, FHWA decided to pursue research in this area.

How Traffic Inductive Loop Sensors Work

Traffic detector engineers need to know not only whether and where a loop is present but also whether it is working and how well it is working.

Traffic sensor loops are coils of wire installed in slots 2 to 4 inches (5 to 10 centimeters) deep beneath the pavement surface. The loops are connected inside roadside junction boxes by splices to shielded lead-in cables that in turn connect to detector electronics on a loop amplifier card located in traffic controller cabinets. Junction boxes are usually approximately 1 cubic foot (0.028 square meter) in size and placed underground with a removable cover flush with the ground surface.

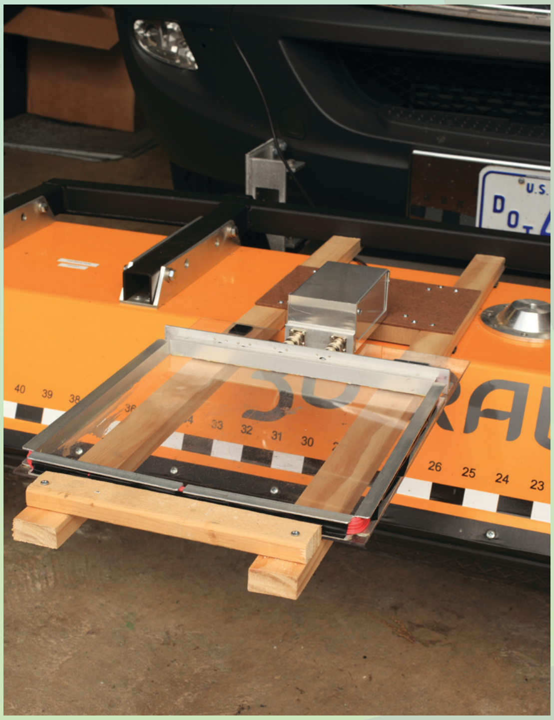
Most inductive loop detector systems operate in a frequency range of 20 kilohertz (kHz) to 100 kHz. All inductive loop detector systems have an oscillator in the loop amplifier card. An oscillator is a device for generating oscillating electric currents or voltages by nonmechanical means. The oscillator current in the loop wires generates a magnetic field around the loop. The passage of the conductive components of a vehicle through the loop's magnetic field generates a current in the conductive vehicle components. The conductive components are those capable of conducting electricity. In turn, the currents induced in the vehicle's conductive components also generate a magnetic field, which reduces the loop's magnetic field and inductance. Inductance is the property of an electrical circuit measuring the induced electric voltage compared to the rate of change of the electric current in the circuit. The decreased loop inductance causes an increase in the loop's oscillator frequency. The magnitude of the frequency shift indicates the loop's sensitivity or ability to detect vehicles.

Some loop detectors fail to function because they have breaks in the loop wires such that they no longer conduct currents. Others do not operate correctly due to reduced sensitivity, which can be caused by a problem with the loop installation, loop splice connection, lead-in cable, or pavement conditions.

"Modern digital loop detector electronics have adequate detection sensitivity, so when there is a problem, it is attributable to one of these other factors," says Dan Middleton, program manager, of the Texas Transportation Institute.

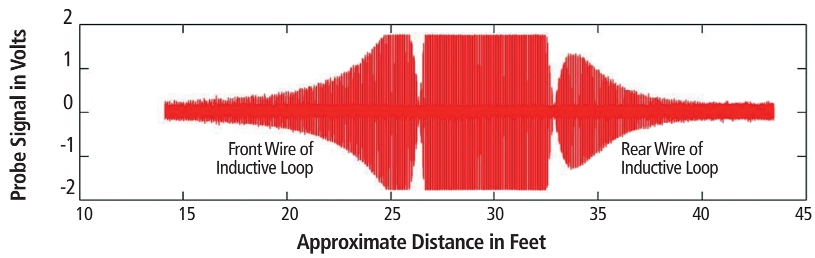
Measuring Loop Sensitivity

Because traffic engineers need to know whether inductive loop sensors are present and how well they



Shown here is FHWA's prototype sensitivity probe mounted on a GPR antenna array on the front of a vehicle. The equipment consists of a calibrated wire wrapped with multiple turns around a square frame mounted above the pavement surface in a plane parallel to the roadway probe loop and with the outer loop wires of both loops on parallel planes.

Inductive Loop Probe (100 kHz 10 mi/h)



As shown in this graph, the probe's reflected signal strength increases as the vehicle, traveling at 10 miles per hour (16 kilometers per hour), approaches and travels over the loop sensor. The signal strength then declines as the vehicle moves away from the sensor. The probe signal is sampled 100,000 times per second (100 kHz) for 10 seconds, producing 1 million data points. *Source: FHWA.*

are working, FHWA researchers proposed to measure the detection sensitivity using equipment mounted on a vehicle passing over the buried loops. The researchers placed a prototype sensitivity probe on a GPR antenna array on the front of the vehicle. A cable connected the probe with a frequency measurement device inside the vehicle. Combining, filtering, and amplifying the voltage from the probe enabled the researchers to measure the frequency shift and thus determine the presence and sensitivity of a loop. The researchers spaced the probe far enough ahead of the vehicle so that they could measure the initial resonant frequency from the roadway loop prior to the frequency shift caused by the sensor's detection of the vehicle.

As noted earlier, the measured maximum frequency change is proportional to the loop's detection sensitivity. The researchers calibrated the measurement sensitivity of the vehicle probe with a standard detector loop system of known sensitivity. As the measurement vehicle traveled down the roadway, the calibration enabled researchers in the vehicle to correlate that data with NDE data from the GPR system and thereby tell whether a correctly working loop was present.

The measured signal strength of a working loop increases as the probe loop sensor approaches the sensor loop, goes over the front of the loop, travels across the body of the sensor, and then declines as the probe travels away from the loop. The sharp breaks as the probe travels across the leading and trailing edges of the sensor provided additional confirmation of the loop's geolocation.

The Technology As It Existed

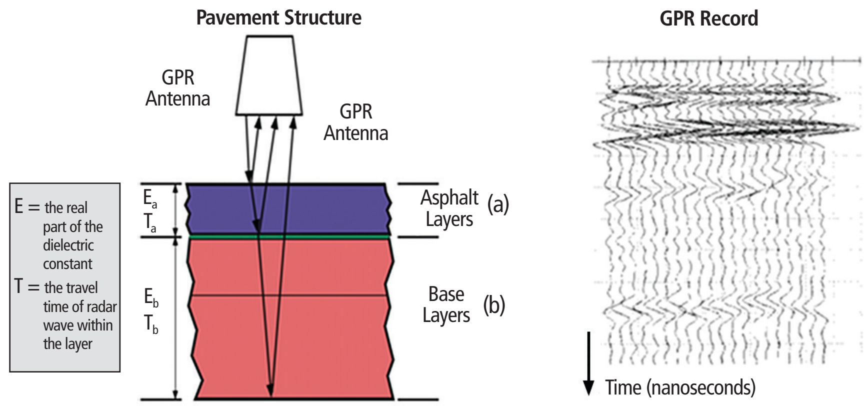
The highway community has used GPR for measurement and evaluation of road conditions since the mid-1970s, as reported by R. M. Morey in the Transportation Research Board report *Ground Penetrating Radar for Evaluating Subsurface Conditions for Transportation Facilities*. Transportation engineers also employ this technology to measure pavement thickness using calibration cores. The GPR approach often is less expensive than traditional methods that require a greater number of core samples.

"Many transportation professionals recognize the efficiency of the ground-penetrating radar method," says Mort Oskard, retired operations research engineer with FHWA's Advanced Research Team.

The radar signals employed in GPR are electromagnetic waves transmitted from an antenna source. These waves are continuous in step frequency GPR (SF GPR) systems, while they are impulses in impulse GPR (I GPR) systems. For both SF GPR and I GPR, radar reflections occur at the boundaries between the dielectric materials (insulators that do not have free charges inside them) used in civil engineering applications, such as pavement layer interfaces. The materials on each side of a pavement interface often have different dielectric properties. Therefore, these materials have different wave propagation and loss characteristics that cause wave reflection and refraction to occur at material boundaries, allowing the GPR to detect them. Radar waves also can detect and image metal inclusions or boundaries, including reinforcing steel within concrete, because they produce strong GPR wave reflections and do not effectively penetrate metals or other conductors.

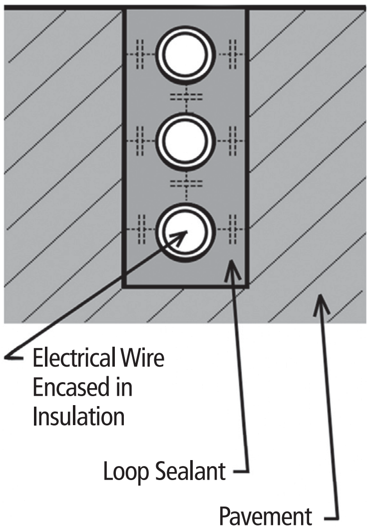
The height offset from the pavement surface of a GPR antenna used in pavement analysis can range from 10 inches (25 centimeters) up to 3 feet (0.9 meter) or more and thus are called air-coupled systems because the radar couples with the surface through the air. This contrasts with ground-coupled systems, which are mounted only 2 inches (5 centimeters) or less above the

Principles Used for Measuring Pavement Thickness



(Left) This schematic drawing of a GPR antenna shows signals being reflected by each pavement layer. (Right) This time trace shows the signals being returned by the reflection of the radar by each layer as the GPR antenna moves down the roadway. *Source: FHWA.*

A Loop Sensor



Shown here is a plan view representation of a loop wire embedded in a sawcut in the road pavement and sealant covering up the sawcut. *Source: FHWA.*

pavement, so the signal does not travel for a significant amount of time in the air and thus interacts directly with the surface. The SF GPR system and corresponding antennas used in the FHWA research can operate in an air-coupled or ground-coupled configuration.

Technicians may use each type of GPR system to record the time, amplitude, and phase of radar wave reflections, and computer software can be used to process two- or three-dimensional data. SF GPR data used in the FHWA study was collected in three dimensions. Traffic detector engineers process the data using a variety of algorithms, including classical synthetic aperture methods, which can generate a mathematically focused image if dielectric material properties are known. Super-resolution methods such as MUltiple SIgnal Classification (MUSIC) algorithms have the potential to provide even more refined images.

GPR using classical synthetic aperture radar (SAR) detects features 0.25 inch (6 millimeters) or smaller during measurements of pavement thickness or other applications. However, even high-resolution GPR systems were only able to resolve the separation between two closely spaced subsurface features (such as the two ends of a break in a loop wire) if the separation was at least 1.6 inches (4 centimeters) wide. In 2001, staff members with FHWA's Office of Infrastructure R&D stated in a Web report, the "HERMES II Bridge Inspector Project," that their most advanced GPR system "did not provide the necessary range resolution to definitively image typical delamination cracks, but field testing has shown that reinforcing steel and bridge deck details are typically rendered in [output] images." More recent technology allowed some delamination cracks to be imaged by a prototype GPR system, but results remained inconsistent, and regulatory requirements subsequently reduced performance. The regulations that reduce I GPR performance involved Federal Communications Commission rules in 2002 that reduced the power output and frequency content available to GPR users.

Technology Improvements That Were Needed

For engineers to use GPR to image loop wire features and potential defects or deterioration, significant improvements were needed in the resolution achievable by an NDE system and the corresponding visualization software. Related improvements in resolution were necessary to characterize the sealant surrounding the loop wire in the sawcut and determine its condition and potential problems due to moisture. Measurement of moisture content is critical to determine whether the loop wire will conduct the inductive signals to the loop detector card in the signal controller cabinet.

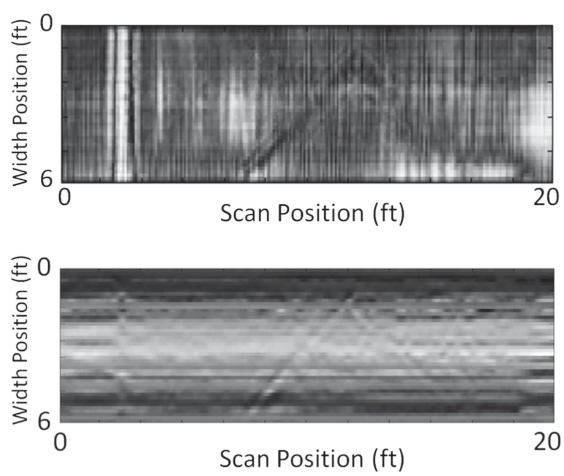
In other words, both defects and material deterioration associated with sensor, sealant, and pavement failures must be characterized with a much higher degree of precision than is required for conventional GPR used in pavement and subgrade applications. Cracks and wire features can be as small as 0.125 inch to 0.0625 inch (3 millimeters to 1.6 millimeters), requiring a significantly improved GPR detection and resolution capability. A corresponding step up in the frequency of the GPR radar signals used to image these features, and an improvement in the imaging algorithms was applied to produce images of the loop wire sawcut and embedded loop wire.

Technology Development And Testing

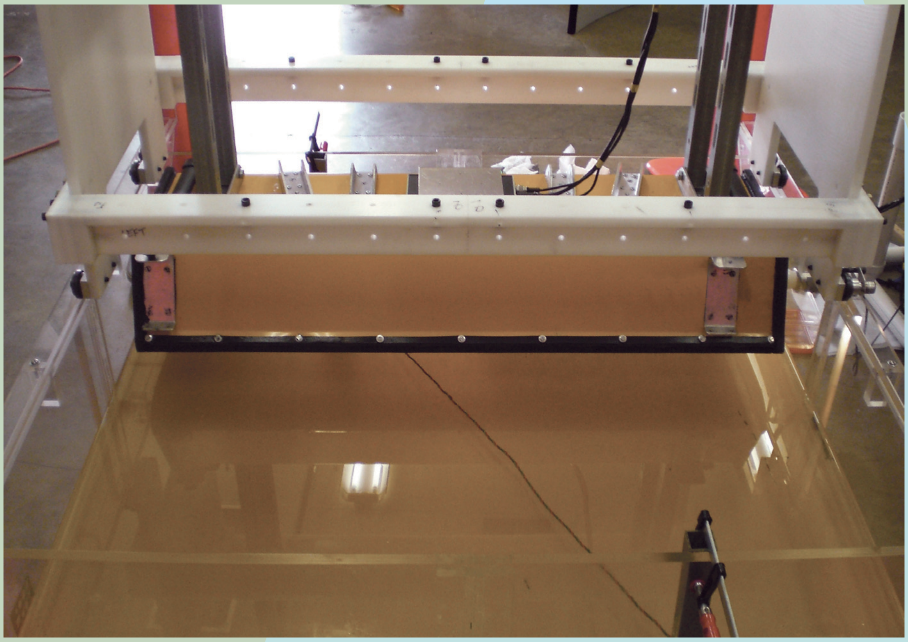
To summarize, the researchers developed and tested two complementary technologies: a passive probe sensor and a SF GPR-based method for data collection and analysis imaging. The passive probe successfully determines whether the loop is functioning and, if functioning, shows its location through a plot of its signal strength. The SF GPR method then images the loop wire in the pavement to evaluate potential cracks, defects, or deterioration in the wire or adjoining pavement.

GPR Detection of Traffic Loop Sensors and Results

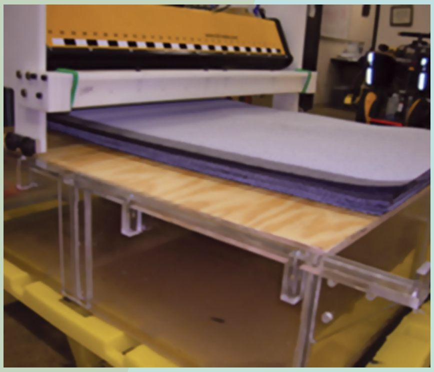
Based on the need for a rapid, efficient technology for NDE inspection and evaluation of loop wires, FHWA defined four objectives for the GPR detection of traffic sensor



Shown here are migrated computer-generated field images of surface layer (top) and loop wire depth layer (bottom) signal returns from the SF GPR signal used to image pavement characteristics. The top photo shows the radar return signal information from the surface layer of the pavement, and the bottom photo shows the radar return signal information from the depth at which the loop wire lies.



The researchers tested GPR over simulated pavement using treated canola oil, as shown here. By adding materials to the canola oil, it is possible to match the dielectric constant of the oil to that of asphalt, allowing lab testing of the radar responses of different objects in the simulated asphalt without having to lay real asphalt pavement over them.



Shown here is laboratory test apparatus used to conduct parametric performance studies. By using asphalt roofing shingles composed of materials very similar to asphalt pavement, it is possible to match the dielectric constant to that of asphalt. This allows lab testing of the radar responses of different objects in the simulated asphalt of varying depths by changing the number of layers of shingles. Again, this can be done without having to lay real asphalt pavement over them.

wires, and achieved the following diagnostic results:

Objective: Locate a loop wire sensor with a new SF GPR technique.

Result: The capability to locate loop wire sensors with a new SF GPR technique was demonstrated at slow vehicle speeds (<5 miles per hour, mi/h) (<8 kilometers per hour, km/h).

Objective: Perform test to determine whether the loop is functional, using both the passive approach (sufficient if the detector is connected to a sensor) and the active approach (necessary if the detector is not connected to a sensor).

Result: A passive probe measurement device developed during the study identified functional in-pavement loop wire signals and produced a flat signal response when no functional in-pavement loop wire sensors were present. A second probe measurement device with an active design was not used because SF GPR imaging provides the capability to detect disconnected inductive loop wires.

Objective: Scan the details of a sensor using GPR and classify the record based on the results of the previous step, to be used as ground truth.

Result: The GPR successfully imaged functional in-pavement loop wire sensors identified by the passive probe measurement and confirmed them to be free from indications of defects or deterioration. A laboratory experiment successfully detected gaps in wires.

Objective: Perform detailed analysis of GPR data to assess the condition of a sensor, with the goal of detecting the causes of malfunction.

Result: The researchers analyzed the GPR condition data for functional sensors, indicating a continuous loop wire with no breaks. Additional field testing will further validate the SF GPR imaging algorithms, especially for nonfunctional inductive loop wires. With improved hardware capabilities, refinements of the MUSIC algorithms will be possible in the future to further increase the resolution, accuracy, and speed of acquisition.

The loop wire imaging method developed and implemented in the FHWA study currently meets basic detection needs for many loop wire evaluation applications, but the researchers expect that further advancements in technology and analysis will make the images sharper and more versatile.

The researchers achieved most of the basic objectives, including successful location and sensitivity measurement with the loop wire probe sensor, and imaging of loop wires and nearby pavement features such as loop wire sawcuts. The researchers detected and imaged loop wires, both in the laboratory and in the field with three turns of 14-gauge wire, corresponding to standard installation practices.

Primary goals that they did not achieve due to budget and time constraints included detection of defect and deterioration features in field loop wires and the lack of an active probe sensor to complement the passive probe sensor. Also, due to the wide emission spectrum of the SF GPR, the research team was required to use reduced power for the GPR relative to optimum levels and had to notch some emissions at specific frequencies to comply with emerging SF GPR rules. These changes reduced the resolution available from the advanced algorithms developed and will require additional research to overcome.

Conclusion

Some important goals remain before the new technology can be commercialized. The passive loop probe sensor measurement hardware performs well but will benefit from additional field hardening to

Researchers are using the Advanced Pavement Evaluation system (mounted on the front of the van) to scan loop wires embedded in the pavement. The loop wires are diamond-shaped (left) and square-shaped (right), as indicated by the adhesive-filled sawcut marks in the pavement surface.

make it practical for commercialization. SF GPR imaging methods are functional but need to be tested further on defective or deteriorating field loop wires. Improvements to the hardware and complementary software will bring the final elements of a commercially viable, higher resolution product to market.

Other needs are the ability to detect defects immediately after loop wire installation as part of a quality control procedure and to detect deterioration as quickly as possible after it has occurred to minimize the negative impacts of sensor downtime. These improvements would provide a way to prioritize repairs and maintain the efficiency of the transportation system.

"This research developed technologies that meet many loop wire evaluation needs, and it also developed capabilities and tools that can solve other highway infrastructure nondestructive evaluation problems, such as crack detection and crack density mapping of pavements as well as delaminations in pavement lifts," says FHWA's Peters. "Research and development is proceeding in some of these areas, such as the evaluation of this technology on asphalt and concrete pavements."

James A. Arnold is a research electronics engineer on the Enabling Technologies Team in FHWA's Office of Operations R&D. He received a bachelor's degree in electrical engineering from the University of Delaware and a master's degree in electrical engineering from Florida Institute of Technology. His expertise includes civilian- and defense-related telecommunications, radionavigation, and spectrum management.

David R.P. Gibson, P.E., is a highway research engineer on the Enabling Technologies Team in FHWA's Office of Operations R&D. He has a bachelor's degree in civil engineering and a master's degree in transportation from Virginia Polytechnic Institute and State University. His expertise includes traffic sensor technology, traffic control hardware, modeling, and traffic engineering education.

Milton K. "Pete" Mills is an electrical engineer, now retired, from FHWA's Office of Safety R&D. He holds a bachelor's in electrical engineering from North Carolina State University and a master's from The Catholic University of America. At FHWA, he managed development and evaluation of systems for sensing vehicles from infrastructure.

Michael Scott, Ph.D., is a research engineer specializing in GPR for Starodub, Inc. Scott received a B.S. in mechanical engineering from Texas A&M University and an M.S. in engineering science and mechanics and a Ph.D. in civil engineering from Virginia Polytechnic Institute and State University. During the past 3 years, he has been the principal investigator on a SBIR project on SF GPR.

Jack Youtcheff, Ph.D., is the team leader for the Pavement Materials Team in FHWA's Office of Infrastructure R&D. He received a bachelor's degree in chemistry and a doctorate in fuel science from Pennsylvania State University. His expertise includes materials characterization, asphalt technology, and asphalt chemistry.

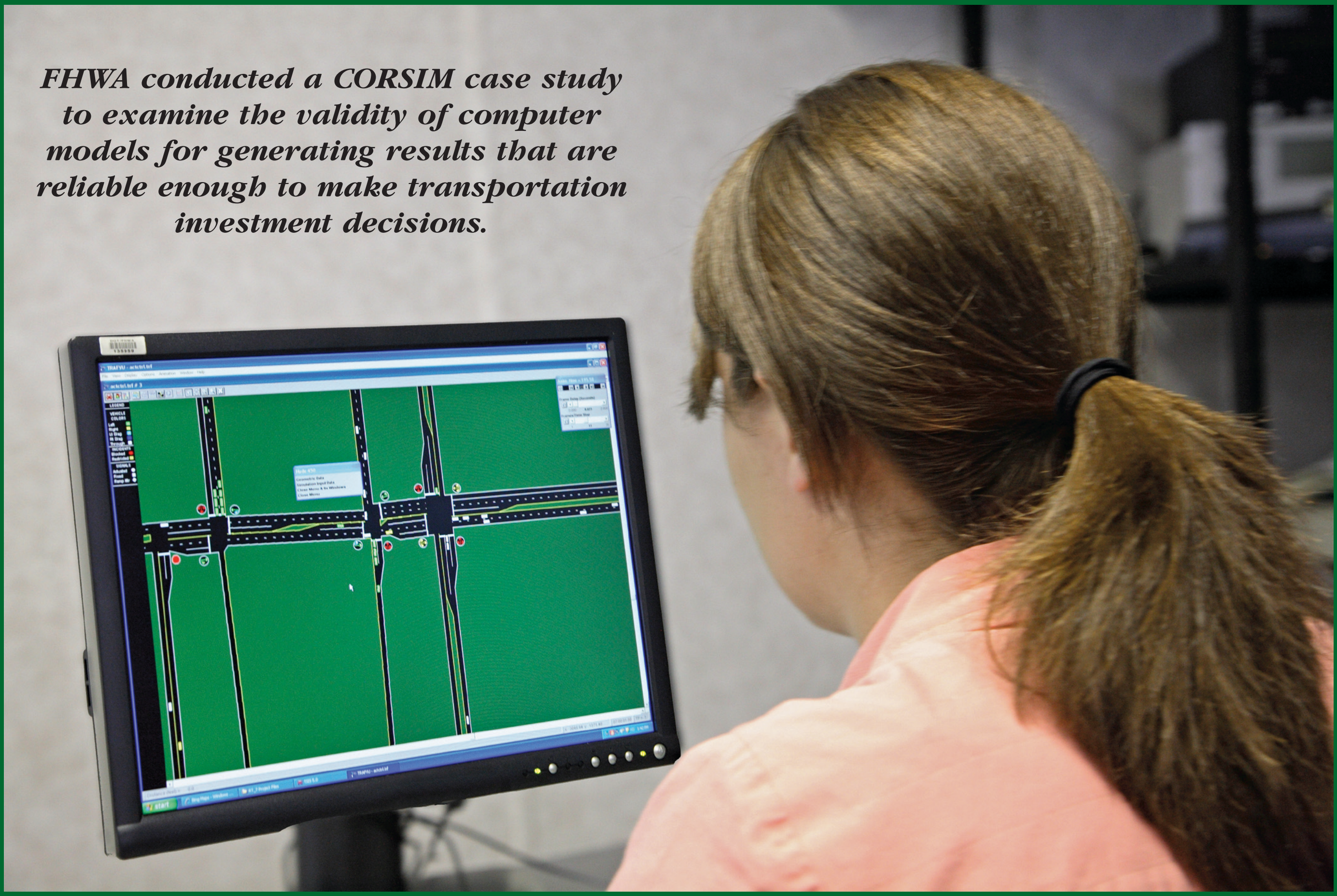
For more information, contact James Arnold at 202-493-3265 or james.a.arnold@dot.gov, David Gibson at 202-493-3271 or david.gibson@dot.gov, Milton Mills at 202-244-1136 or pete.mills @erols.com, Michael Scott at 202-493-3124 or mscott.ctr@dot.gov, or Jack Youtcheff at 202-493-3090 or jack.youtcheff@dot.gov.

The sponsoring agency of this project was FHWA's Turner-Fairbank Highway Research Center. This research was conducted through FHWA's SBIR Program. The U.S. Department of Transportation's SBIR Program is administered by the Research and Innovative Technology Administration (RITA)/John A. Volpe National Transportation Systems Center. The authors would like to acknowledge the efforts of Leisa Moniz, Linda Duck, and Darren Shaffer of the Volpe Center. Their help on the initiation and administration of this complex research was key to its success.

Traffic Simulation Runs: How Many Needed?

by Jonathan D. Wiegand and C. Y. David Yang

FHWA conducted a CORSIM case study to examine the validity of computer models for generating results that are reliable enough to make transportation investment decisions.



(Above) A student is running a CORSIM computerized traffic simulation for an FHWA case study designed to determine the ideal number of microsimulation runs needed to achieve stable results for effective decisionmaking.

Engineers use microsimulation models to replicate individual vehicle movements on a second-by-second or even a subsecond basis to assess the traffic performance of highway and street systems. Microsimulation software uses factors such as vehicle type, road geometry, and driver aggressiveness to best replicate the day-to-day variability of drivers and make decisions in the model. To use these models to make significant decisions about infrastructure improvements and investments, however, State departments of transportation (DOTs) and others need mean values or ranges of values that account for the hour-to-hour and day-to-day variability of traffic. To determine these mean values so they can be used in analyzing transportation design alternatives, engineers run a microscopic simulation model multiple times for the roadway segment and traffic period being analyzed.

"All too often we see only one run used for a given alternative," says Grant Zammit, operations team manager of the Federal Highway Administration (FHWA) Resource Center. "This approach does not recognize the stochastic nature of simulation, may erode the confidence and credibility of the recommendation or decision, and may unintentionally mislead the decisionmaker and the public." With tight budgets and limited human resources, DOTs often elect to reduce the number of runs and save money in the microsimulation analysis portion of project development.

So the question is: "How does a State DOT attain a balance between available resources versus acceptable results?"

To address this question, FHWA carried out an in-house study in 2009 and 2010 investigating the relationship between the number of traffic simulation runs and the aggregate results under various levels of error. The goal was to determine the level of simulation required for a calibrated network—a model that reproduces field-measured traffic conditions—to be considered statistically significant at a predefined confidence level for various measures of effectiveness (MOEs).

MOEs are system performance statistics that show the degree to which a model meets performance objectives. Common systemwide MOEs, measuring traffic operations across the entire model network, include vehicle-miles traveled (total miles traveled by all vehicles on the network), vehicle-hours traveled (total hours of travel by all vehicles on the network), and mean system speed (mean speed of all vehicles on the network). Common link-level MOEs, which measure only the traffic conditions on a specific link (freeway segment), include mean speed, mean link discharge (number of vehicles exiting a link per time period), and link density (number of vehicles on a link in a specific time period).

Typically, a State DOT or other sponsoring agency devises predetermined calibration levels of acceptance for specific MOEs. However, funding and time available for a project often limit the extent of traffic analysis and thus the number of simulations run by the performing entity.

According to FHWA's *Traffic Analysis Toolbox Volume III: Guidelines for Applying Traffic Microsimulation Modeling Software* (FHWA-HRT-04-040), the results from individual runs can vary by 25 percent or higher, and a single run cannot be expected to reflect any specific field condition. But without analyzing the traffic variability within the network and the run's results, how can a transportation professional conclude that an analysis is complete at 5 or 10 runs? Because of traffic variability, or randomness of driver characteristics, a statistically calculated number of runs is necessary to achieve a predetermined level of confidence in the results as prescribed by the sponsoring agency. A model may require 25, 30, 50, or more runs to minimize variability and stabilize results, providing a mean value or range of values that decisionmakers can use and be confident that they are designing for real-life conditions. What would be the effects, or the impacts on results, of concluding that the mean values from a model at 5 runs are acceptable, when in reality 30 runs are actually needed to provide results that best reflect typical traffic conditions at a predetermined level of confidence?

The FHWA researchers recently set out to answer these questions using FHWA's Corridor Simulation (CORSIM) software, a traffic microsimulation program, in a case study of computer model runs.

Design of the Study

The FHWA research utilized a calibrated model of six freeway links on I-694 and I-35W in the northern Minneapolis/St. Paul, MN, metropolitan area. This model was calibrated in accordance with *Traffic Analysis Toolbox Volume IV: Guidelines for Applying CORSIM Microsimulation Modeling Software* (FHWA-HOP-07-079). Each freeway facility had either two or three through lanes in each direction, with peak hour volumes of nearly 2,000 vehicles per lane. The researchers analyzed the six links for the afternoon peak period of 3 to 6 p.m. They calculated three link-level MOEs—lane density, link discharge, and link speed—for each link by analyzing the measured data collected during the CORSIM simulation runs. They also calculated the sampling error for the mean value at 95 percent confidence for each MOE. For this study, the researchers followed the rule of thumb that a sampling error under 10 percent represents stability in the mean value because the number of runs minimizes the variability of results.

For each of the six freeway links, the researchers carried out six independent run sets (5, 10, 15, 20, 25, and 30). To ensure that there was no correlation between individual runs and each run set, each run was different and independent of all other runs and run sets. This independence ensures that the full variability between runs is captured and provides examples of the progressions toward stabilized runs.

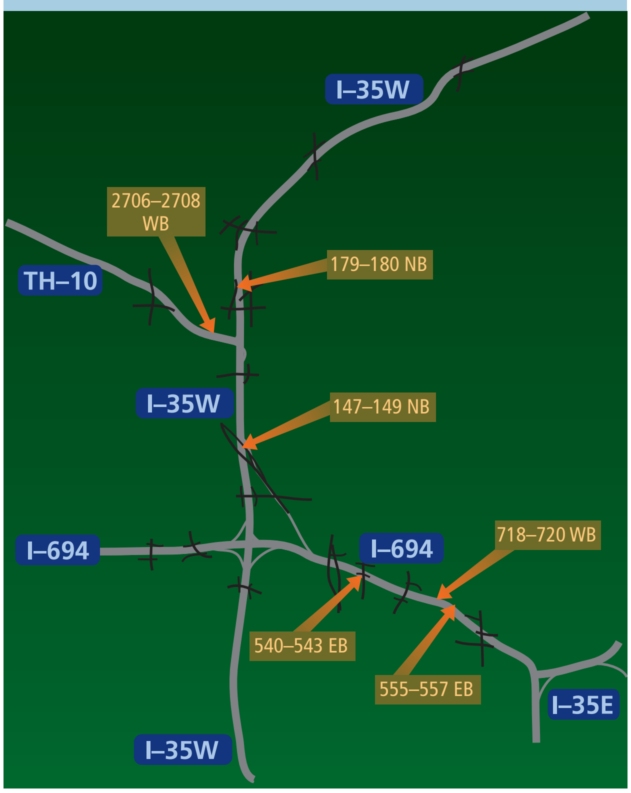
Level of Effort

For each model simulation, the researchers documented the level of effort required to run the sets for the six scenarios, noting the time required for additional runs, the total time to complete all runs and analysis, the average time per run, and the range of times per run for each set.

The following were the total times to complete all runs within a given set:

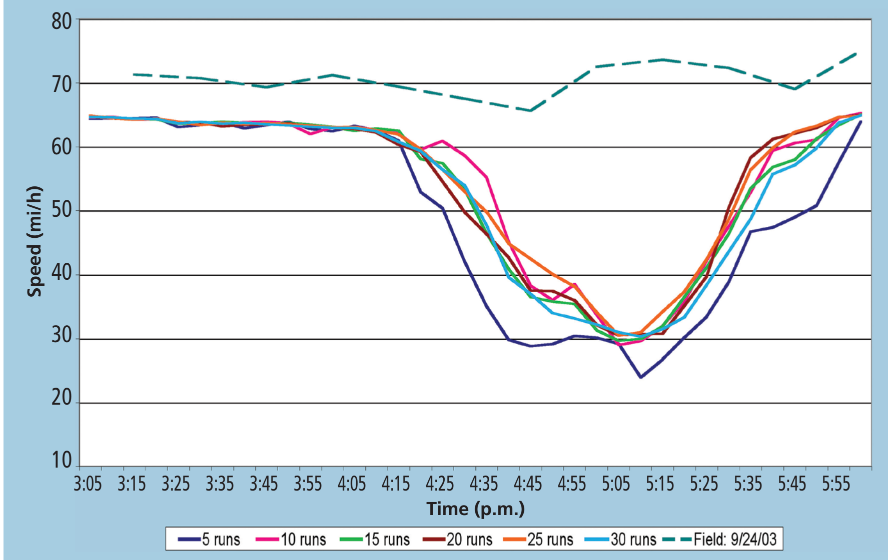
- 5 runs: 45 minutes
- 10 runs: 1 hour 17 minutes
- 15 runs: 1 hour 53 minutes
- 20 runs: 3 hours 19 minutes
- 25 runs: 3 hours 18 minutes

CORSIM Study Link Locations



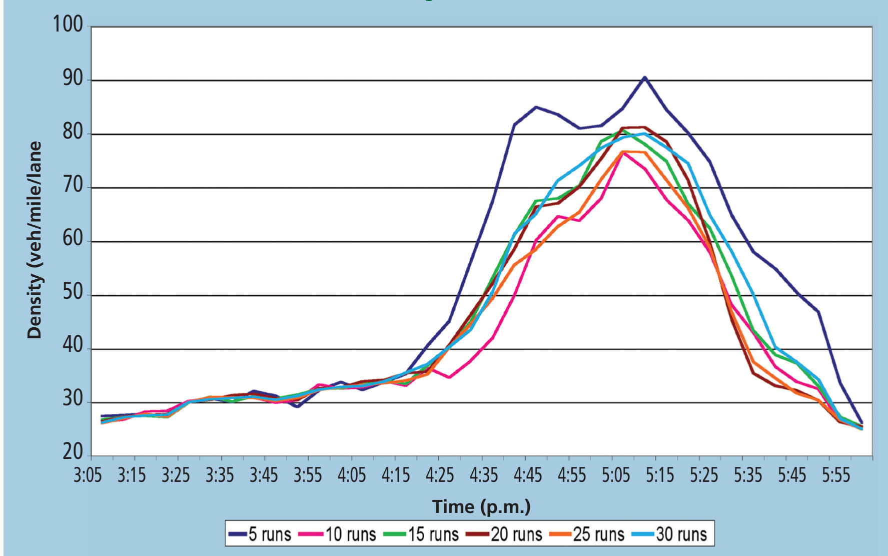
This map shows the locations of the six freeway segments near Minneapolis/St. Paul, MN, studied in the FHWA case study on traffic simulation runs. *Source: FHWA.*

Mean Speed, I–35W Link 147–149



This graph shows the mean speed values for the model runs and field data for Link 147–149. Although not representing the field-measured speed on this link, the mean model values became more stabilized as the number of simulation runs increased. *Source: FHWA.*

Mean Lane Density, I–35W Link 147–149



This graph shows the mean lane density values for the model runs for Link 147–149. The 5-run set had significantly different mean lane density values than the other run sets during congested conditions. As the number of simulation runs increased, more consistent outputs were generated. *Source: FHWA.*

(a likely reason for the 1-minute reduction in run time was a greater availability of computer and processing resources because fewer other computer programs were open at the same time)

- 30 runs: 4 hours 29 minutes

For all runs, the time-per-run ranged from 6.8 to 11.1 minutes.

The researchers considered these scenarios to be adequate examples of real-world urban freeway models. The level of effort will vary, depending on model complexity, size, data collection, and traffic volumes. Additional variation of the simulation duration may occur because of factors such as number of programs running on the computer being used and the number of simulations already completed on a given day.

Based on this case study, the researchers concluded that the level of effort for additional runs was not significant. Thirty simulation runs can be completed in a few hours (approximately 4.5 hours for this case study), and the runs can be carried out in the background while working on other tasks on the computer.

Overall Results

Many of the numerical and graphical representations of the run sets revealed recognizable improvements to the results between 5 and 10 runs. But overall evidence from this particular case study indicated that at least 10 to 15 simulation runs were needed to stabilize the results. It is important to note that the number of simulation runs necessary to attain stabilized results varies from one project to the next. Further, stabilized results do not necessarily mean that they meet the predetermined levels of confidence in reflecting real-world traffic conditions. A statistical analysis is necessary to validate the model results for project approval.

After the researchers achieved a stabilized run set, minimal benefit was obtained from additional runs. In addition, the researchers found that the most significant variability between runs occurred at the onset of congested conditions (that is, peak hours), because the beginning of queue development varied in intensity and initiation time.

Of the six scenarios, the two that contained readily apparent nuances for comparison were the northbound segments 147–149 on I-35W and westbound segments 718–720 on I-694.

Scenario A: Link 147–149

Link 147–149 on I-35W was entered in the model as a three-lane freeway segment approximately 1,300 feet (396 meters) in length. As determined by collecting field data, the traffic on this link exhibited free-flow conditions through the first hour of the afternoon peak period analyzed, until approximately 4:15 p.m. From there, speed began to steadily decrease from 60 to 30 miles per hour, mi/h (97 to 48 kilometers per hour, km/h) at 5 p.m.,

Shown here is the interchange at I–694 and I–35W, one of the freeway segments in the FHWA case study.

resulting in increases in density and a gradual decrease in discharge volumes. Congestion was present at this location until approximately 5:45 p.m., at which time traffic movement was back to free-flow conditions.

The mean link discharge model values did not vary significantly between run sets and generally followed the shape of the field data within 5 to 10 percent. The link discharge sampling error was less than 10 percent for all run sets, showing minimal variability across all runs, and tended to stabilize around 2 percent after more runs. Overall, minimal improvement in the results for mean link discharge was gained from additional runs.

Although the model's mean speed values generally followed a similar trend across all run sets, the 5-run set had a mean speed approximately 5 to 10 mi/h (8 to 16 km/h) lower than the others during congestion. The 15-run set was similar to the results from the 30-run set, indicating a minimal gain on investment after 15 simulation runs.

Further investigation of the model's speed values showed the variability of the results from individual runs. The mean speed sampling error was high for the 5-run set, exceeding 50 percent error of the mean. The error was reduced by nearly half to 25 percent for run sets 10 through 20. However, the incremental error reductions between the 20-, 25-, and 30-run sets were minimal, only reducing error to just under 20 percent and leveling out. Significantly improved stabilization occurred with each additional run up to 10 runs. However, running the model in excess of 10 runs provided minimal additional benefit in reducing error.

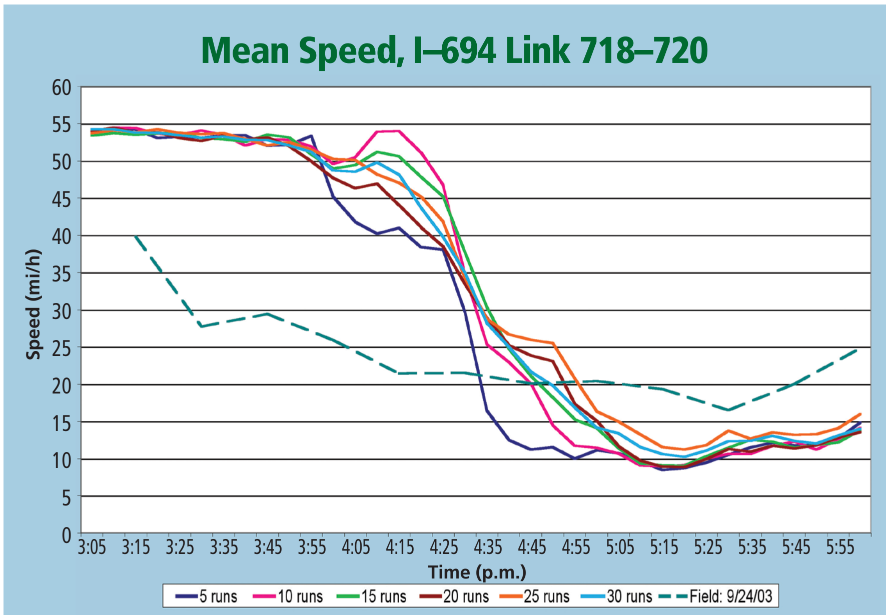
Similar to the trend shown in the mean speed graph, the 5-run set stood out from the other run sets for the mean lane densities. The 5-run set varied from the other sets by as much as 30 vehicles per mile per lane between the onset and closeout of congestion. The other sets varied among each other by a range of 5 to 10 vehicles per mile per lane.

The sampling error of the mean exceeded 60 percent for the 5-run set between 5:20 p.m. and 6 p.m., indicating significant variability in the mean density values between runs. For this time period, as the number of runs increased, the sampling error decreased dramatically. The 15-run set had a peak sampling error of nearly 30 percent, and the 30-run set had a peak sampling error of 20 percent, both significant improvements from the 60 percent for the 5-run set. With this trend, more than 30 runs would be necessary to reduce the sampling error to less than 10 percent.

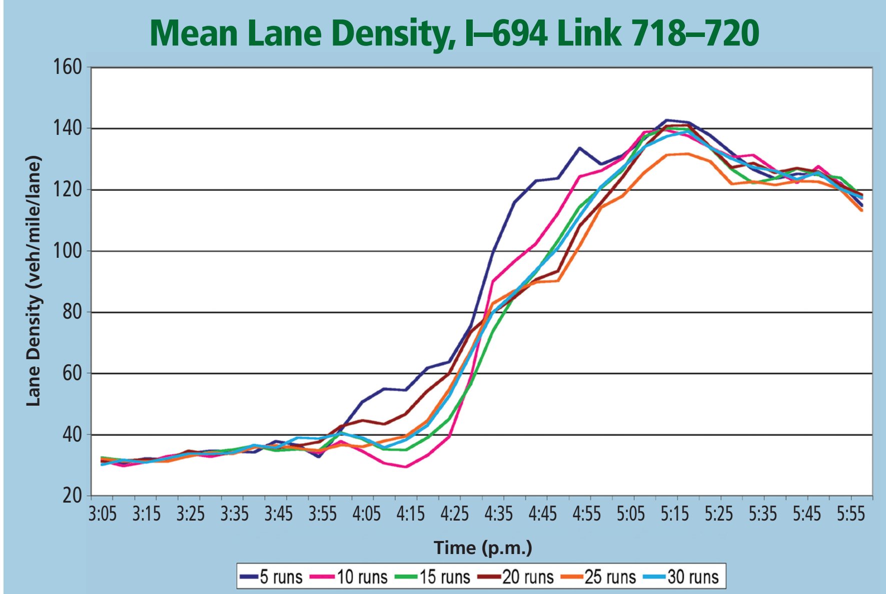
In conclusion, for Link 147–149 the return on effort was typically minimized after about 20 runs. The scenario provided several examples of variability for queue initiation time and intensity, as well as the effect on the sampling error for lane density and link speed. Although the model results for the mean link discharge were quite similar across all run sets, the mean link speed and lane density MOE deviated much more significantly. This result was most evident with the differences between mean values of the 5-run set and the other run sets.

Scenario B: Link 718–720

Link 718–720 on I-694 was coded in the model as a two-lane freeway segment approximately 1,400 feet (427 meters) in length. According to the



This graph shows the mean speed values for the field data and model runs for Link 718–720 on I–694. The extreme peaks and valleys are reduced as the number of runs are increased, shown by comparing the 5- and 10-run sets with the 30-run set. *Source: FHWA.*



This graph shows the mean lane density values for the model runs for Link 718–720 on I–694. A significant difference is apparent between the 5- and 30-run sets. *Source: FHWA.*

field data, traffic exhibited free-flow conditions until 4 p.m., the onset of the link's congested conditions. Operations broke down reaching a point of minimal throughput between 5 p.m. to 6 p.m. This scenario highlighted the effects of simulation variability when a link transitioned from uncongested to congested conditions, plus the importance of performing multiple runs.

Comparable to Link 147–149, the simulation results for the mean link discharge were similar across the six run sets. The sampling error exceeded 10 percent for only one 15-minute time interval for the 5-run set. The error continued to be reduced with additional runs and stabilized between 2 and 4 percent at 15 runs. Thereafter, the researchers found minimal improvement with additional runs.

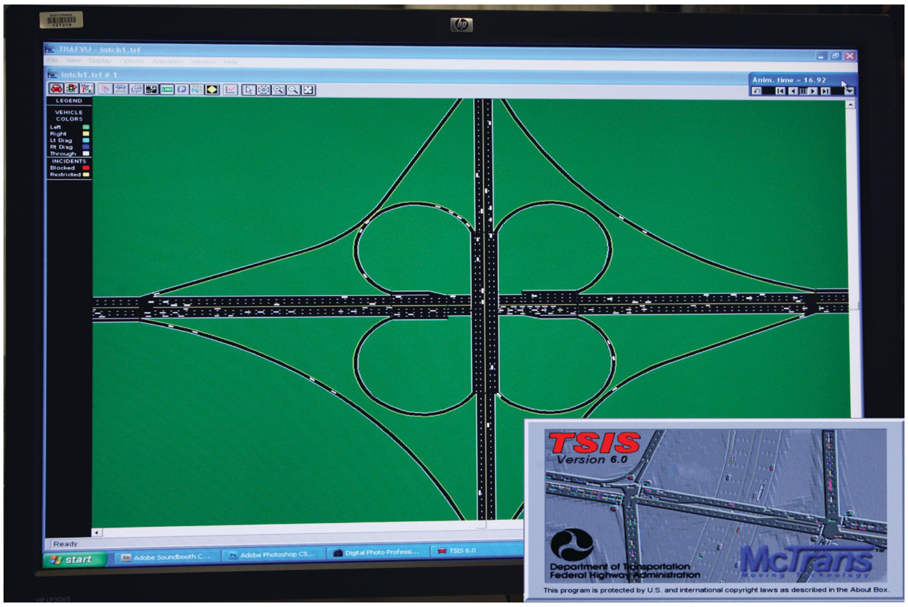
The mean speed plot highlighted the transition from uncongested to congested conditions beginning at 4 p.m. The vehicle speeds steadily declined until 5 p.m., where they stabilized between 10 and 15 mi/h (16 and 24 km/h) and remained there through the end of the analysis period. Although each run set followed a general trend, noticeable differences between them appeared. The onset and intensity of the congested conditions varied between run sets, thus showing the inherent variability of individual runs. This was highlighted in two time periods:

- At 4:10 p.m., the mean speed for the 5-run set was 40 mi/h (64 km/h), while the mean speed for the 10-run set was nearly 55 mi/h (89 km/h) and about 49 mi/h (79 km/h) with 30 runs.
- Similarly, at 4:45 p.m., the mean speed of the 5-run set was about 11 mi/h (18 km/h), while the mean speed with 25 runs was over 25 mi/h (40 km/h).

The variability of individual runs was further evident in the sampling error for mean speed. The sampling error across all run sets was in excess of 25 percent between 4 p.m. and 5 p.m., with the 5- and 10-run sets in excess of 50 percent on two occurrences. Significant error was still present at the 25-run set, with values that were nearly three times higher than those for 10-, 15-, and 20-run sets from 5 p.m. to 6 p.m. Additional runs would be necessary to reduce the error below 10 percent for the mean speed MOE.

Although all run sets followed a similar trend of increasing mean lane densities, there were notable extremes for the 5- and 10-run sets. The 15- through 30-run sets tended to show similar mean values, indicating a gravitation toward stabilization. The sampling error peaked at over 70 percent for the 5-run set during the queue formation but was reduced to 30 percent for the 10-run set, which was a significant improvement. The error was further reduced to 20 percent for the 30-run set.

Results from Link 718–720 showed the importance of establishing predetermined levels of acceptance prior to calibration in order to identify the goals for level of effort and a confidence level in the results. By looking only at the link discharge MOE, a transportation professional might



This screenshot shows an example of a cloverleaf interchange generated by CORSIM, a microsimulation program available at http://mctrans.ce.ufl.edu/featured/TSIS.

conclude that only 5 or 10 simulation runs were necessary to reduce the sampling error below 10 percent. However, other MOEs showed that more than 30 runs were needed to provide a confidence level with errors under 10 percent. The onset of congested conditions, and continued deterioration, was difficult to model because of varying queue characteristics, such as start time, intensity, and traffic conditions upstream and down.

Field Data and Model Results

Traffic data collected in the field is the basis for modeling real-life traffic conditions on a selected network. The selected network is calibrated toward this field data, which represents a typical, or average, traffic period. As shown in the examples in this research, a certain number of runs are needed to provide model results that mirror the field results, thus minimizing the individual variability of the model runs.

The examples in this research look only at link-level MOEs, not network level MOEs. The specific links and calibration MOEs used by the model developers during calibration are unknown and thus might differ from the links and MOEs analyzed in this case study. Although the model results were similar to the field data for mean link discharge, the variation from field-measured data and model results for mean speed often were significant.

Concluding Remarks

Results generated from Scenarios A and B on calibrated models of I–35W and I–694 in the northern Minneapolis/St. Paul metropolitan area provide graphical examples of the differences in the number of microsimulation runs, which engineers ultimately use to help make transportation improvement and investment decisions. As shown, the improvements to the mean values vary between run sets, some with significant differences and others with irrelevant ones. According to the case study, the most notable differences were between the 5- and 10-run sets, and results generally became stabilized at some point after 10 to 15 simulation runs.

Sharp peaks and valleys were noticeable in those sets with a smaller number of simulation runs. With fewer runs, the presence of outliers and the influence of the variability of the queue initiation were more apparent in the mean and sampling error plots. Sets with a larger number of runs tended to generate more rounded and stable line plots. Additional runs might reduce the sampling error because, as the number of runs increased, the mean of the runs and sampling errors per set stabilized. In this case study, the stabilization occurred within the 20-, 25-, and 30-run sets for the three MOEs.

The examples provided in this case study show the effects of carrying out too few simulation runs on reducing variability in the results. Similarly, when applying future increases in annual traffic demand, the impacts of a poorly calibrated model might skew the results exponentially based upon the level of increased demand. State DOT and local agencies usually use calibration acceptance targets such as error tolerance and confidence intervals to ensure that an acceptable level of calibration is achieved.

Jonathan D. Wiegand is a transportation engineer with FHWA's Nebraska Division Office. Wiegand joined FHWA in 2007. He received a B.S. in civil and environmental engineering from South Dakota State University and an M.S. in civil engineering (transportation) from Iowa State University.

C. Y. David Yang, Ph.D., is a research engineer with FHWA's Office of Operations Research and Development in McLean, VA. Yang joined FHWA in 2008 and is responsible for traffic modeling and simulation research at the Turner-Fairbank Highway Research Center. He is the chair of the Transportation Research Board's Committee on User Information Systems and serves on the editorial board of the *Journal of Intelligent Transportation Systems*. He attended Purdue University and received B.S., M.S., and Ph.D. degrees in civil engineering.

The authors would like to thank James McCarthy of FHWA's Minnesota Division Office for providing the data used in the case study and Randall VanGorder of FHWA's Office of Operations Research and Development for providing two of the CORSIM photos, and acknowledge John Halkias from the Office of Operations for his advice and comments at the beginning stage of this work.

For more information, contact Jonathan Wiegand at jonathan.wiegand@dot.gov or 402-742-8475 or David Yang at david.yang@dot.gov or 202-493-3284.

Pooling Talent and Technologies

by Steve Albert
and O. A. Elrahman

How University Transportation Centers are improving transportation through innovative partnerships, creating a win-win for government, universities, industry—and motorists.

(Above) A city transportation maintenance engineer is giving a hands-on demonstration of new signal coordination equipment to undergraduates who are enrolled in a course at Montana State University's University Transportation Center. UTCs—partnerships of universities, government, and industry—are helping educate the next generation of engineering professionals. *Photo: Western Transportation Institute.*

The 21st century brings old and new challenges to transportation users, practitioners, and researchers. In addition to persisting problems of congestion, mobility, safety, security, air quality, and environmental preservation, the transportation community is grappling with a renewed set of problems—"old wine in new bottles." The global recession, intensified global competition, and the need to maintain the Nation's competitive edge—in short, the old wine of economic issues—are compelling transportation practitioners to focus more closely on revitalizing the U.S. transportation infrastructure. The transportation system has been, and continues to be, a vital and tried-and-tested engine of economic vitality.

Added to these challenges, moreover, are persistent concerns over the availability of a sufficient pool of technical expertise in the transportation field. Two *ITE Journal* articles (M.E. Lipinski and E.M. Wilson's "Undergraduate Transportation Education—Who Is Responsible?" and J.M. Mason Jr.'s "Transportation Education and Workforce Development") point out a decrease in undergraduate hours devoted to transportation-related courses. One result is insufficient transfer of transportation planning and engineering knowledge and skills. For more on this issue, see Chen-Fu Liao, Henry X. Liu, and David M.

Levinson's 2009 article on engaging undergraduates in transportation studies, published in the journal of the Transportation Research Board.

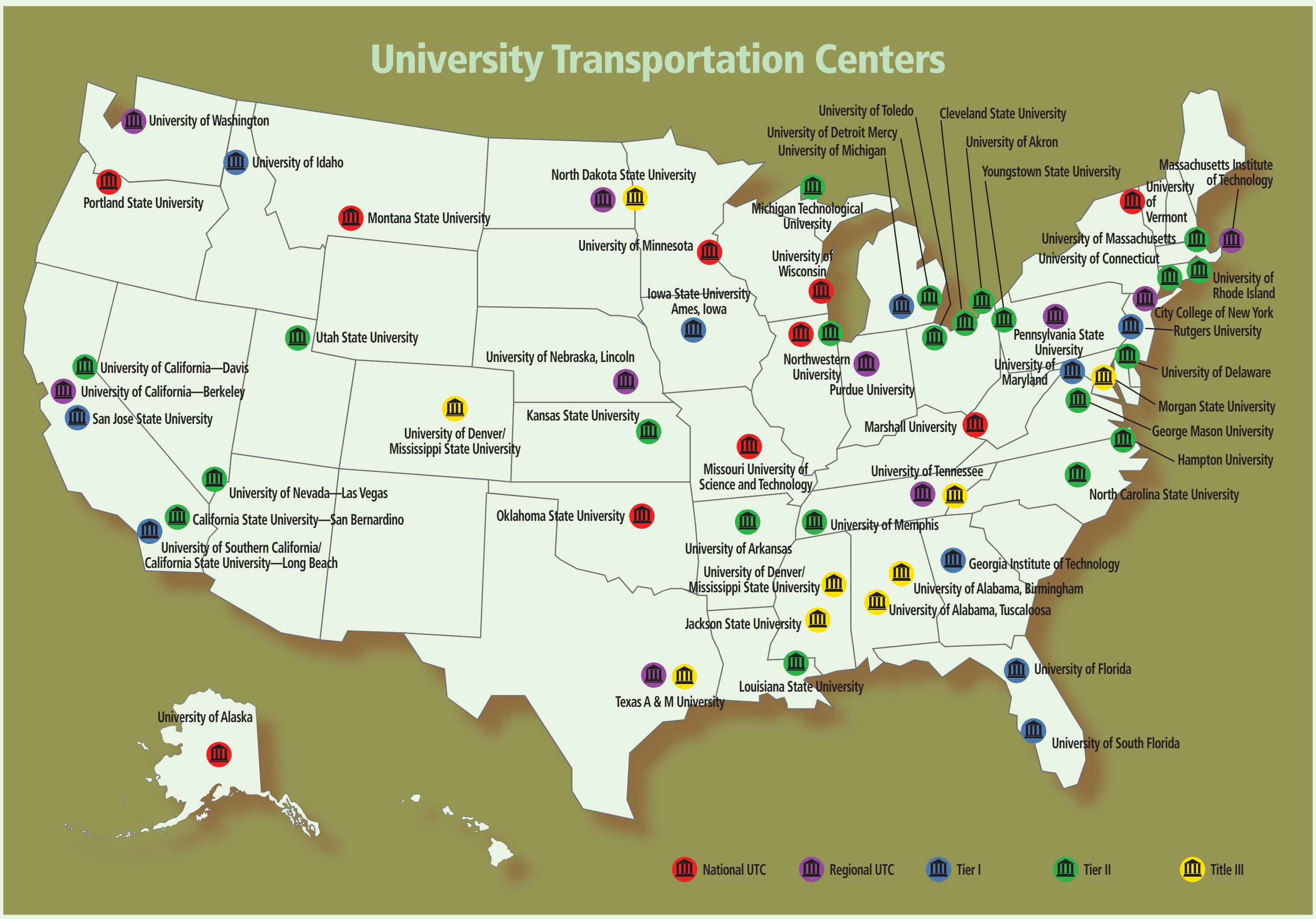
The fast pace of change in information technologies used in the transportation field mandates a new paradigm in teaching and learning. But transportation has been slow to keep up with changes in communications technologies. Persistence in traditional pedagogies exacerbates the danger of losing student interest and motivation, and thus the risk of eroding the transportation community's ability to recruit and retain the best and brightest.

On another level, the changing pace of technological innovations and the intensification of transportation challenges demand a more integrated, cross-sector approach. To meet all these needs, partnerships of government, universities, and the private industry need to play a significant role in creating new, market-ready transportation technologies, while passing the knowledge to the next generation of professionals. The University Transportation Center (UTC) is a model of government-university-industry collaboration that strives to bring stakeholders together, leverage resources, and ensure prompt application of evidence-based best practices.

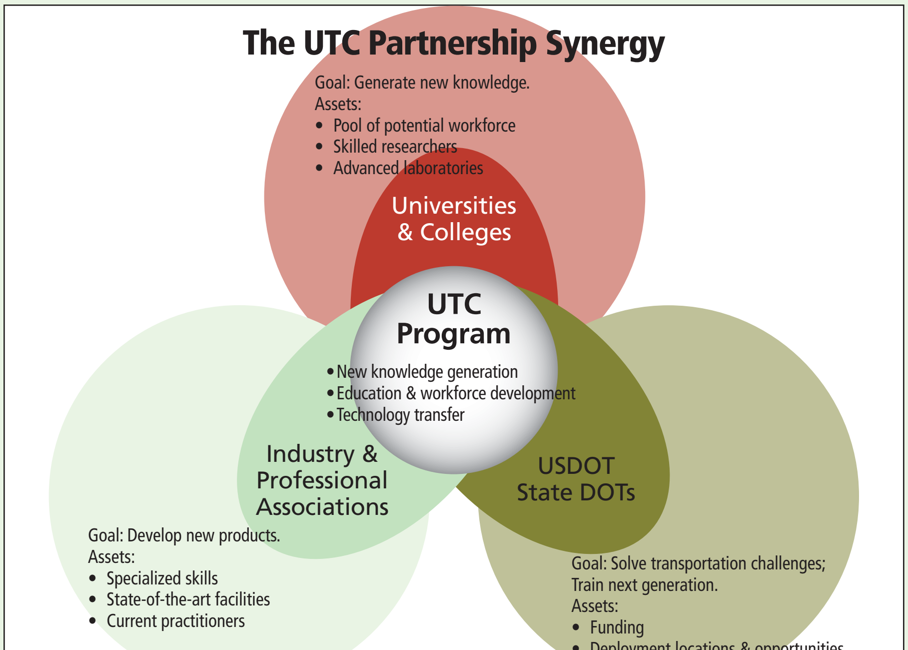
"Because UTC partnerships bring together a broad range of transportation stakeholders, they are in a natural position to lay the foundation for long-term advances," says Joseph S. Toole, associate administrator of the Federal Highway Administration's (FHWA) Office of Safety. "One example is providing guidance in developing roadmaps for the future by identifying critical emerging issues, serving as leaders for stakeholder outreach, and facilitating issue prioritization for sound transportation planning and infrastructure investment."

History of the UTC Model

Individual transportation centers at major universities have been actively conducting research for as long as 50 years, having been established after World War II with public funding to nurture the highway construction boom. But in 1974, with research funding on the decline, a group of university leaders initiated a grassroots effort aimed at producing highly qualified professionals, enhancing technology transfer, and strengthening research at the U.S. Department of Transportation (USDOT). In 1977, five university centers established an unofficial organization called the Council of University Transportation Research Centers, which eventually was incorporated



This map shows the national and regional UTCs. Their role is to advance transportation research on critical national transportation issues and to expand the workforce of transportation professionals. Tier 1 UTCs include 10 competitively selected centers that receive $1 million per year in Federal funds, while Tier 2 designates 22 centers that receive $500,000. Title 3 UTCs are authorized under a separate Federal law that designates 8 additional centers with individualized authorization amounts. *Source: Research and Innovative Technologies Administration, USDOT.*



Source: Western Transportation Institute.

in 1982. Membership in the council increased from the 5 founding university centers to 43 members by 1992.

The founders' vision of a formal university-government partnership was fully realized in 1987 with passage of the Surface Transportation and Uniform Relocation Assistance Act, which funded 10 federally designated UTCs—one in each of the FHWA regions that existed at that time. Today, the UTC system has grown to include 59 centers involving 125 universities in 41 States. USDOT provides the primary funding, with the centers adding a 1:1 match through partnerships with State departments of transportation (DOTs), universities, private industries, foundations, and other research entities.

Strengths of the UTCs

The fundamental strength of the UTC model is that the centers can pool—and leverage—the specialized resources of diverse partners to their mutual benefit. All of the partners have an incentive to promote transportation advances and education: Private industry wants to develop new products and business, universities want to conduct cutting-edge research and offer relevant programs for their students, and the State DOTs and USDOT want solutions to current and projected operational and infrastructure challenges. All partners have an interest in up-to-date knowledge transfer for the transportation workforce's next generation.

Each partner brings valuable resources to research and educational efforts. Private industry offers technical knowledge and specialized facilities, universities provide research expertise and a pool of potential future employees, DOTs offer real-world test beds for model deployments, and USDOT provides funding and national exposure.

UTCs serve as a point of convergence where partners can combine and integrate their strengths by working together to generate and test new research findings, to spread the knowledge so it can be implemented quickly and broadly, and to incorporate it into programs for educational and professional development. In addition, UTCs offer a formalized structure and administrative and leadership practices that promote success. Among those management practices are the following:

- Identification and inclusion of all key stakeholders
- Clearly articulated goals and formalized groundrules for interaction, articulated in formal agreements
- Strong coordination and communication networks among the partners
- Champions in each partner agency to advocate for specific research
- An inclusive, participatory decisionmaking process
- Agreement on initial and long-term funding issues
- Distribution of benefits among partners

These strengths are common to all centers, but the UTC system is enhanced by individual centers focusing on themes that enable them to develop specialized expertise on particular issues. A theme might reflect transportation challenges specific to the region where the UTC is located or special needs identified by area stakeholders. Examples include sustainable transportation, multimodal freight movement, rural transportation, advanced technologies and information systems, transportation in cold regions, and advanced materials and infrastructure design.

Solutions to Current Challenges

The breadth and depth of UTC assets enable the partnerships to develop projects that leverage limited or scattered resources and put new ideas into practice in the real world. The following are three examples of how UTCs are facilitating and expediting progress through creative collaboration.

This aerial photograph shows the Texas Transportation Institute's Proving Grounds Research Facility at Texas A&M University. The facility enables UTC researchers to conduct field studies related to safety and structural systems, traffic engineering, human factors, and the environment.

Texas Transportation Institute

These researchers at the Western Transportation Institute at Montana State University are installing strain and temperature instrumentation on a bridge deck before concrete is poured. These sensors will enable researchers to monitor, measure, and compare the long-term performance of three types of concrete bridge decks to help DOTs choose cost-effective design options.

Comparison of animal detection systems. By partnering with the private sector to test new ideas and technologies, UTCs can match a highly trained researcher at a university with a new product under development at a private company for testing that furthers the interests of both parties. For example, in partnership with FHWA and the Montana Department of Transportation, the Western Transportation Institute at Montana State University conducted concurrent tests in 2007 to evaluate the reliability of nine animal detection systems from five partners: Xtralis, STS, Calonder Energy, Camrix, and Goodson. Researchers installed the animal detection systems at the same site under similar circumstances. This project produced data that helped DOTs compare the effectiveness of similar systems prior to deployment and helped the manufacturers set minimum standards for system reliability.

Emerging technologies survey. State and regional DOTs identify operational challenges at specific roadway locations that offer ideal opportunities for product development of emerging technologies that would benefit from field testing. For example, in 2008, the Rensselaer Polytechnic Institute conducted a comprehensive assessment of 46 promising technologies that are likely to affect transportation performance in the New York Metropolitan Transportation Council region. The product development included testing of such technologies as those that target congestion reduction and management, global positioning systems, personal travel assistance, and adaptive ramp metering.

Intersection decision support. USDOT sets national policy goals, such as highway safety or environmental stewardship, but needs to collaborate with organizations that have the technical expertise to pilot-test specific concepts or implement particular programs. In 2007, USDOT selected the Minnesota Department of Transportation and the Intelligent Transportation Systems (ITS) Institute to participate in USDOT's Cooperative Intersection Collision Avoidance Systems research. Participation in the initiative led to Minnesota's Stop Sign Assist research, which explored wireless communication mechanisms that would send warnings to individual drivers and vehicles at rural unsignalized intersections.

Educating for the Future

With an entire generation of engineers, managers, and other professional practitioners set to retire, workforce development is the sleeping giant of transportation challenges. UTCs can provide a vital bridge linking the prospective workforce (university students) to public and private transportation careers. The centers also offer opportunities for practicing professionals to take advantage of ongoing education on new technologies.

For example, the University of Massachusetts Transportation Center is one of the partners in the Regional Traveler Information Center, which provides faculty with a teaching laboratory for graduate courses on traffic flow modeling, ITS, and simulation modeling to demonstrate field applications of new technologies. Dozens of students have benefited from this hands-on experience and

Shown here is the vantage point from the driver's seat inside a UTC driving simulator, one of the innovative technologies used in studies to analyze driver behavior and test safety measures before they are implemented.

subsequently have accepted challenging positions in transportation.

Also, UTCs can combine extensive research resources with advanced teaching methods and case studies to create comprehensive and relevant informational and guidance tools that meet the needs of transportation practitioners. For example, a team of UTCs recently launched the Paul S. Sarbanes Transit in Parks Technical Assistance Center (TAC), which reaches out to Federal land managers implementing alternative transportation projects in national parks, Federal recreation areas, and other public lands. In conjunction with the Federal Transit Administration and other partners, the UTCs are amassing informational resources for the TAC and developing training tools, such as online courses, webinars, and peer-to-peer mentoring.

What's Ahead

UTCs have a recognized history of leadership on transportation issues. Individuals representing UTCs regularly provide testimony before Congress and other national bodies to assist with the development of national policies and priorities.

Because the UTC collaborative model continues to produce results from the innovative transportation research taking place at the centers, many UTC initiatives are securing increasing levels of financial support, successfully attracting large contributions from State DOTs and private entities. The National Center for Transportation and Industrial Productivity, a UTC at the New Jersey Institute of Technology, for example, obtained non-Federal matching funds at a two-to-one ratio, or better. In another example, between 1999 and 2002, Alabama's UTC matched $2.6 million in Federal funds with $3.9 million from the Alabama Department of Transportation.

Says FHWA's Toole, "UTCs have been one of the vehicles that help us fill the pipelines of transportation professionals and ensure that we are adopting an integrated approach that channels the talents of all stakeholders to solving the challenges that we face."

Steve Albert is director of the Western Transportation Institute at Montana State University and president of the Council of University Transportation Centers. He holds a master's degree in urban and regional planning from Texas A&M University.

O. A. Elrahman is head of Research Coordination & Technology Transfer in the Transportation R&D Bureau at the New York State Department of Transportation (NYSDOT). From 1995 to 2003, he served as liaison for NYSDOT-sponsored research conducted by the UTC. He also served as program manager for NYSDOT's Transportation Infrastructure Research Consortium led by Cornell University. He holds a Ph.D. in urban and environmental studies from Rensselaer Polytechnic Institute.

For more information, contact Steve Albert at 406-994-6114 or stevea@coe.montana.edu, or O. A. Elrahman at 518-457-4689 or oelrahman@dot.state.ny.us. *The authors would like to acknowledge the contributions of Michael Griffith, director of the Office of Safety Integration at FHWA's Office of Safety, and Carla Little, research writer at Western Transportation Institute (WTI), Montana State University, to this article.*

Western Transportation Institute

This portable research trailer is outfitted with traffic cameras mounted on an extendable mast and powered by solar panel-charged batteries. UTC researchers developed this custom equipment to collect traffic data for safety studies, even from remote locations.

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 (USDOT) sources unless otherwise indicated. Your suggestions and input are welcome. Let's meet along the road.

Management and Administration

USDOT Rises in Best Places to Work Rankings

USDOT significantly rose in the Partnership for Public Service's 2010 The Best Places to Work in the Federal Government® rankings released in September. The Partnership for Public Service, a nonprofit organization, surveys civil servants to produce rankings of employee satisfaction and commitment. USDOT saw one of the greatest improvements in the index among large agencies, with a 15.8 percent increase over 2009, placing 26 out of 32 in the 2010 survey.

USDOT officials credit the rise to focusing on the competencies of first-line supervisors in the areas of effective leadership, empowerment, employee engagement, and ethics. Further, an employee satisfaction goal was included in all Senior Executive Service performance plans. Secretary of Transportation Ray LaHood led the improvement efforts by holding townhall meetings with employees and asking agency administrators to meet regularly with employees to focus on leadership development and internal communications, and to create tailored action plans, which include measurable benchmarks for their agencies.

USDOT also achieved its highest response rate ever with 67 percent of employees taking the survey. The Federal Government's overall response rate was 52.2 percent.

For more information on the survey, visit http://bestplacestowork.org/BPTW/rankings/overall/large.

Technical News

FHWA Issues New Guidance on Pavement Friction Management

In June 2010, FHWA issued a new technical advisory, Pavement Friction Management (T 5040.38), that provides guidance to State and local highway agencies on managing pavement surface friction. The new advisory supersedes FHWA Technical Advisory 5040.17, Skid Accident Reduction Program, issued in December 1980.

The advisory outlines the purpose of pavement management programs, which is to minimize friction-related vehicle crashes by ensuring that new surfaces are designed, constructed, and maintained to provide adequate and durable friction properties. Pavement programs also aim to identify and correct sections of roadways that have elevated friction-related crash rates and to prioritize the use of resources to implement these programs cost effectively.

The advisory covers topics such as measuring pavement friction using testing equipment, identifying and classifying roadway locations with elevated crash rates, prioritizing projects for improving pavement friction, determining the appropriate frequency and extent of friction testing on a highway network, and assessing the effectiveness of a friction management program. The advisory also lists additional reference materials.

For more information, visit www.fhwa.dot.gov/pavement/t504038.cfm.

Public Information and Information Exchange

Massachusetts Announces Sustainable Transportation Initiative

The Massachusetts Department of Transportation (MassDOT) recently launched a comprehensive environmental responsibility and sustainability initiative called GreenDOT. GreenDOT has three primary goals: (1) reduce greenhouse gas (GHG) emissions; (2) promote healthy transportation options such as walking, bicycling, and public transit; and (3) support smart growth development.

GreenDOT calls for MassDOT to incorporate sustainability into all its activities, from strategic planning to project design, construction, and system operation. Currently, the transportation sector generates more than one-third of the total GHG emissions produced in Massachusetts. The initiative sets a goal of reducing those emissions by more than 2 million tons (1.8 million metric tons) by 2020.

The GreenDOT initiative outlines a range of measures to help achieve the reductions. In cooperation with regional planning agencies, MassDOT will balance highway system expansion with projects that support smart growth and promote public transit, walking, and bicycling. Examples include transit and rail projects, complete streets planning with bicycle and pedestrian accommodations, and investments in greener, more efficient fleet vehicles and renewable power.

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

MassDOT

Initiative Encourages Communities To Be "Walk Friendly"

FHWA and the Pedestrian and Bicycle Information Center (PBIC) recently launched Walk Friendly Communities to encourage communities across the country to support pedestrian safety. The program will recognize communities that are working to improve a wide range of conditions related to walking, including safety, mobility, access, and comfort.

At the core of the program is a comprehensive assessment tool that evaluates community walkability and pedestrian safety through questions related to engineering, education, encouragement, enforcement, evaluation, and planning. Based on a community's answers, the tool evaluates conditions for walking and provides feedback and ideas for improving pedestrian safety.

"We're very excited to see cities and towns across the country commit to making pedestrian safety a high priority through the Walk Friendly Communities program," says Gabe Rousseau, bicycle and pedestrian program manager with FHWA. "This program will help

www.pedbikeimages.org, Dan Burden

North Las Vegas, NV, created a more walking-friendly environment for pedestrians by including landscaped space between the road and the sidewalk as shown here.

them understand their communities' specific opportunities to improve safety and reveal creative ways to address pedestrian safety concerns."

The national launch comes on the heels of a successful pilot in which nine communities tested the application and online assessment tool.

For more information, visit www.walkfriendly.org.

Rock Slope Stabilization Method Wins Award

The George Washington Memorial Parkway in Arlington, VA, recently received an award for its innovative rock slope stabilization design from the Association of Environmental & Engineering Geologists (AEG). AEG recognized the project as the 2010 Outstanding Environmental and Engineering Geologic Project for its cost-effective solution to achieving the dual goals of protecting the traveling public from rockfalls and preserving highway aesthetics.

In 2002, when failure of a 35-foot (10.7-meter)-high, 240-foot (73.1-meter)-long cut slope along the parkway

EFLHD

FHWA and EFLHD used a technique called "rock gluing" to stabilize this rock slope along the George Washington Memorial Parkway in Arlington, VA.

released several large pieces of rock onto the shoulder and travel lanes, FHWA officials with the Eastern Federal Lands Highway Division (EFLHD) began exploring options to stabilize the slope. The project resulted in an innovative approach called "rock gluing," which involves injecting polyurethane resin grout into fractured rock mass to bond individual blocks into a continuous, more stable mass.

AEG selected the project for the award because the innovative rock gluing technique can have broader applications. EFLHD already has used rock gluing as a practical solution for other projects and will continue to use the technique in the future.

AEG

Report Quantifies Transportation Projects' Impacts on Economy

According to a recent report by the American Road & Transportation Builders Association (ARTBA), the annual value of transportation construction in the United States will surpass $120 billion in 2010—higher than other industry sectors, including farming ($97.5 billion) and coal mining ($29.8 billion). ARTBA released the 100-page report, *U.S. Transportation Construction Industry Profile*, in October 2010.

The report states that money invested in 2010 in employment and purchases for the transportation construction industry will generate more than $380 billion in economic activity. That is nearly 3 percent of the Nation's gross domestic product. The report also observes that transportation construction supports 3.4 million American jobs—1.7 million directly involved in construction and related activities and 1.7 million in sustained spending by transportation construction employees, firms, and agencies throughout the U.S. economy.

In addition, the report notes the important role transportation infrastructure plays in making all kinds of other economic activities possible. For example, industries such as tourism, manufacturing, agriculture, forestry, and retailing and wholesaling are all dependent on the work done by the transportation construction industry to move goods and services. The report also includes State-specific data.

For more information, visit www.artba.org/economic-profile.

ARTBA

USDOT Holds Second National Distracted Driving Summit

On September 21, 2010, USDOT held the second national Distracted Driving Summit in Washington, DC. Leading transportation officials, safety advocates, law enforcement, industry representatives, researchers, and victims affected by distraction-related crashes gathered to discuss challenges and identify opportunities for national efforts to prevent distracted driving.

Major focuses included enforcement efforts, outreach to young drivers, and invehicle technologies. Also at the forefront of the discussions was the recent release of interim data from yearlong pilot enforcement programs in Hartford, CT, and Syracuse, NY. According to onsite

Julie Fischer for USDOT

Transportation Secretary Ray LaHood addresses attendees at the second national Distracted Driving Summit in Washington, DC.

observations and surveys at driver licensing offices at the pilot sites, hand-held cell phone use has dropped 56 percent in Hartford and 38 percent in Syracuse to date, and texting while driving has declined 68 percent in Hartford and 42 percent in Syracuse.

On the day before the summit, Transportation Secretary Ray LaHood announced new regulations for drivers transporting hazardous materials. The posted rules ban commercial bus and truck drivers from texting on the job and restrict train operators from using cell phones and other electronic devices while driving. The Secretary also identified more than 550 U.S. companies—employing 1.5 million people nationwide—that have committed to enacting anti-distracted driving policies for their employees in the next 12 months.

For more information, visit www.distraction.gov.

FHWA Develops Online Work Zone Training Compendium

FHWA recently created an online Work Zone Training Compendium, which details opportunities for highway work zone training and provides guidance materials. The compendium is available at www.ops.fhwa.dot.gov/wz/outreach/wz_training/index.htm.

The online resource includes current training courses, materials, and contact information related to work zones. For each class, workshop, or training opportunity, the compendium lists the title, description, format, length, provider, cost, target audience, and contact. Similar summary information is included for each of the guidance documents and reference materials. The information is available on the Web site or by downloading a spreadsheet from the site.

FHWA created the online compendium to serve as a one-stop source for work zone information. The site organizes relevant training and reference materials in 10 categories: design for work zones, inspection of work zones, intelligent transportation systems, law enforcement, management of work zones, nighttime work zone operations, short-duration work zones, traffic control in work zones, worker safety, and work zone guides and documents.

In addition to the compendium, FHWA recently added new work zone resources on worker safety to its Web site at www.ops.fhwa.dot.gov/wz/workersafety/index.htm.

by Gregory G. Nadeau

Every Day Counts in Building Transportation Infrastructure

In a time of constrained resources, governments at all levels are looking for ways to give taxpayers maximum value for every dollar. Transportation is no exception. The public expects and demands enhanced transportation infrastructure to improve safety and support the Nation's 21st century economy. In fall 2009, Federal Highway Administrator Victor Mendez launched an initiative called Every Day Counts to bring a greater focus on innovation in the way the Federal Highway Administration (FHWA) approaches the challenges of building and maintaining the highway system in today's economy.

To support the initiative, FHWA launched the "Every Day Counts" Web site at www.fhwa.dot.gov/everydaycounts in September 2010. The goal of the Web site is not only to inform transportation professionals about specific initiatives but also to help with implementation. Administrator Mendez also has established a strong partnership with the American Association of State Highway and Transportation Officials and other key stakeholders to join FHWA in this effort. State and local transportation agencies, as well as private sector contractors, will be critical to accelerating the deployment of innovations across the Nation.

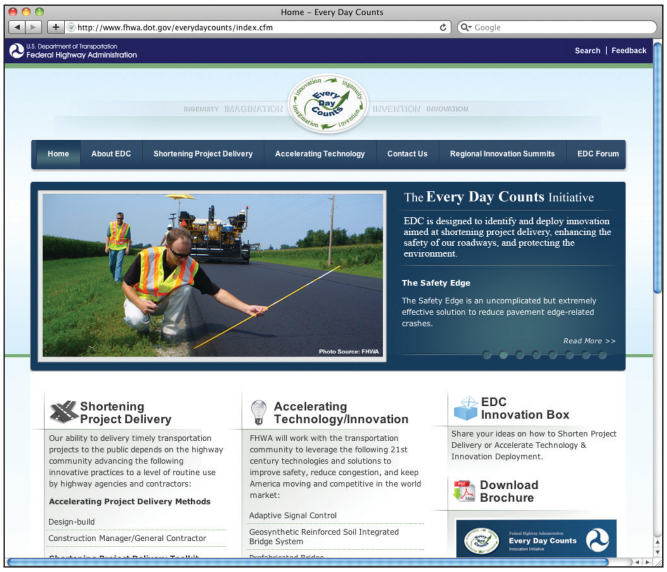
"Highways impact our communities in so many ways," says Administrator Mendez. "By making driving safer and reducing congestion, we contribute to more livable communities. Because highways are vital to our economic well-being, they must be able to facilitate trade and the movement of goods. And the way highways are constructed and perform has a direct impact on air quality and our ability to conserve energy. These are important challenges that not only need to be addressed, but approached with a real sense of urgency."

Built on Two "Pillars"

Every Day Counts is built on two pillars. The first involves a number of specific strategies designed to help shorten the time it takes to deliver major projects. Although there is some debate about the exact figure, the general thinking is that a major highway project takes an average of 13 years to go from concept to ribbon-cutting. Every Day Counts offers a range of strategies and tools for reducing that time, while continuing to protect the environment and deliver quality projects.

In general, these strategies attempt to eliminate duplication of effort in the planning process and encourage the use of flexibilities in current laws and regulations. These tools also offer innovative contracting solutions that engage the contractor earlier in the process, which helps provide a better handle on costs, risks, possible problems, and potential solutions.

The second pillar focuses on deploying five effective technologies into widespread use. One is adaptive signal control, which is a technology for adjusting the timing of traffic lights to accommodate changing traffic patterns.



Another is geosynthetic reinforced soil in an integrated bridge system, which uses alternating layers of compacted granular fill material and fabric sheets of geotextile reinforcement to provide bridge support. The third technology is prefabricated bridge elements and systems. The fourth is the safety edge, a solution that paves the edge of the roadway surface at angles of 30 degrees, making it easier for drivers to regain control if they start to leave the road. The fifth key technology is warm-mix asphalt.

Some of the technologies enhance safety, while others reduce construction time or save energy. The goal is to move these technologies off the shelf and into daily use.

Navigating the Web Site

The home page of the Every Day Counts Web site sets out the two pillars, with sections on shortening project delivery and accelerating technology deployment. In each section, site users can link to the specific strategies or technologies to learn more. For example, clicking on the "Flexibilities in Utility Accommodation and Relocation" link under "Shortening Project Delivery Toolkit," pulls up a page with best practices, training, and Federal laws, regulations, and policies relevant to utilities.

In addition to information-gathering functions, the site enables the transportation community to share feedback and ideas. The "Innovation Box," featured on the home page, is a direct link to FHWA where site visitors can send ideas for shortening project delivery or recommend new technologies.

"We must find better, faster, and smarter ways of delivering projects, enhancing safety, making our communities more livable, enabling commerce, and sustaining our environment," Administrator Mendez says. "The Every Day Counts initiative is an important first step in responding to that challenge, and the Web site lays out the route ahead."

Gregory G. Nadeau is deputy administrator of FHWA and leads the Every Day Counts effort.

Training Update

NATIONAL HIGHWAY INSTITUTE

by Lilly Pinto

Instruction for Bridge Inspectors Improved

As the Nation's bridges age and experience increased use from year to year, the need to improve and maintain them becomes more critical. A key component to ensuring that bridges remain safe and functional is a properly trained workforce of bridge inspectors.

To ensure that the workforce meets the Federal requirements and stays up to date on the latest practices, the Federal Highway Administration (FHWA) and National Highway Institute (NHI) continually develop and refresh course content. The recent introduction of a course titled Fracture Critical Inspection Techniques for Steel Bridges (FHWA-NHI-130078) is an example of how NHI strives to incorporate current practices and emerging technologies for bridge inspectors.

Fracture Critical Inspection Techniques for Steel Bridges is an important course because "the consequences of failure of a fracture critical member [of a bridge] are potentially very severe," says Thomas Everett, team leader of the Bridge Programs Team in FHWA's Office of Bridge Technology. "It is important that inspectors have the skills needed to identify fracture critical members and recognize problems before they become a safety concern."

Fracture Critical Inspection Techniques for Steel Bridges

Fracture Critical Inspection Techniques for Steel Bridges is a 3.5-day course that focuses on popular types of nondestructive testing (NDT) equipment—equipment used for in-place examination of material for structural integrity without damaging the material—and a case study of a bridge inspection plan. The first day of training provides an overview of NDT methods and an introduction to fracture critical members, which are bridge components that are subject to stress and potentially could lead to failure of the structure. The second day features demonstrations of various NDT techniques such as dye penetrant, magnetic particle, ultrasonics, and eddy current, and hands-on training sessions. Days three and four focus on inspection procedures and reporting on common fracture critical members, as well as a case study detailing the preparation of an inspection plan for a fracture critical bridge.

"This training will help inspectors evaluate bridges more thoroughly and will provide them with additional knowledge of how structures work and what can happen when they don't work," says Bill Drosehn, district bridge inspection engineer for the Massachusetts Department of Transportation, which hosted the pilot session of this course.

The course is geared toward public and private sector bridge inspectors, supervisors, project engineers, maintenance engineers, shop inspectors, shop foreman, and others responsible for shop fabrication and field inspection of fracture critical steel bridge members. All participants should have prior field experience in bridge inspection and possess a thorough understanding of bridge mechanics and safety inspection procedures. Participants who do not meet the prerequisites can take an introductory course, Safety Inspection of In-Service Bridges (FHWA-NHI-130055).

Phil Fish, Fish & Associates Inc.

A bridge inspector conducts ultrasonic tests on a steel bridge.

New and Updated Bridge Inspection Courses

NHI recently released several other new or updated courses that offer training on current inspection techniques and practices.

Bridge Inspection Refresher Training (FHWA-NHI-130053A). This 3.5-day course, designed to refresh the skills of practicing bridge inspectors, is based on the *Bridge Inspector's Reference Manual* (FHWA-NHI-03-001) and offers additional topics, such as fiber reinforced plastic, inspection of truss gusset plates, structure inventory and appraisal overview, and common National Bridge Inventory miscodings.

Safety Inspection of In-Service Bridges (FHWA-NHI-130055). This 2-week course, also based on the *Bridge Inspector's Reference Manual*, provides training on the safety inspection of in-service highway bridges. The session covers the advantages and disadvantages of material inspection equipment and component- and element-level data rating. Once completed successfully, this course can fulfill the training requirements of the National Bridge Inspection Standards.

Underwater Bridge Repair, Rehabilitation, and Countermeasures (FHWA-NHI-30091A). This 2-day course provides training on techniques for selecting and executing repairs to bridge elements that are underwater. The primary goal is to enable design engineers to select, design, and specify appropriate and durable repairs to submerged bridge elements.

Lilly Pinto is a contractor for NHI.

Communication Product Updates

Compiled by Zachary Ellis of FHWA's Office of Corporate Research, Technology, and Innovation Management

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

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

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Telephone: 703–605–6000
Toll-free number: 800–553–NTIS (6847)
Web site: www.ntis.gov

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

R&T Product Distribution Center
Szanca Solutions/FHWA PDC
13710 Dunnings Highway
Claysburg, PA 16625
Telephone: 814–239–1160
Fax: 814–239–2156
Email: report.center@dot.gov

For more information on R&T communications products available from FHWA, visit FHWA's Web site at www.fhwa.dot.gov, the National Transportation Library's Web site at http://ntl.bts.gov, or the OneDOT information network at http://dotlibrary.dot.gov.

Evaluation of Lane Reduction "Road Diet" Measures on Crashes (Summary Report)
Publication No. FHWA-HRT-10-053

A road diet involves narrowing or eliminating travel lanes on a roadway to make more room for pedestrians and bicyclists. Although there can be more than four travel lanes before treatment, road diets often are conversions of four-lane, undivided roads into three lanes—two through-lanes plus a center turn lane. The fourth lane might be converted to a bicycle lane, sidewalk, or onstreet parking. This summary replaces *Evaluation of Lane Reduction "Road Diet" Measures and Their Effects on Crashes and Injuries* (FHWA-HRT-04-082), which described an evaluation of road diet treatments in cities in California and Washington. For this summary, researchers reexamined those data using more advanced study techniques and added an analysis of road diet sites in smaller urban communities in Iowa.

The basic objective of this reanalysis was to estimate the change in total crashes in each of the two databases resulting from the conversions and to combine those estimates into a crash modification factor. To do this, researchers used the empirical Bayes method, which calculates the expected crash frequency of a particular site. The evaluation indicated a statistically significant effect of the road diet treatment in each of the two datasets and when the results are combined. The Iowa data indicate a 47 percent reduction in total crashes while the California and Washington data indicate a 19 percent decrease—a difference probably due to the differences in traffic volumes and types of urban environments where the treatments were implemented. The reanalysis results also differ from the original Iowa study results (25 percent reduction) and from the original California and Washington results (6 percent reduction). Combining both datasets results in a 29 percent reduction in total crashes.

The document is available at www.fhwa.dot.gov/publications/research/safety/10053/index.cfm. Printed copies also are available from the PDC.

Benefits of High Volume Fly Ash: New Concrete Mixtures Provide Financial, Environmental, and Performance Gains (Fact Sheet)
Publication No. FHWA-HRT-10-051

High volume fly ash (HVFA) concrete mixtures offer many benefits, including decreased cost, reduced energy content, enhanced environmental sustainability, and improved long-term performance. To identify innovative methods to overcome barriers to HVFA use in pavements and transportation structures, the FHWA Exploratory Advanced Research (EAR) Program is sponsoring a study called Greatly Increased Use of Fly Ash in Hydraulic Cement Concrete for Pavement Layers and Transportation Structures. This fact sheet from the study discusses obstacles to HVFA use, how the project is moving forward, areas examined, and how the project might affect the future of concrete.

Many producers and transportation agencies aim to increase the use of fly ash in transportation infrastructure; however, several barriers exist to implementing new mixtures. A particular concern of many practitioners is the difficulty of predicting strength gain in full-scale structures. This ongoing EAR project addresses the problem using temperature management software and the development of a database with analytical prediction tools.

In addition, agencies and contractors are concerned about potential incompatibilities between fly ash, admixtures, and cement. Therefore, the project team is developing screening procedures to identify the influence and properties of residual carbon on the rate of admixture absorption. The goal is to implement innovative strategies such as fly ash treatment, timing and rate of admixture addition, and prescreening of components to improve overall performance. The project is scheduled to be completed in fall 2011.

The document is available at www.fhwa.dot.gov/advancedresearch/pubs/10051/index.cfm. Printed copies are available from the PDC.

An Evaluation of Signing for Three-Lane Roundabouts (Summary Report)
Publication No. FHWA-HRT-10-030

Although multilane roundabouts have been found to be safer than conventional alternatives, they are not without safety challenges. FHWA studied driver reaction through driving simulations using three selected signing conditions on the approaches to three-lane roundabouts. In addition, FHWA sent questionnaires to participants to identify signing and marking strategies that result in higher levels of comprehension and compliance in lane selection on the approach to roundabouts. This summary report discusses the objectives, approach, method, driving simulation study, results, and recommendations.

One of the challenges of using multilane roundabouts is getting motorists to select and stay in their proper lanes as they navigate the roundabout. Another challenge is that motorists sometimes have difficulty interpreting lane control arrows in the roundabout context. Even with these unresolved issues, the safety and operational advantages of one- and two-lane roundabouts are so substantial that engineers have begun to introduce three-lane roundabouts where traffic cannot be accommodated in one or two lanes.

For roundabouts with three entering lanes, the study found that overhead advance navigation signage is more effective than other types of signage. In addition, it appears that additional treatments beyond the overhead signs tested in this study are needed to keep drivers from changing lanes within roundabouts.

The document is available at www.fhwa.dot.gov/publications/research/safety/10030/index.cfm. Printed copies are available from the PDC.

Crash Impact of Smooth Lane Narrowing with Rumble Strips at Two-Lane Rural Stop-Controlled Intersections (TechBrief)
Publication No. FHWA-HRT-10-047

According to the National Highway Traffic Safety Administration, fatal crashes at unsignalized rural intersections constitute approximately 37 percent of all fatal crashes at intersections nationwide. About 90 percent of the crashes at unsignalized rural intersections occur on two-lane roads. As a low-cost remedy to address this type of crash, FHWA developed and evaluated a treatment to reduce approach speeds by narrowing lanes using rumble strips in the median and on the right-lane edge. This summary report provides information on typical field design features, analytical methods and findings, conclusions, and recommendations for future deployments.

For this study, the lane narrowing was applied to approximately 150 feet (45.7 meters) on the major road approach to two-way stop-controlled intersections on high-speed rural roads. Researchers applied the treatment to eight intersections in five States and collected crash data for the pre- and post-treatment periods. They then used the empirical Bayes method to estimate the effectiveness of the treatment in enhancing safety. The method showed that, on average, the lane narrowing reduced the total number of crashes by 32 percent, while it reduced fatal/injury crashes by 34 percent.

The document is available at www.fhwa.dot.gov/publications/research/safety/10047/index.cfm. Printed copies are available from the PDC.

Reporting Changes of Address

PUBLIC ROADS has two categories of subscribers. One includes the organizations and people who receive the magazine without charge; the editorial office of the magazine maintains the mailing list for this group. The other category is the group of people and companies that pay to receive the magazine; the mailing list for this group is maintained by the Superintendent of Documents for the U.S. Government Printing Office.

Free copies are distributed to offices of the Federal Highway Administration, State highway agencies, technology transfer centers, and selected leaders who have responsibility for highway-related issues. Most of these copies are mailed to offices for their internal distribution or to people by position title rather than by name. If any office or individual subscriber in this category has a change of address, please send the complete previous mailing address and the complete new address to our distribution manager, Paula Magoulas, via email (paula.magoulas@dot.gov), telephone (202–493–3398), or mail (Paula Magoulas, PUBLIC ROADS Distribution Manager (HRTM), Federal Highway Administration, 6300 Georgetown Pike, McLean, VA, 22101-2296).

Paid subscribers who have an address change should notify the U.S. Government Printing Office, Claims Office, Washington, DC, 20402; or call 202–512–1800; or fax 202–512–2168. Please do not send an address change for a paid subscription to the editorial office of PUBLIC ROADS. We do not manage the paid subscription program or mailing list, and we are not able to make the requested change.

Conferences/Special Events Calendar

Date	Conference	Sponsors	Location	Contact
March 27–29, 2011	Lifesavers Conference: National Conference on Highway Safety Priorities	See conference Web site for a list of sponsors.	Phoenix, AZ	Mary Lofgren 703-922-7944 marylofgren@cox.net www.lifesaversconference.org
March 28–30, 2011	24th Annual GIS for Transportation Symposium	American Association of State Highway and Transportation Officials (AASHTO)	Hershey, PA	Daris Ormesher 605-773-6242 daris.ormesher@state.sd.us www.gis-t.org
April 3–6, 2011	ITE Technical Conference and Exhibit: Moving Toward Zero	Institute of Transportation Engineers (ITE)	Lake Buena Vista, FL	Sallie Dollins 202-785-0060 x149 sdollins@ite.org www.ite.org
April 14–16, 2011	2011 Structures Congress	Structural Engineering Institute of the American Society of Civil Engineers	Las Vegas, NV	Debbie Smith dsmith@asce.org http://content.asce.org/conferences/structures2011/index.html
April 17–21, 2011	NACE Annual Conference	National Association of County Engineers (NACE)	Minneapolis, MN	Bonnie West 202-393-5041 bwest@naco.org www.countyengineers.org
May 1–4, 2011	International Transportation Economic Development Conference: Economic Impact of Connecting People, Goods, Markets, Employment, Services, and Production	See conference Web site for a list of sponsors.	Charleston, WV	Traci Ulberg 866-633-8110 or 406-273-7224 info@ited2011.org www.ited2011.org
May 2–6, 2011	AASHTO Spring Meeting	AASHTO	Las Vegas, NV	Monica Russell 202-624-3696 mrussell@aashto.org www.transportation.org
May 18–20, 2011	3rd International Conference on Roundabouts	Transportation Research Board	Carmel, IN	Richard Pain 202-334-2964 rpain@nas.edu www.trb.org/calendar

NATIONAL HIGHWAY INSTITUTE

Improving Performance Through Training

Training Categories

- Asset Management
- Business, Public Administration, and Quality
- Communications
- Construction and Maintenance
- Design and Traffic Operations
- Environment
- Financial Management
- Freight and Transportation Logistics
- Geotechnical
- Highway Safety
- Hydraulics
- Intelligent Transportation Systems
- Pavement and Materials
- Real Estate
- Structures
- Transportation Planning

The transportation industry depends on a knowledgeable and skilled workforce. As the training arm of the Federal Highway Administration, the National Highway Institute (NHI) helps tens of thousands of transportation professionals develop core competencies, hone new skills, and learn about leading technologies and current practices.

With hundreds of courses in 16 topic areas and Web-based courses available 24/7, NHI makes training accessible for even the busiest professionals.

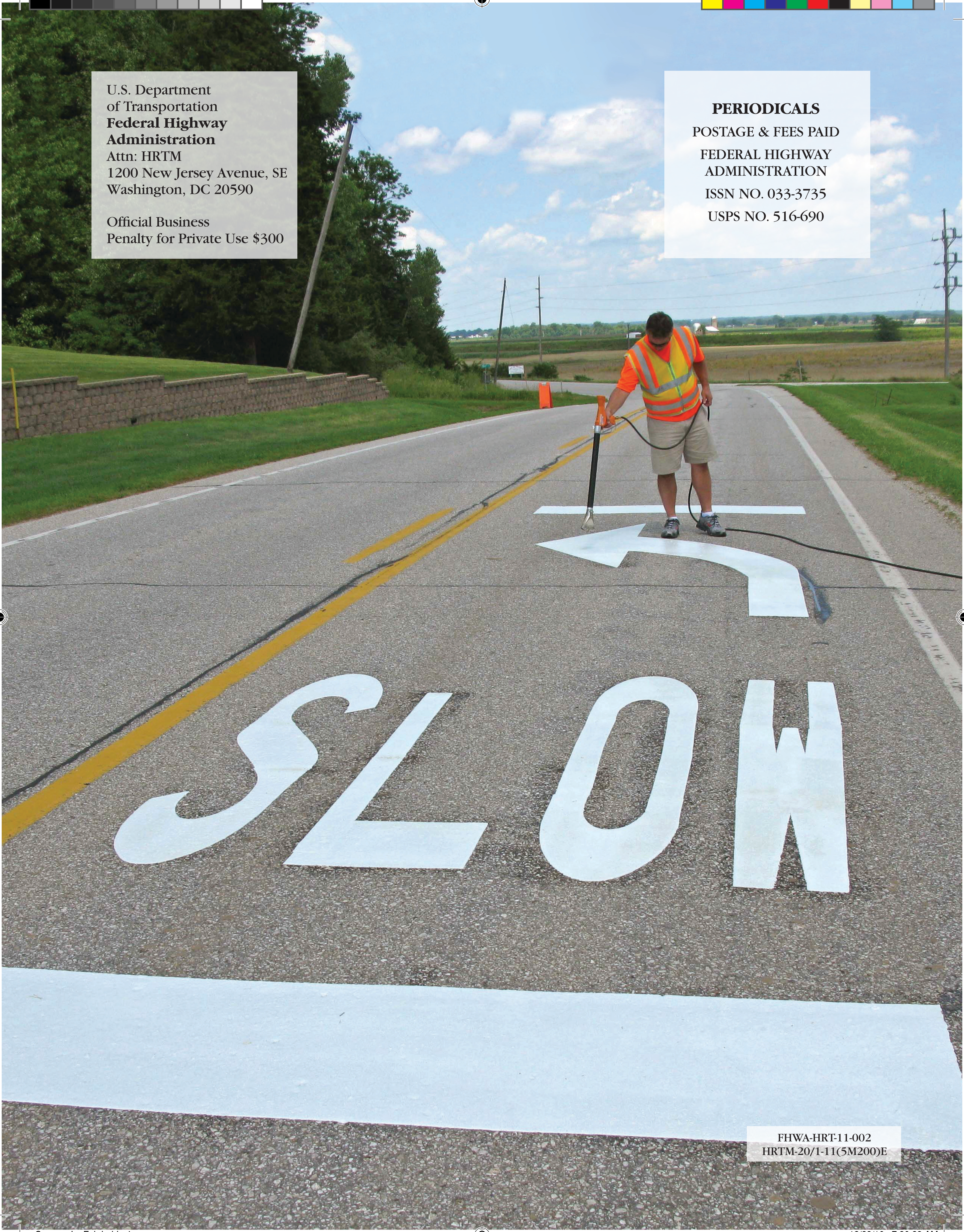
Visit www.nhi.fhwa.dot.gov to register today!

U.S. Department of Transportation
Federal Highway Administration

U.S. Department
of Transportation
**Federal Highway
Administration**
Attn: HRTM
1200 New Jersey Avenue, SE
Washington, DC 20590

Official Business
Penalty for Private Use $300

PERIODICALS
POSTAGE & FEES PAID
FEDERAL HIGHWAY
ADMINISTRATION
ISSN NO. 033-3735
USPS NO. 516-690



FHWA-HRT-11-002
HRTM-20/1-11(5M200)E