Public Roads

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Subsurface Utilities
Hazard Mitigation
Concrete Sustainability

U.S. Department of Transportation
Federal Highway Administration

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

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Front cover—These three technicians are using minimally intrusive vacuum excavation equipment on a project in Las Vegas, NV, to expose subsurface utilities. The resulting three-dimensional information enables transportation planners and designers to avoid unexpected utility conflicts and possible delays in order to accelerate project delivery. For more information, see "Subsurface Utility Engineering," on page 2 in this issue of PUBLIC ROADS. *Photo by Gary Borland, Cardno TBE, Inc.*

Back cover—This technician is using ground penetrating radar equipment on a U.S. 19 project in Clearwater, FL, to trace a subsurface utility system and interpret the surface geophysics. Engineers will use the resulting information to determine where critical conflicts exist with proposed transportation plans and to make decisions for avoiding delays and accelerating project completion. *Photo by Gary Borland, Cardno TBE, Inc.*

U.S. Department of Transportation
Federal Highway Administration

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Guest Editorial

Introducing a Series on Hazard Mitigation R&D

According to the National Science and Technology Council's Subcommittee on Disaster Reduction, the impacts of natural and manmade hazards in the United States cost an estimated $52 billion per year in lives lost and economic damages. Given impacts of this magnitude, research is critical to reducing risks to the Nation's infrastructure. In addition to vulnerability to natural events such as floods, earthquakes, hurricanes, tsunamis, and wildfires, the surface transportation infrastructure is at risk from human-induced threats like arson, technological hazards, and terrorism.

An important role of the Federal Highway Administration (FHWA) is to conduct research that helps improve the performance of the transportation infrastructure. FHWA's hazard mitigation research and development (R&D) program is helping lower risks to highways and bridges. Hydraulics and aerodynamics laboratories housed at FHWA's Turner-Fairbank Highway Research Center (TFHRC) play a key role in testing innovative concepts and developing countermeasures and new systems for hazard mitigation.

FHWA's research has resulted in improved bridge scour equations for foundation design and countermeasures to reduce the potential impact of scour on the stability of bridge foundations during floods. After the devastating damage to bridge infrastructure caused by hurricanes along the coasts of Alabama, Florida, and Mississippi, research conducted at the TFHRC hydraulics laboratory resulted in improved guidelines and procedures to address wave force impacts on bridge decks.

The aerodynamics laboratory is the only wind tunnel facility in the United States that is dedicated solely to the study of wind effects on transportation structures. Researchers in this laboratory conduct wind tunnel modeling and field monitoring of actual structures to study measures to control bridge vibrations. Concepts developed through this research have been deployed in many of the Nation's long-span bridges.

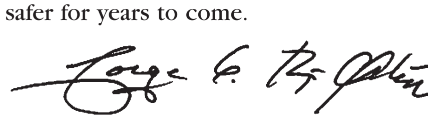
Earthquake hazards are addressed through FHWA's seismic research program, which focuses on measures to strengthen structures in high seismic risk areas. TFHRC researchers also participate in seismic reconnaissance efforts in other countries. For example, a team was deployed in April 2010 to Chile to evaluate the effects of the devastating February 27, 2010, earthquake on that country's surface transportation infrastructure. Findings from similar deployments have provided valuable information that has led to updates to seismic design codes and specifications.

For manmade hazards, TFHRC's security research program concentrates on developing innovative solutions to protect bridges against terrorist threats. The researchers are engaged in developing design aids and guidelines for use by infrastructure owners to protect vulnerable bridge components.

Communication between FHWA's researchers and stakeholders is vital. Listening to feedback from transportation stakeholders regarding their needs and what they are working on helps FHWA identify research issues of national importance. In addition to interaction with the American Association of State Highway and Transportation Officials' technical committees, FHWA researchers consult with others in the national and international arenas who are conducting relevant research.

This issue of PUBLIC ROADS initiates a series of articles on FHWA's R&D focused on hazard mitigation strategies. The first article, "Taking a Key Role in Reducing Disaster Risks," provides an overview of how hazard mitigation R&D is reducing risks to the Nation's infrastructure. Subsequent articles in future issues will detail ongoing R&D related to four specific hazards: flooding and scour, wind, earthquakes, and terrorism.

Research provides the key to developing new and improved technologies to make the Nation's highways and bridges safer for years to come.



Jorge E. Pagán-Ortiz
Director, Office of Infrastructure Research and Development
Federal Highway Administration

SUE
Subsurface Utility Engineering

by C. Paul Scott

The SUE process revolutionized how designers, engineers, and contractors handle underground pipes and power lines during highway planning, design, and construction.

Every year, thousands of problems occur on highway projects in the United States when contractors fail to locate subsurface utilities reliably prior to excavation, drilling, or boring. Last year, the Common Ground Alliance, an industry association devoted to reducing damages to underground utilities, published its fifth annual Damage Information Reporting Tool (DIRT) report, *CGA DIRT Analysis & Recommendations,* which notes that approximately 200,000 subsurface utilities were damaged in the United States in 2008. The number is conservative because only reported hits are included.

To cite a few examples from 2008 and 2009, a Texas Department of Transportation (TxDOT) subcontractor drilled through a 20-inch (51-centimeter) water main beneath

This technician is using an air lance to loosen soil in conjunction with a nondestructive vacuum excavation to locate an underground utility line during a project in Las Vegas, NV.

All photos by Gary Borland, Cardno TBE, Inc.

a roadway in Lubbock, TX. Repairs to the water line disrupted traffic at a major intersection for days. In a California case, a contractor excavating for a new manhole clipped an underground high-pressure line, discharging natural gas into the sky above Novato, CA, for nearly 8 hours. The leak occurred within 500 yards (457 meters) of two preschools.

This kind of problem probably happens in every State. When a Florida DOT contractor nicked a fiber-optic cable in Chipley, FL, while placing a sign during a resurfacing project, Internet service for 5,000 customers was out for 2 days. In Massachusetts, a massive outage in Braintree left about 75 percent of the city without electricity for 45 minutes after a contractor struck one of the town's primary transmission lines. These examples are only a few of many described in the January/February 2009 issue of *Underground Focus* magazine.

For almost 20 years, the Federal Highway Administration (FHWA) has promoted an engineering practice called subsurface utility engineering (SUE) to avoid problems like these. Before the development of SUE, traditional methods of dealing with subsurface utilities were not working. Designing projects without consideration of utilities and dealing with utility problems later during construction was common practice. This approach resulted in unexpected encounters with subsurface utilities, many unnecessary utility relocations, construction delays, and unanticipated costs.

The roadway owners in the examples described earlier probably did not locate the utilities or did not locate them correctly—and almost certainly did not use SUE. However, largely due to extensive private-public promotional efforts, many State departments of transportation (DOTs) today use SUE routinely on Federal-aid highway and other major construction projects. As a result, they minimize the risk of costly mistakes and schedule delays, saving time and money.

"Since we began using SUE, we have been able to design around utilities and avoid utility hits during construction," says Cheryl Cathey, section chief of preliminary engineering at the Illinois DOT.

This SUE technician is using a pipe and cable locator and painting marks on the ground to designate the approximate horizontal position of a subsurface utility.

How Does SUE Work?

As an engineering practice, SUE enables State and local DOTs, design consultants, and utility companies to locate existing subsurface utilities with a high degree of accuracy and comprehensiveness. SUE combines elements of civil engineering, geophysics, and surveying. It uses surface geophysical methods (quantitative physical methods designed to interpret ambient or applied energy fields), mapping technologies such as computer-aided design and drafting (CADD) and geographic information systems (GIS), and vacuum excavation (pressurized air or water used to break up and lift soil out of the excavation area). When used properly, SUE can minimize project-utility conflicts and reduces project delays.

The SUE provider, who could be a DOT staff member but most likely is a private engineering consultant, begins by conducting extensive research of utility records to identify facilities that might affect the project under development.

The provider then obtains pertinent as-built information from utility owners and plots the resulting information on a utility composite drawing or its equivalent. The result is base-level information, termed quality level D (QL-D).

The next step involves field observations to identify visible aboveground utility features, such as manholes, valve boxes, and fire hydrants. The SUE provider surveys these observed quality level C (QL-C) features, correlates them with the previously obtained QL-D information, and resolves any discrepancies.

Next, the SUE provider uses appropriate surface geophysical methods such as pipe and cable locators, terrain conductivity methods, metal detectors, and ground-penetrating radar to designate existing subsurface utilities or to trace a particular utility system. Weather, terrain, and utility depths, types, and materials influence the methods required, the types of equipment needed, and the cost. Several methods and types of equipment often are required for any given project. The SUE provider surveys the resulting quality level B (QL-B) information, correlates it with the QL-D and QL-C information, resolves discrepancies, and depicts it in the client's CADD system, GIS databases, or onto plan sheets or other relevant documents.

The SUE provider next develops a matrix showing all possible highway-utility conflicts. This step

Three SUE technicians are using a pipe and cable locator and nondestructive vacuum excavation to locate subsurface utilities. After exposing the utilities, the workers survey and record information pertinent to the type of utility and its size, depth, and condition. The workers record the data both electronically and on a poster board, which they photograph (as shown here) for quality assurance purposes.

involves comparing the collected QL-B information on utilities with the proposed plans for the highway, bridge, drainage, maintenance-of-traffic, or other projects. One of the purposes of the conflict matrix is to determine whether additional information is needed.

Finally, the SUE provider uses minimally intrusive excavation methods, such as vacuum excavation, to expose selected subsurface utilities. Having determined the depth of the subsurface utilities and other information (size, composition, and condition of the utility, soil type, site conditions) through these targeted quality-level (QL-A) excavations, the provider then can correlate QL-A and QL-B information and depict the utility location in three-dimensions (3–D) in the client's CADD system, GIS databases, or onto plan sheets or other relevant documents.

Although these are the general steps, the practice of SUE does not follow any set pattern but rather is tailored to individual projects. Essentially, it involves systematically identifying the quality of utility information needed to design a project, then acquiring and managing that level of information.

Why Is SUE Important?

John Campbell, P.E., director of the Right of Way Division at TxDOT and chair of the American Association of State Highway and Transportation Officials' (AASHTO) Subcommittee on Right-of-Way and Utilities, initiated the SUE program in Texas. "The SUE process, specifically the assignment of quality levels to the utility data collected, provides valuable engineering information from which to make risk-based decisions…for the delivery of transportation projects," Campbell says. "At TxDOT, the use of SUE in project planning and design enables us to avoid unnecessary impacts to existing utilities and to save the incalculable costs of adjustments" that were not required because the SUE process located the utilities beforehand and construction delays never occurred.

An FHWA guidebook, *Program Guide: Utility Relocation and Accommodation on Federal-Aid Highway Projects* (FHWA-IF-03-014), states that the proper use of this cost-effective professional engineering service will eliminate many of the utility problems typically encountered on highway projects. According to the guide, problems reduced or eliminated include project delays caused by (1) waiting for utility relocations to be completed, so highway construction can begin; and (2) redesign when construction cannot follow the original design due to unexpected utility conflicts. Other problems avoided include (3) delays to contractors during highway construction caused by cutting, damaging, or discovering utility lines that were not known to be present; (4) claims by contractors to project owners for delays resulting from unexpected encounters with utilities; and (5) deaths, injuries, property damage, and releases of product (such as natural gas or wastewater) into the environment caused by damaging utility lines that were not known to be there.

Jeffrey Zaharewicz, FHWA value engineering/utilities program manager, describes SUE as "one of the best tools available to successfully integrate the activities associated with utility relocation and coordination into the project development process."

SUE Success Stories

A sampling of successful outcomes that resulted from the use of SUE further demonstrates the benefits of this process.

When widening I–75, the Georgia Department of Transportation (GDOT) planned to relocate existing water and sewer mains that led from a rest area to a source several miles away. After obtaining and analyzing SUE data, however, GDOT determined that no conflicts were present, and therefore relocating the lines would be unnecessary. This decision conservatively saved GDOT at least $400,000.

In Texas, the use of SUE data enabled consultants working for TxDOT to design around several high-pressure pipelines crossing a major State highway, SH–130. To achieve this outcome, the designers shifted the schematic right-of-way approximately 300 feet (91 meters), avoiding costly pipeline relocations. The right-of-way shift prevented project delays and resulted in a cost savings of $3 million.

Hurricane Wilma damaged an estimated 10,000 trees in Coral Springs, FL, that therefore needed to be removed. Wishing to be proactive and prevent costly utility damage, the city hired an SUE provider to locate utilities ahead of the tree removal crews. During the first week, SUE prevented several major utility hits. Due to the quantity of utility lines found by the provider, the city changed its approach and decided to grind many tree trunks instead of going ahead with complete stump removal. In one area, where SUE was not used, the tree removal crews hit a major water line on the first day.

The Early Days of SUE

The value of SUE became apparent to highway engineers when an engineering company in Manassas Park, VA, introduced the practice in 1982. The company combined two relatively new technologies—surface geophysics and air/vacuum excavation—to gather data on the exact location of subsurface utilities early in the development of projects.

One year later, the transportation department in nearby Fairfax County, VA, became the first government agency to use SUE on highway projects. In 1985 the Virginia Department of Transportation (VDOT) became the first State agency to use it.

"We discovered many years ago that the old ways of obtaining utilities information for design purposes were not working," says Greg Wroniewicz, VDOT utility engineer. "SUE *does* work, and we use it on nearly every highway project."

FHWA began promoting SUE in 1991, shortly after its nationwide potential was recognized by Jim Overton, now retired but then-acting branch chief, and Jerry Poston, now deceased but then-branch chief, of FHWA's former Railroads, Utilities, and Programs Branch. Poston was often heard to say that SUE would revolutionize the way utilities are handled on highway projects.

"His prophecy certainly came true," says Jon Obenberger, FHWA preconstruction group team leader. "Reliable subsurface utility data now can be provided to highway designers, and it is no longer acceptable practice to design highways or construct projects without consideration of those data."

How Has SUE Evolved?

By the 1990s, the new approach had spread from Virginia into nearby States (Delaware, Maryland, North Carolina, and Pennsylvania) and then to more distant States (Arizona and Florida). As the practice of SUE spread, it evolved to include surveying, CADD, affixing of a professional engineer's seal to deliverables, and professional liability insurance.

SUE flourished in the 1990s as more States began using it, and more providers began to emerge. Probably the most significant advance in that decade involved the introduction of the concept of the quality levels, which enabled designers to certify on project plans a certain level of comprehensiveness and accuracy for the utility information.

By the end of the 1990s, however, some confusion still existed as to just exactly what SUE was. Some companies were claiming that SUE meant subsurface utility exploration or "pot-holing," rather than subsurface utility engineering. The latter provides more accurate and comprehensive information than can be obtained by randomly digging pot-holes. Some DOTs bought into the former concept with poor results that soured them on continuing the use of SUE.

The leading providers were aware that SUE was an engineering practice with quality levels and were promoting it as such. FHWA also recognized the distinction between an engineering practice and pot-holing and began strongly encouraging State DOTs to acquire the services of reputable SUE providers.

The need to quantify the value of SUE on highway projects had become apparent, as well as the need

Two workers are surveying a subsurface utility to determine its exact depth beneath the surface. In addition to depth, they will record on a poster board the type (gas, electric, water) and thickness of the buried utility, as well as materials, condition, and other data.

A worker loosens soil with an air lance in preparation for excavating a test hole.

to establish standard guidelines for its use. FHWA commissioned Purdue University to document and quantify SUE's value, and the American Society of Civil Engineers (ASCE), working with FHWA and industry, agreed to establish national guidelines for collecting and depicting existing subsurface utility data.

Research on the Effectiveness of SUE

Purdue University published its report, *Cost Savings on Highway Projects Utilizing Subsurface Utility Engineering*, in 2000. The Purdue researchers studied 71 projects in North Carolina, Ohio, Texas, and Virginia. The projects involved a mix of interstate, arterial, and collector roads in urban, suburban, and rural settings.

Two broad categories of savings emerged—quantifiable and qualitative savings. The Purdue study quantified a total of $4.62 in avoided costs for every $1.00 spent on SUE. The greatest savings came from avoiding utility relocations and reducing delay claims. Although qualitative savings (for example, avoided impacts on nearby homes and businesses) were not measurable, the researchers believed those savings were significant and possibly many times more valuable than the quantifiable savings.

The study concluded that SUE is a viable technological practice that reduces project costs related to subsurface utilities and that DOTs should use it in a systematic manner.

In addition, the Ontario Sewer and Watermain Contractors Association commissioned the University of Toronto to investigate the practice of using SUE on large infrastructure projects in Ontario. This study chose nine case studies and determined that the average rate of return for each dollar spent on SUE services on those projects was $3.41. The study also made a number of qualitative recommendations regarding the use of SUE.

The ASCE Standard

In 2003, ASCE defined SUE as an engineering practice in CI/ASCE 38-02, *Standard Guideline for the Collection and Depiction of Existing Subsurface Utility Data*. The importance of this standard is that it indicated that, in addition to FHWA, a prominent national engineering organization defined SUE as an acceptable engineering practice and provided guidance for applying it on projects.

The standard presents the system of classifying the quality level of subsurface utility data. The classification enables project owners, engineers, and construction companies to develop strategies to reduce risks related to existing subsurface utilities or, at a minimum, to allocate the risks in a defined manner. The standard closely follows concepts already in place in the SUE profession. Many State DOTs therefore are already in compliance with the standard through their use of SUE or through their inclusion of SUE specifications in their engineering contracts.

The Private Sector And FHWA Roles

The growth of SUE resulted from efforts by FHWA's headquarters and division offices to encourage State DOTs to use it and from State DOT officials telling their counterparts about it. But some of the credit also must go to SUE professionals who understood the process and worked to sell the concept to potential clients.

FHWA encouraged the use of SUE through memos to field offices. Also, division administrators and their staff engineers discussed SUE with their State DOT counterparts and encouraged them to

An SUE technician is applying paint marks on the pavement at approximate 25-foot (7.6-meter) intervals as he traces out a utility line. After the line is surveyed, the marks will be shown on the plans as quality level B.

give it a try. FHWA developed flyers, brochures, and handbooks and distributed them to the divisions and State DOT offices; wrote numerous papers for conferences and publications; set aside funds for SUE-related research projects; delivered presentations at conferences and workshops at approximately 20 State DOTs and other venues; obtained funds to develop and/or distribute instructional videos; and funded demonstration projects in Oregon, Puerto Rico, and Wyoming.

State DOTs promoted SUE by word of mouth and continue to do so. "State DOT utility engineers get together every year to discuss common issues," says Chuck Schmidt, chief of design services at the New Hampshire DOT and vice-chair of AASHTO's Subcommittee on Right-of-Way and Utilities. "In the 1990s DOT utility engineers would meet at the National Highway Utility Conference, and for the past decade, we have gotten together at the AASHTO subcommittee conference on right-of-way and utilities. We have special sessions where we talk about our common problems and possible solutions. Those who use SUE are not bashful about singing its praises and encouraging everyone to use it. In turn, several States, including New Hampshire, have included SUE as a normal course of business on several of our projects."

While FHWA and State DOTs were promoting the new approach, the SUE professionals were on the front lines. They visited State DOTs in all parts of the country; wrote papers for conferences and articles for industry publications; provided numerous presentations, demonstrations, and exhibits at workshops and conferences; developed educational videos and provided them to FHWA for distribution; and held numerous workshops for State DOTs.

Nick Zembillas, senior principal and senior vice president, Cardno TBE, says, "Highway engineers had been locating underground utilities with inaccurate as-builts and backhoes, often with disastrous results, and it was hard to convince them that there was a better way to obtain the information. But we didn't give up and are still not giving up on the ones that continue to hold to the old ways. SUE is here to stay as an industry standard of care."

Surveyors are preparing to obtain SUE information on a project in Las Vegas, NV. The surveyed information will be depicted in the client's CADD system, in GIS databases, or on plan sheets or other relevant documents.

SUE Today

Federal, State, and local highway agencies are using SUE, as are design consultants, highway contractors, and utility companies for public works projects around the country. The military, airports, transit, hospitals, and ports also use it.

SUE spread from the United States into Canada in 2002 where it is used routinely on highway projects from Toronto in the east to Calgary in the west. One company alone has carried out more than 450 projects. To standardize the practice in Canada, the Canadian Standards Association is developing a standard for mapping underground utility infrastructure that will reference the use of SUE and the ASCE 38-02 quality levels.

After SUE was introduced into the United Kingdom (UK) in 2008, it slowly gained recognition in London and other major cities as a sound engineering process. Only a few small projects have been completed to date, but interest in developing something similar to the ASCE 38-02 standard seems to be growing.

In addition, Standards Australia is working with ASCE to develop an engineering standard similar to ASCE 38-02 in anticipation of the growth of SUE. The practice was introduced only recently in Belgium, China, New Zealand, and the United Arab Emirates.

SUE is an integral part of the National Highway Institute's course Highway/Utility Issues (FHWA-NHI-134006). The course currently is being updated to include conflict analysis, which is the newest engineering practice to evolve from SUE. SUE continues to be the subject of many presentations and workshops at conferences such as the annual conference of the AASHTO Right-of-Way and Utilities subcommittee, the Transportation Research Board annual meeting, and others.

Today, utilities should no longer be unnecessarily relocated or unexpectedly encountered on highway projects. The application of SUE by transportation agencies and qualified providers who understand the practice makes it possible to avoid utility-related problems that have plagued highway engineers for decades and thereby accelerate project delivery.

C. Paul Scott, P.E., has been Cardno TBE's national utilities liaison since 2003, joining it after retiring from FHWA, where he worked for 34 years. He received his B.S. in civil engineering from the University of Tennessee and is a registered professional engineer in Kentucky and Virginia.

For more information, please visit www.fhwa.dot.gov/programadmin/sueindex.cfm or contact C. Paul Scott at 571-233-4023 or pscott@tbegroup.com.

Seizing opportunities in the design, construction, and maintenance phases of concrete pavements can provide a more sustainable highway infrastructure.

by Suneel N. Vanikar, Jim Grove, and Leif Wathne

Leaving a Smaller Footprint

The Federal-aid highway system consists of about 160,000 miles (256,000 kilometers) of concrete, asphalt, and other materials that stitch together a roadway network critical to the Nation's economy, defense, and mobility. Though the system continues to provide efficient and cost-effective movement of people, goods, and services, due to the ever-increasing traffic levels and age of the system, thousands of miles now require maintenance, rehabilitation, or reconstruction every year.

How transportation agencies address these needs for system preservation can play a critical role in ensuring the sustainability of infrastructure, especially in light of growing debate among scientists, policymakers, and the public regarding climate change and greenhouse gas emissions, such as carbon dioxide (CO_2).

(Above) A construction crew is using diamond-grinding to rehabilitate a portion of I–70 near Rifle, CO, in this 2005 photo. Diamond-grinding is one of many practices that can increase the longevity and sustainability of concrete pavements. *Photo: IGGA.*

Concrete, one of the most widely used materials on Earth, is a key building material in all sorts of modern public works projects—from water treatment facilities, aqueducts, underground utilities, hydroelectric dams, containment structures, and buildings to slabs, foundations, levees, tunnels, safety barriers, bridges, and of course pavements. According to the Carbon Dioxide Information Analysis Center, the manufacture of cement for use in concrete accounts for roughly 4 percent of global CO_2 emissions.

Responsible, sustainable practices in the selection, design, and construction of concrete pavements can limit the material's environmental footprint, putting highway agencies in the driver's seat to become part of the solution to the Nation's sustainability challenges.

"Concrete pavement preservation projects offer a long-term repair solution engineered to last many years, even decades," says John H. Roberts, executive director of the International Grooving & Grinding Association® (IGGA). "They can be designed and packaged for bid in a matter of days. Stiff competition within the industry and advancements in technology ensure that pricing is typically far less than alternative repair treatments."

Indeed, transportation agencies can seize opportunities in all phases of a concrete pavement's life cycle—before, during, and after construction—to bring about more sustainable infrastructure.

Opportunities Before Construction

The design phase of a concrete paving project affords two main opportunities to focus on sustainability. Transportation agencies can optimize pavement design to maximize longevity and minimize use of virgin materials and energy.

When developing concrete mixtures to meet project-specific needs, pavement designers can incorporate industrial byproducts, such as fly ash from coal-burning plants and blast furnace slag, and other constituents that might have lower carbon footprints than conventional materials. By incorporating industrial byproducts as replacements for virgin aggregates and cementitious materials, designers can produce a more sustainable concrete and improve performance at the same time. For example, in 2007 researchers with the Iowa Department of Transportation found that a test section construction on I–29 in 1994 incorporating a blended pozzolan (calcined clay) cement was in "excellent condition," while other parts of the project experienced early pavement deterioration.

In the context of sustainability, longevity is paramount. A long-lasting concrete pavement does not require rehabilitation or reconstruction as often as a typical pavement and therefore consumes fewer materials in the long run. Because a long-lasting pavement requires less frequent reconstruction, it entails fewer work zones and thus has less impact on traffic congestion, with accompanying energy savings and a reduction in vehicle pollutants. The latter is particularly important: By most estimates, the sustainability footprint associated with the usage phase of a roadway facility dwarfs the footprint associated with highway materials production and construction.

The longevity of concrete pavements is well documented. Countless concrete highways in North America have lasted 50 years or more, supporting traffic volumes much greater than originally anticipated. A notable example is I–10 in California's San Bernardino Valley, originally constructed in 1946 as part of Route 66. Portions of this concrete highway still carry more than 200,000 vehicles per day. The California Department of Transportation (Caltrans) has renewed the highway three times by surface grinding over its 60-plus-year life, testament to concrete pavement's sustainability.

Other key opportunities to improve the sustainability of concrete pavements before construction lie in use of the latest pavement design guidelines, two-lift pavement design, modular concrete pavement, materials selection and mixture design, and choice of cementitious materials.

Pavement Design

Many States have begun to implement the procedures and designs described in the new *Mechanistic-Empirical Pavement Design Guide* published by the American Association of State Highway and Transportation Officials (AASHTO). The latest guide replaces earlier ones that served highway agencies well for half a century but were based on limited foundational data. The new guide can help designers optimize pavement thickness to meet the design-life criteria with greater reliability, but without overbuilding. Further, it enables a pavement designer to optimize use of materials, thereby minimizing waste and reducing a highway's environmental footprint.

ACPA

Caltrans has surface-ground this portion of I–10 near Pomona three times, helping extend the life of the heavily traveled route to more than 60 years, without significant reconstruction.

Two-Lift Design and Pervious Concrete

Two-lift concrete pavement design is making a comeback in the United States. Two-lift construction involves placement of two wet-on-wet layers of concrete instead of the homogenous single layer commonly placed in concrete paving. The bottom layer is thick and consists of lower quality (lower durability and strength) aggregate. The top layer is thin and consists of high-quality aggregate that provides better resistance to freeze-thaw damage, reduced noise, and improved friction. In the past, cost, mixture design, and construction concerns inhibited use of two-lift paving.

Lately, however, changes in the availability of a good quality aggregate, advances in materials knowledge and construction equipment, and increasing demands for pavement surfaces that meet specific noise, durability, and safety objectives are prompting the need to reconsider two-lift paving. Currently, the greatest resistance to this technique is economic: Two-lift paving would likely result in the use of two concrete plants, two slipform paving machines (although single machines do exist to perform this operation), and a special haul road, all of which add to a project's cost.

A promising advancement for two-lift pavements is use of recycled concrete, or even recycled asphalt, material in the lower lift, which enables transportation agencies to avoid using virgin materials that require mining or processing. If the existing concrete pavement is to be recycled for use in the lower lift, agencies also can take advantage of a process for recycling pavement in place. Developed more than 15 years ago, the technique significantly reduces material hauling and saves energy.

In another design approach, agencies can use roller-compacted concrete to meet design criteria. This alternative requires less cementitious material than conventional concrete, which helps to minimize the CO_2 emissions required to produce the final concrete mixture.

Pervious concrete can provide environmental advantages, such as reduced stormwater runoff. To date, this technology has been used successfully for parking lots, city streets, and alleys. (See "Greener Alleys" on page 26 in this issue of

Koss Construction Co.

A contractor is using a slip-form paving machine on I–70 in Kansas to build a two-lift concrete pavement, a construction method coming back into vogue with the availability of new aggregates and equipment.

ACPA, Missouri/Kansas Chapter

The cities of Leawood and Overland Park, KS, paved this 1.9-mile (3.1-kilometer) section of Nall Avenue with 1,100 tons (998 metric tons) of slag cement, which is long lasting and lightens the surface color considerably, improving visibility.

PUBLIC ROADS.) Research is underway in Australia and the United States to develop a procedure that would allow placement of pervious pavement as the top lift of a two-lift pavement and thereby reduce noise and increase safety through reduced splash and spray.

Modular Concrete Pavement

Modular concrete pavement technologies facilitate accelerated pavement construction and provide long-lasting concrete pavements. They are particularly effective in urban areas and in situations with high traffic volumes. Precast, prestressed and nonprestressed concrete systems are available, and several such projects have been constructed in the United States over the last 10 years.

Materials Selection And Mixture Design

In some areas of the United States, engineers have successfully incorporated blast furnace slag generated from steel production as coarse aggregate in new concrete. The slag aggregate is highly absorptive, and experience shows it can help support a durable, long-lasting concrete. Using blast furnace slag as aggregate not only puts a former waste material to productive use, avoiding landfilling and reducing the demand for virgin aggregate, but also the slag releases absorbed water during hydration that increases strength and lowers permeability of the concrete.

Cementitious Materials

The concrete component that has the greatest carbon footprint is cement. Cement manufacture produces CO_2 from both the calcination of limestone and the combustion of fuels to generate the high kiln temperatures needed to produce clinker. Therefore, if engineers can reduce the amount of cement in a concrete mixture, or reduce the amount of clinker needed to produce cement, they can thereby reduce concrete's carbon footprint.

In 2004, ASTM International changed the specification for cement manufacture to allow up to 5 percent uncalcined limestone. This allowance directly reduced the amount of clinker needed, plus the CO_2 footprint per unit mass of cement by the same amount. A report by the Portland Cement Association, *The Use of Limestone in Portland Cement: A State-of-the-Art Report*, concludes that there is no discernable difference in the properties of concrete resulting from this change.

Use of supplementary cementitious materials (SCMs) as a replacement for cement can improve the performance of concrete, reduce environmental impacts, and lower the cost. Concrete made with SCMs produces less heat during the hydration process (a benefit for constructability in hot, summer weather), is more workable, and has greater strength and lower permeability.

Most SCMs are byproducts from other industries. A common SCM in concrete pavements is fly ash, which is a byproduct of coal burning at electricity generating stations. Others include ground granulated blast furnace slag (a byproduct of extracting iron from iron ore), silica fume (a byproduct of silicon manufacture), metakaolin, rice hull ash, and other natural pozzolans, which are used to increase concrete strength, density, and resistance to chemicals. (California recently included in its specifications the option to incorporate rice hull ash into concrete mixtures.)

The volume of SCMs designed into a mixture depends on the intended use of the concrete. Engineers at CanmetENERGY (Canada's center for clean energy research and technology development) are working on projects in India that utilize high volumes of fly ash. The approach of using high volumes of fly ash is not new, but its sustainability benefits have rekindled interest in determining how such a mixture can be used most successfully.

Blended cements have become more popular in recent years. They are the product of blending or intergrinding cement with one or more SCMs, which can take the place of as much as 50 percent of the cement in concrete, thereby reducing the clinker that needs to be produced, also by up to 50 percent. Engineers also are evaluating alternatives to portland cements. Geopolymer cements, particularly those made from fly ash, have vastly reduced environmental impacts yet have similar properties to portland cements.

Photocatalytic cement, which uses energy from the sun's ultraviolet rays to oxidize most organic and some inorganic compounds on the surface of the concrete structure, offers significant air pollution benefits. The active ingredients (including titanium dioxide) are not consumed during these reactions; they act solely as catalysts. Water from rain and melted snow then wash the solid pollutants away from the surface, and the process continues. Pavements made with this type of concrete can reduce nitrogen oxides, major contributors to ozone and smog, by as much as 80 percent.

Opportunities During Construction

Transportation agencies have many opportunities to enhance the sustainability of concrete pavements during construction. These opportunities include using locally available materials, recycling, accelerated construction, contracting flexibility, and equipment innovations.

By using locally available materials, such as from nearby aggregate quarries, contractors can reduce hauling distances, fuel use, and carbon footprints. Use of mobile batch plants onsite (instead of hauling concrete from fixed concrete plants distant from the construction site) offers similar sustainability benefits. Contractors often select local materials for economic reasons, but certain project characteristics could make it even more attractive to use such materials.

For example, with two-lift pavements, locally available yet marginal aggregates that ordinarily would not be suitable for the surface layer of a pavement could be used for the bottom (bulk) layer. In this case, only the upper, much thinner layer would require aggregates brought in from outside the local area. Using well-graded and durable aggregates that further extend the longevity of the bulk layer could further reduce the pavement's carbon footprint.

Recycling

In-place recycling is another means to enhance pavement sustainability during construction. By using recycled concrete aggregates in new pavements, agencies can virtually eliminate the need for mining and transporting virgin aggregates. Furthermore, recycling the existing concrete pavement onsite eliminates the need to transport the old concrete to an offsite crusher and processing facility and back to the concrete plant.

The strategy of using recycled aggregate in new concrete pavements has proven successful in many applications across the United States, resulting in excellent long-term concrete performance. One notable example is I–35 near Guthrie, OK, where the Oklahoma Department of Transportation (ODOT) reconstructed a 6-mile (10-kilometer) section in 1988.

A crew working with the Iowa Department of Transportation is using in-place recycling on this project on Interstate 80 near Colfax, IA.

By way of a two-sentence notation on the construction plan, ODOT allowed the contractor the option of salvaging the old concrete to produce coarse aggregate for the new concrete mixture. According to the contractor, the yield of coarse aggregate (#57 stone) that could be reused in the project was about 40 percent of the total crushed. The remaining 60 percent of the old concrete became about 25 percent chips and 35 percent screenings. Although ODOT did not incorporate the latter materials into the pavement in that project, today the chips would be a valuable intermediate aggregate for an optimized combined aggregate.

The I–35 project has a rare educational value because ODOT paved only the southbound lanes with the recycled aggregate; the agency paved the northbound lanes with virgin limestone aggregate. Offering further testament that sustainable practices can yield long-term success, David M. Howard, president/CEO of Koss Construction Co., says, "Today the stretch of roadway is 20 years old and there is no evidence of any difference in quality between the lanes."

Even 22 years after completing the work, ODOT has found no difference in quality and longevity between these I–35 lanes paved with recycled aggregate and those paved with traditional aggregate. *Photo: Koss Construction Co.*

Accelerated Construction

Congestion is a significant contributor to energy waste, CO_2 emissions, and pollution. Any construction activity, including resurfacing, rehabilitation, preservation, and reconstruction, can result in some degree of congestion. Accelerated construction strategies, however, can reduce congestion and minimize the overall environmental footprint.

One of those strategies, fast-track paving, generally entails using the least time-consuming construction techniques that project-specific conditions will allow. This technique requires well-planned construction sequencing and sound traffic-handling plans. Contractors and specifying agencies should be aware that operation adjustments will be necessary while paving crews become accustomed to the characteristics of fast-track concrete mixtures.

Contracting Flexibility and Equipment Innovations

For concrete pavements, many other approaches can accelerate construction. Traditional acceleration methods include contract incentives and disincentives for completing projects on time, or using lane rental charges, a commonly used technique to assess a fee to the contractor for every hour a lane is taken out of service. Contractors often meet these requirements by lengthening the workday or increasing the size of construction crews.

Transportation agencies have other opportunities for shortening construction times, such as giving contractors flexibility to use different materials, technologies, and equipment. Some agencies have allowed contractors to use concrete mixtures tailored to a particular situation, rather than applying just one mixture approved for all placements. This approach not only encourages innovation but makes good engineering sense.

For example, use of several different mixtures often is appropriate for a single project, as the first concrete placed during a construction window will have more time to gain strength than the last concrete placed. A variety of cementitious materials and specialty admixtures are available to contractors that can help optimize the strength gain for any given situation.

Allowing use of early-age joint sawing—sawing to induce cracks at desired locations on a pavement—helps minimize uncontrolled cracking in fast-track paving. The typical time sequence for joint sawing and sealing is not necessarily compatible with accelerated construction and early opening to traffic. A contractor must take into consideration that sawing is necessary much sooner after paving with accelerated construction than with normal concrete. Light saws that handle easily and are more versatile generally will be more effective for accelerated construction projects.

In-place and nondestructive testing to determine concrete strength is particularly attractive for accelerated construction projects, as there is little time to evaluate strength using test specimens cast onsite during construction. Nondestructive tests evaluate strength, or load-carrying capacity, by monitoring internal concrete temperature in the field and can help establish when the concrete pavement is ready for sawing or to accept traffic.

The basis for determining when a concrete pavement is ready to accept traffic should be its strength and not an arbitrary time after placement, such as 1 day or 12 hours. The required concrete strength is a function of the type and volume of traffic as well as pavement thickness and geometry. Restricting use to automobile traffic during early ages can accelerate the time to opening.

Recent equipment innovations also can facilitate rapid construction. Slipform paving technology continues to improve and now can accommodate variable-width paving, which reduces equipment setup and adjustment times, and speeds overall operations. Automatic dowel bar inserters and tie bar inserters can reduce paving time as well by eliminating the time typically needed to place and affix baskets. Also, stringless paving technologies (involving a computer-aided electronic guidance system controlling the slip form paver instead of the conventional string line guidance) not only eliminate the time required to set up and maintain a paving string line, but promise to improve pavement smoothness.

"The recent push for stringless paving technology in the mainline concrete paving market has accelerated equipment innovation," says Ron Meskis, national sales manager at Guntert & Zimmerman Const. Div., Inc. "With the savings from string line, stringless paving technology puts concrete at its highest advantage."

This crew working on I–40 near Checotah, OK, is using a concrete overlay machine outfitted with an automatic dowel bar inserter, which expedites the paving process.

Opportunities After Construction

Once a concrete pavement is placed and opened to traffic, what can be done to help enhance its sustainability? The only opportunities at this point involve preservation and restoration strategies. In general, preservation and restoration include a series of engineering techniques to manage the rate of deterioration and renew a pavement. The techniques restore the pavement to a condition close to original and reduce the need for major and more costly repairs later.

Such practices include dowel bar retrofits, cross-stitching, partial-depth repairs, joint and crack resealing, slab stabilization, and most important, diamond grinding. Diamond grinding involves removing a thin layer of a concrete pavement's surface using closely spaced diamond saw blades—analogous to refinishing a hardwood floor with a drum sander. Diamond grinding at once smoothes the pavement to improve the ride and improves its frictional characteristics, thereby enhancing safety.

Transportation agencies typically combine diamond grinding with at least one other restoration procedure when significant structural distresses are present. Diamond grinding restores ride or smoothness, while the other procedures address structural problems.

"Concrete preservation projects use environmentally friendly products manufactured in the United States that don't contain a drop of foreign oil," says IGGA's Roberts. "And motorists benefit from the resulting smooth, safe, and quiet ride after pavements are completed."

Based on a Caltrans study of 76 test sections nationwide (including pavements in freeze-thaw zones), the average longevity of a diamond-ground project is about 14 years. Crews can diamond-grind concrete

Here, crews are placing a concrete overlay on a pavement in Oklahoma on U.S. 59.

Duit Construction Co., Inc.

pavements up to three times before major reconstruction is needed. Combined with routine maintenance, diamond grinding can extend the service life of a pavement to twice its normal design life. Plus, diamond grinding is done during off-peak hours, thereby minimizing disruption to traffic flow.

The benefit for the environmental footprint is that the rehabilitation activities use no virgin aggregates or binder materials. The rehabilitation has two other major advantages: (1) improved texturing, resulting in enhanced skid resistance, and (2) reduced tire/pavement interface noise levels.

In addition, highway agencies increasingly are adopting concrete overlays as a way to preserve the structural value of concrete and asphalt pavements near the end of their service lives. Concrete overlays, which are applications of thin layers of new concrete over old and worn concrete or asphalt, offer cost-effective, versatile solutions for the full range of pavement needs. And they can last 15 to 30 years.

Future

The future looks promising for improving the sustainability of highway infrastructure through innovations in concrete pavement design, construction, and maintenance. "Sustainability in concrete pavements is simply good engineering, which always involves working with limited resources to achieve the best product possible," says Thomas Van Dam, program director at Applied Pavement Technology, Inc.

Researchers in the private sector continue to develop innovative manufactured materials, such as ceramics, epoxies, and polymers. Synthetic aggregates, such as lightweight and slag aggregates, already are available. More synthetics and carbon-sequestering aggregates might be available in the near future.

Photocatalytic cements have caught the interest of commercial and public specifiers alike and could see wider use in highway infrastructure—not just to remove smog from the air in urban areas but also to reduce the urban heat island effect.

The latest design procedures for concrete pavements, available in AASHTO's design guide, will likely see widespread adoption over the coming years. Improved quality assurance and quality control tools will further facilitate construction of cost-effective and sustainable concrete pavements. Researchers at universities and in the private sector in the United States and overseas continue to pursue nanotechnology applications for cement and concrete, zero-carbon cements, composite materials, and equipment innovations that will further enhance the sustainability of concrete pavements.

"Implementation of new technologies for sustainable concrete pavements is as important as the research and development that create them," says Peter Stephanos, director of the FHWA Office of Pavement Technology. "Collaboration among researchers, developers, and practicing engineers representing customers and stakeholders is the key to quick adoption of sustainable approaches to concrete pavements."

Suneel Vanikar, P.E., leads the concrete group in the FHWA Office of Pavement Technology. An FHWA employee for more than 30 years, he is responsible for activities related to concrete pavements and materials, including policy, guidance, and technology transfer. He earned his M.S. degree in civil engineering from Colorado State University.

Jim Grove, P.E., is the senior project engineer in FHWA's Office of Pavement Technology, where he is involved in special projects concerning concrete materials, mixture design, durability, and pavement construction; quality testing and assurance; nanotechnology; and sustainability. He worked for 16 years with the Iowa Department of Transportation and 5 years with the National Concrete Pavement Technology Center at Iowa State University. He has a master's degree in transportation engineering and a bachelor's in civil engineering, both from Iowa State University.

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New York City is transforming itself into a metropolis that is friendly to bicyclists, pedestrians, and transit riders. Learn how the Big Apple is doing it.

World Class Streets

by Megan Cornog and Dan Gelinne

Over the past decade, New York City's avenues and boulevards have been undergoing a transformation. What was until recently a metropolis with streets intended mainly to move automobiles now is becoming a city where all users—bicyclists, pedestrians, and transit riders, as well as motorists—are integrated into the metropolitan transportation system.

Improvements in bicycle infrastructure, combined with rising fuel costs, over the past 10 years have resulted in unprecedented spikes in bicycle commuting, and improvements to pedestrian facilities have increased safety. But the need to tackle problems such as inadequate public spaces and insufficient amenities for pedestrians and bicyclists culminated in a commitment to create a livable community. In 2007, New York City released *PlaNYC: A Greener, Greater New York*, a long-range, comprehensive plan to address economic, social, and environmental concerns facing the city's five boroughs: the Bronx, Brooklyn, Manhattan, Queens, and Staten Island.

One year later, in spring 2008, the city turned its focus specifically to transportation and released *Sustainable Streets*, a strategic plan for the New York City Department of Transportation (NYC DOT). This document emphasizes planning and designing a transportation system with all road users in mind. Strategies include enhancing existing sidewalk networks, expanding bicycle facilities, and improving transit accessibility.

To answer questions such as how its streets are being used and what is missing from the sidewalks and public plazas, NYC DOT commissioned a consultant to conduct public life surveys around the city. To understand how people use city spaces, the consultants counted the number of pedestrians at various points around the city. Meanwhile, volunteers conducted activity surveys, recording their observations of pedestrian activity at various sites.

NYC DOT released the findings in a 2008 report, *World Class Streets: Remaking New York City's Public Realm*. According to the count results and surveys, several key types

(Above) A bicyclist waits in a "bike box," a street marking designed to promote safe and visible movements for bicyclists at intersections. New York City's transportation department has initiated a number of bicycling improvements, reflecting a commitment to designing streets for all users. *Photo: Laura Sandt, PBIC.*

of public space need improvement. Overcrowded, obstructed sidewalks force pedestrians into the streets. Lack of seating leaves many New Yorkers and visitors with no places to rest. Few children and elderly citizens are present on the sidewalks, a sign that the streets are not comfortable for all users.

NYC DOT took on these challenges. In the report, the department outlined an overall approach called the World Class Streets initiative. Included under this initiative are a number of new programs and guidelines that respond directly to overall problems and individual issues on specific streets: the NYC Plaza Program, Broadway Boulevard, development of complete streets design guidelines, Safe Streets for Seniors, and Summer Streets.

"Describing these unique initiatives will help other communities learn from the challenges New York City faces—and is overcoming—to make the city a more livable and sustainable community," says Gabe Rousseau, bicycle and pedestrian program manager at the Federal Highway Administration (FHWA).

NYC Transportation Commissioner Janette Sadik-Khan writes in the *World Class Streets* report that her department seeks to promote "a broad strategy for developing and caring for the public realm—the space between buildings" to ensure that it remains safe and accessible for all users.

Public Plazas

Some of New York City's streets and vacant lots are underused and uninviting to the boroughs' many pedestrians. Despite the city's renowned Central Park and recent expansion of other parkland, many residents still lack access to nearby open space. *PlaNYC* states that the amount of green space per resident is inadequate at present and will become increasingly insufficient as the population continues to grow.

According to the plan's chapter on open space, "as competition from housing, office space, and other uses intensifies, the need to create new parks and open space will increase." In response, the plan includes a goal to ensure that all New York City residents live within a 10-minute walk of a park.

As part of the World Class Streets initiative, NYC DOT is partnering with merchant and neighborhood associations to transform sections of streets into vital public plazas. The NYC Plaza Program uses a competitive application process to help NYC DOT identify, design, and construct new public spaces throughout the city. The program prioritizes projects based on lack of open space paired with availability of local nonprofits willing to maintain the plazas.

The program identifies some plaza projects as part of transportation improvements that are already in the works. Additional opportunities arise from Greenstreets, a program run by the NYC Department of Parks & Recreation. Third, the city is creating more open space in an especially innovative way by reclaiming some of its 6,000 miles (9,656 kilometers) of streets and rights-of-way for use as plaza spaces. The city asks local nonprofit groups to identify potential spaces in their neighborhoods and apply to the program to have those sites transformed from roadway to plaza. The groups also must accept maintenance responsibility for the plazas once they are built. The first round of the NYC Plaza Program, launched in the summer of 2008, drew 22 applications from the five boroughs. Out of these, NYC DOT selected nine locations in the Bronx, Brooklyn, and Manhattan, based on factors such as adjacent land uses, pedestrian traffic volumes, and the absence of any nearby parks. Other factors included whether the site under consideration was an NYC DOT property and whether the project would require traffic rerouting.

The program has generated significant interest, as indicated by the number of applications. NYC DOT is reviewing a subsequent round of submittals and launched a third round in spring 2010. Thus far, the department and its area partners have begun improvements on 21 plazas across the city.

Once a location is selected, NYC DOT funds the design and construction of the public space, based on community input. The department attempts to ensure that plaza enhancements are sensitive to the history and culture of the area, as well as the vision and expectations of the neighborhood's residents, visitors, and business owners.

Plaza construction may include the addition of trees, planters, bollards (posts set at intervals to exclude vehicles), and seating; signs and information; paving and painting; and other pedestrian or bicycle amenities. With these enhancements, New York City is attempting to ensure that its streets are destinations and resting spots for residents and visitors alike, and to increase life and vibrancy at the street level.

"We are looking explicitly at opportunities to provide social places for people to gather, rest, and hold events," says Assistant Commissioner for Planning and Sustainability Andy Wiley-Schwartz, creator of the program. "These spaces not only make

Charlie Zegeer, PBIC

These heavy planters (left) serve as bollards to separate auto traffic from public space. Use of temporary features like these enables the city to evaluate new public plazas before moving from pilot phases into permanent changes.

NYC DOT

At the plaza at Madison Square, planters and seating create a safe, inviting place to rest, relax, and enjoy the views.

neighborhoods more livable, they also help encourage people to walk to their commercial centers by providing comfortable places for them to sit, eat, or meet friends."

Madison Square, at the intersection of Broadway, Fifth Avenue, and 23rd Street, is home to one of the most extensive and successful public plaza transformations undertaken to date under the NYC Plaza Program. Prior to improvements, the square—an oddly shaped confluence of streets—presented safety and operational challenges for pedestrians, bicyclists, automobiles, and buses. Areas of concern included confusing traffic patterns, sidewalk diversions, street crossings that equaled the length of two football fields, incomplete bicycle lanes, and inefficient bus routing. In addition, the street arrangement divided the neighborhood and adversely affected area businesses.

In September 2008, NYC DOT completed the pilot phase of the Madison Square transformation. The project included a number of changes, such as a simplified traffic pattern with lane reductions; a furnished and landscaped plaza space that echoes the shape of the Flatiron Building, a major tourist attraction located nearby; shortened pedestrian crossings; additional bicycle lanes; and more direct bus routing through the intersection. In total, the project created more than 16,000 square feet (1,486 square meters) of public space.

Broadway

For years, traffic congestion and pedestrian injuries and fatalities plagued Broadway in midtown Manhattan, a destination for tourists and residents alike. In addition, despite high volumes of pedestrian traffic, locations along Broadway such as Times Square provided minimal space for people. According to *World Class Streets*, only 11 percent of Times Square was designated as resting and walking space, while 89 percent of the area was road space accommodating cars.

World Class Streets notes that, unlike many other well-known cities around the globe, New York City is a skyline city, one in which the human-scale details often are overlooked. The report identified Broadway as a project where an acute sensitivity to pedestrian needs could lend vitality to the streets and benefit businesses and visitors.

In the summer of 2008, NYC DOT quickly and dramatically reclaimed much of the street space along Broadway for pedestrian use. In some cases, the transformation occurred overnight. The department converted parts of Broadway between 42nd and 35th Streets into "pedestrian living rooms," areas delineated by pavements that have gravel mixed into the surface. These pedestrian spaces are furnished with planters and lawn chairs and other street furniture, creating an inviting environment for residents and visitors to experience one of the city's most famous landmarks.

Another improvement was the addition of new bicycle lanes. The lanes, painted green, are adjacent to the furnished pedestrian spaces, which separate the bicycle lanes from automobile traffic. To accommodate these facilities, NYC DOT narrowed the road from four lanes of traffic to two. Other improvements, such as changes in signal timing to remediate existing traffic congestion, coincided with the addition of the public spaces.

According to *The New York Times*, NYC DOT spent an estimated $700,000 to construct linear plazas along the seven-block stretch of Broadway. Three area business improvement districts partnered with the city and agreed to maintain the new plazas.

Complete Streets

With the variety of transportation options available throughout New York City, calling the city's streets "incomplete" might seem counterintuitive. In addition to providing space for cars, taxis, and delivery vehicles, most New York City streets have sidewalks, curb ramps for people with disabilities, and street crossing aids, and are served by transit. Pedestrian volumes and high rates of transit ridership indicate the intense use of these facilities.

On occasion, however, the safety and comfort of some road users, such as pedestrians with or without disabilities, can be compromised due to street design. The *World Class Streets* report indicated that sidewalk crowding, obstacles such as street vendors, and lack of seating can affect the pedestrian experience. These conditions appear to disproportionately affect seniors and children.

Across the United States, communities and States are beginning to adopt complete streets policies. These policies indicate a commitment to constructing streets that are safe for everyone, including bicyclists, people with disabilities, transit riders, children, and seniors. Complete streets policies vary significantly, ranging in scope, geography, and the strength of their regulatory teeth.

NYC DOT, in cooperation with 12 other city agencies, included a complete streets vision in its *Street Design Manual*, updated in May

2009. Four of the seven goals in the manual emphasize the importance of considering all road users and modes of traffic when designing and constructing streets. The manual's overall goal is to ensure that creating safe and inviting streets for all users is taken into account in all projects that affect road design. Using the manual's design standards, New York City has begun the process of institutionalizing comprehensive and inclusive street planning.

The department has constructed several complete streets projects and, under the guidance of the *Street Design Manual*, many more are in the works. Completed in October 2008, one project—the 9^{th} Avenue transformation—serves as a model complete street, with safer and more convenient facilities for pedestrians and bicyclists, improved safety for turning vehicles, and traffic calming measures to increase safety for all road users. To meet these objectives, the project included a bicycle lane that is physically separated from traffic by a row of parked cars, signal-protected pedestrian and bicycle signaling that reduce conflicts at intersections by giving each mode (pedestrian, bicycle, and automobile) its own crossing phase, refuge islands to assist pedestrians who are crossing 9^{th} Avenue, increased tree coverage, and turning bays to make left-turn maneuvers safer.

"Thus far, the manual has been well received," says NYC DOT's Wiley-Schwartz. "New York City agencies appreciate that it helps them to create and maintain streets that are inclusive, safe, environmentally sustainable, aesthetically appropriate, and historically aware. Developers appreciate that the manual brings some daylight to what previously was a rather opaque process."

Wiley-Schwartz adds that the complete streets program and the *Street Design Manual* will transform streets that were designed for 20^{th} century transportation into streets that are appropriate for the 21^{st} century.

Safe Streets for Seniors

Adults aged 65 and older make up 12 percent of the city's population, but from 2002 to 2006, they accounted for 39 percent of its pedestrian fatalities. Despite this grim overrepresentation, older pedestrians are underrepresented on the streets of New York City, according to the study commissioned by NYC DOT. The study found that only 10 percent of pedestrians observed were seniors or children, while those two age groups make up 30 percent of the city's population. With the city's senior population expected to nearly double within the next 25 years, pedestrian safety for older adults has become a priority for NYC DOT.

In January 2008, NYC DOT and the city's Department for the Aging partnered to announce the Safe Streets for Seniors program. Using crash history, NYC DOT identified 25 focus areas where pedestrian injuries and fatalities that involved older adults were particularly high.

From these 25 neighborhoods, NYC DOT selected five pilot

NYC DOT

This "before" view of Times Square shows a streetscape that is not very friendly to pedestrians and bicyclists.

NYC DOT

This "after" shot of Times Square shows an area that is inviting to residents and visitors alike.

Laura Sandt, PBIC

Marked bicycle lanes like this one reduce points of conflict with automobile traffic. The network of bicycle lanes has expanded at a rate previously unprecedented for New York City.

neighborhoods—one in each borough—to test the program. The sites were Brighton Beach, Brooklyn; Fordham/University Heights, the Bronx; Lower East Side, Manhattan; Flushing, Queens; and New Dorp/Hylan Boulevard, Staten Island.

The project focuses on safety concerns for senior pedestrians, including insufficient crossing times, broken or missing curb ramps, crosswalks and street markings that are difficult to see, drainage problems at curbs and in crosswalks, and driver behavior problems such as turning vehicles that fail to yield to pedestrians.

Countermeasures involve installing new or upgraded pavement markings, high-visibility crosswalks, and advance stop bars to encourage drivers to stop before a crosswalk rather than in it. Maintenance activities include replacing missing roadway signs, repairing broken curb ramps, and installing needed ramps. The city also has employed other pedestrian-friendly treatments such as leading pedestrian intervals, which activate a walk signal before vehicles get a green light so pedestrians can have a head start into a crosswalk. Leading pedestrian intervals are a particular help to pedestrians who have slower walking speeds.

In 2008 and 2009, NYC DOT moved quickly to assess problems in its five pilot neighborhoods, identify and implement countermeasures, and launch comprehensive educational campaigns about the Safe Streets for Seniors program and associated traffic changes. In the pilot project in Flushing, Queens, NYC DOT took a multipronged approach to address heavy pedestrian and vehicle volumes, conflicts caused by failure of the turning vehicles to yield at crosswalks, dangerous pedestrian behaviors, and long crossing distances.

In this pilot, NYC DOT added 23 new signs instructing users to "Wait for Walk," "Yield to Pedestrians in Crosswalk," and "Wait for Green Light." The department also added several pedestrian refuge islands, left-turn bays for vehicles, high-visibility crosswalks, and advance stop bars. In some cases, NYC DOT narrowed streets by reducing the number of vehicle lanes. The results from this combination of improvements are encouraging. For instance, injuries at the intersection of Northern Boulevard and Bowne Street have decreased by 45 percent since NYC DOT installed a pedestrian refuge island at that location. Pedestrian refuge islands and a road diet (reduced number of lanes with freed space converted to parking, bike lanes, landscaping, walkways, or medians) on Manhattan's Chrystie Street resulted in a 66 percent reduction in pedestrian crashes.

Having completed improvements at the pilot sites, NYC DOT is continuing progress on the Safe Streets for Seniors program. The department selected 10 of the 25 focus areas as phase I projects and currently is reviewing the engineering studies and recommendations prepared for those areas. Studies for phase II areas began in January 2010.

Summer Streets

Streets in New York City are shared by a number of users, including cars, buses, taxis, bicyclists, and pedestrians. As noted earlier, however, congestion and potential traffic dangers make it difficult for pedestrians and bicyclists to fully enjoy the sights and sounds of the city's streets.

The New York City Summer Streets program is modeled on similar initiatives in cities around the world. In Bogotá, Colombia, the presumed birthplace of these types of car-free streets programs, 70 miles (113 kilometers) of street are closed to traffic every Sunday and on major

Laura Sandt, PBIC

Connections between boroughs for bicyclists and pedestrians, such as the Williamsburg Bridge shown here, help ensure safe and convenient access for all road users.

holidays for a weekly event called *recro-vias*, which brings residents and visitors into the streets for fun and physical activity. In most places, this kind of program is part of a larger livable streets movement that aims to make streets more welcoming to nonmotorized transportation.

New York City began experimenting with a car-free streets program in August 2008. For three consecutive Saturdays, the city closed a 6.9-mile (11-kilometer) stretch of road from the Brooklyn Bridge to Central Park. NYC DOT worked with the City of New York Police Department to ensure that the chosen route would have a minimal impact on traffic. The department marketed the program as a new way to enjoy the streets of New York, using the motto, "Your city, your streets, your playground."

An estimated 150,000 people enjoyed the three 2008 Summer Streets road closings. Positive feedback from users, area residents, and news media encouraged NYC DOT to host Summer Streets annually. In 2009, the NY Metro Chapter of the International Special Events Society recognized the success of Summer Streets with a Best Green Initiative award. The department partnered with business improvement districts and neighborhood associations to host similar events in the Bronx, Brooklyn, Queens, and Staten Island, and plans to expand the dates and locations in 2010.

Evaluation

To test the programs' impacts, including public reaction, NYC DOT implements some of the improvements as pilot projects. This approach means that not only are projects subject to change and removal, but also they are constructed out of materials that are less expensive and easier to remove. The department uses several techniques to evaluate a pilot project and determine whether to make it permanent. Using observation, crash data, survey responses requested from the public on streets or other locations, and studies of road user behavior at targeted locations, NYC DOT can obtain a sense of a project's impact on traffic congestion, safety, and use of space, as well as public reaction. The department also uses public input received via NYC 311, a phone service and Web site that enable users to access and report information relevant to city government operations.

In February 2010, NYC DOT announced that it will incorporate permanently the changes implemented along Broadway as part of its Green Light for Midtown pilot program. The *Green Light for Midtown Evaluation Report* provides a detailed look at the analysis performed to measure the outcomes of the network changes and justification for the decision to adopt the improvements permanently. In addition to pedestrian safety improvements, such as a 35 percent decrease in pedestrian injuries, improvements in traffic flow and mobility were demonstrated. The enhancements were also shown to be beneficial to businesses, as 42 percent of surveyed residents indicated that they have shopped in the neighborhood more often since the changes were made.

Next Steps

NYC DOT continues to make strides in creating public spaces for residents and visitors. The department is installing bicycle lanes and other facilities in line with *PlaNYC* objectives. Other components of the World Class Streets initiative—redesigned bus stops, street furniture, and a public art program—also have enhanced the city's environment and public spaces. As a measure of success, in November 2009, the city announced yet another increase of 26 percent in transit commuter bicycling from the previous year.

Although it is a large city, New York has overcome many of the same barriers that exist in smaller cities and towns across the United States. "By creating public space and taking advantage of public and political support for improving conditions for all users, New York City has created innovative programs that any community could emulate," says FHWA's Rousseau.

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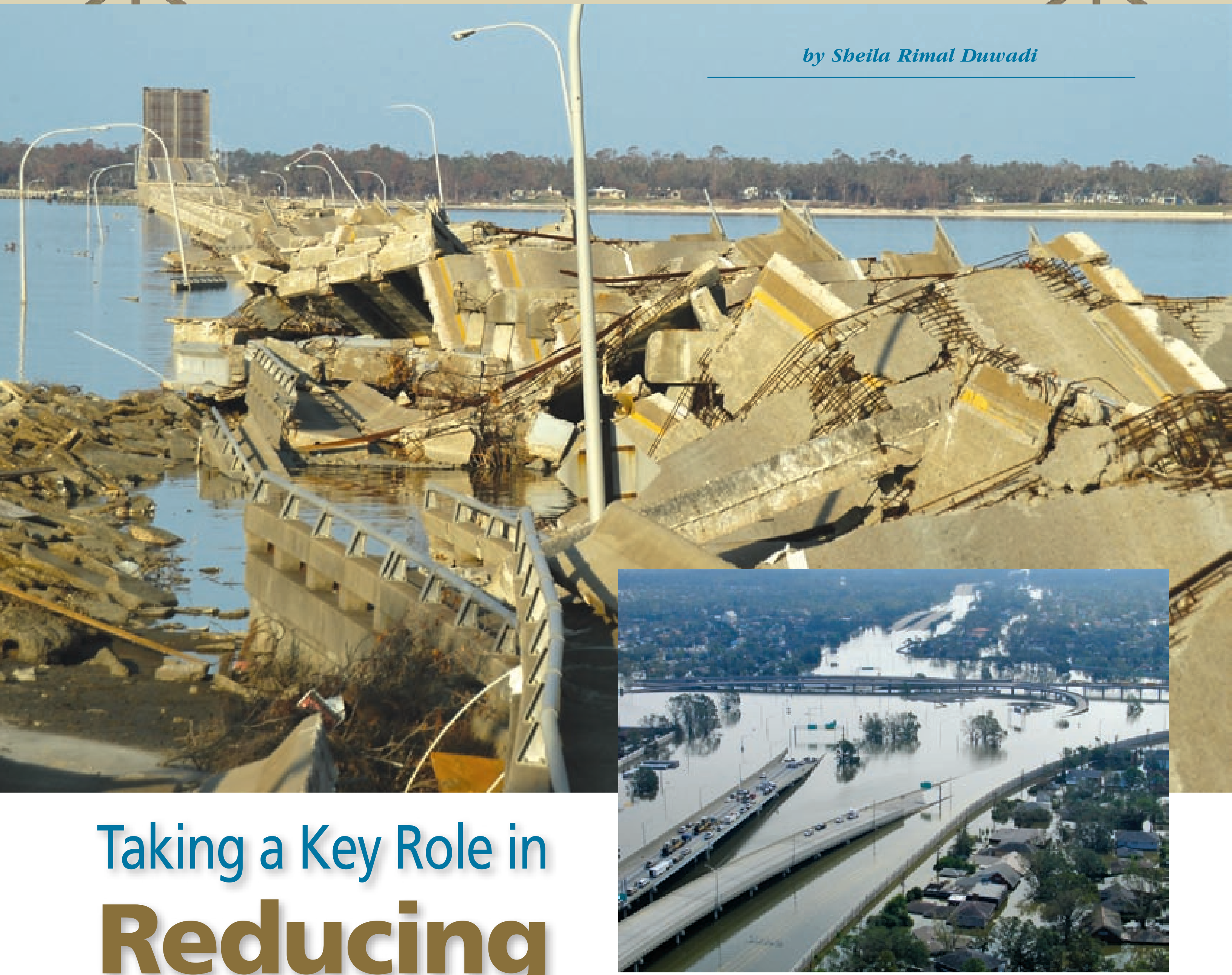
Daniel Kukla/NYC DOT

Bicyclists and pedestrians cross the Grand Central Terminal Park Avenue Viaduct (shown here) during a Summer Streets event.

HAZARD MITIGATION R&D SERIES: ARTICLE 1



by Sheila Rimal Duwadi

Taking a Key Role in Reducing Disaster Risks

FHWA's hazard mitigation R&D program tackles the challenges of providing safer highway bridges and other transportation infrastructure.

(Above) This bridge from Biloxi to Ocean Springs in Mississippi lies in a twisted mass as a result of catastrophic wind and storm surge from Hurricane Katrina in 2005. Road closures along the coastal area complicated recovery efforts. (Inset) This aerial photo shows interstates in New Orleans flooded during Hurricane Katrina. *Photo: George Armstrong/FEMA (Inset: Louisiana Department of Transportation and Development).*

Each year the United States and the global community experience numerous natural and human-induced hazards that often turn into disasters and cause suffering, disrupt lives, and induce economic damage. According to the United Nations Environment Programme, the number of people killed in disasters worldwide during the 1990s averaged 75,252 annually.

The economic impact too is staggering. In 2005, the U.N. reported that damages caused by natural and human-induced hazards globally topped $150 billion. The Federal Emergency Management Agency estimates that Hurricane Katrina alone inflicted $75 billion in damages and was responsible for 1,200 reported deaths.

Natural hazards often have significant impacts on transportation infrastructure. Examples of natural hazards that might affect highways and bridges include coastal inundation, earthquakes, floods, hurricanes, landslides, tornados, tsunamis, volcanoes, wildfires, and winter storms. Not all these events are likely to occur in all parts of the United States, but natural hazards—unlike human-induced events—have a high probability of affecting large geographic areas and therefore a significant number of highways and bridges simultaneously, thus impacting more lives.

For example, in 2002 a barge struck the I–40 Bridge crossing the Arkansas River in Webbers Falls, OK, disrupting a major east-west transportation corridor. In 2005 Katrina's 30-foot (9-meter) storm surge in Mississippi destroyed about 90 percent of all highway bridges located within 0.5 mile (0.8 kilometer) of the coast, even washing away large structures like the Bay St. Louis and Biloxi Bay bridges.

Human-induced events include arson, technological hazards, cyber attacks, and terrorism. Events that can affect highway bridges are the hazards of fire, collision, overloads, blast, and others.

Negative impacts on transportation from natural and human-induced events are only one side of the story. Bridges and highways play a critical role in reducing fatalities and economic damages in times of crisis by providing evacuation routes and access for response and recovery teams conducting rescues and humanitarian assistance. If roads and bridges are flooded or damaged, a manageable event can quickly turn into a disaster because people are unable to go in and out of the affected area. Having access to alternate means of travel such as ferries, transit lines, and other modes is desirable but in many parts of the country these alternate modes are unavailable, leaving the highway system as the only reasonable route. Because of the need to keep the highway network open and passable, the Federal Highway Administration's (FHWA) Turner-Fairbank Highway Research Center (TFHRC) is researching solutions to reduce the impacts of extreme events.

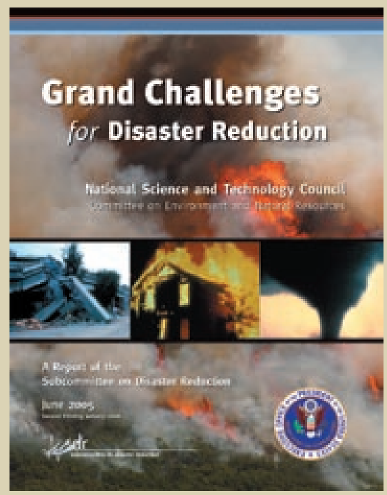
Recognizing that most hazards cannot be prevented, the White House's National Science and Technology Council established the Subcommittee on Disaster Reduction (SDR). The subcommittee is charged with prioritizing Federal investments in science and technology to enhance the Nation's disaster resilience. To accomplish this goal, the subcommittee crafted a 10-year strategy identifying six "grand challenges" to enhance community resilience and thus create a more disaster-resilient Nation. The

National Science and Technology Council's Subcommittee on Disaster Reduction

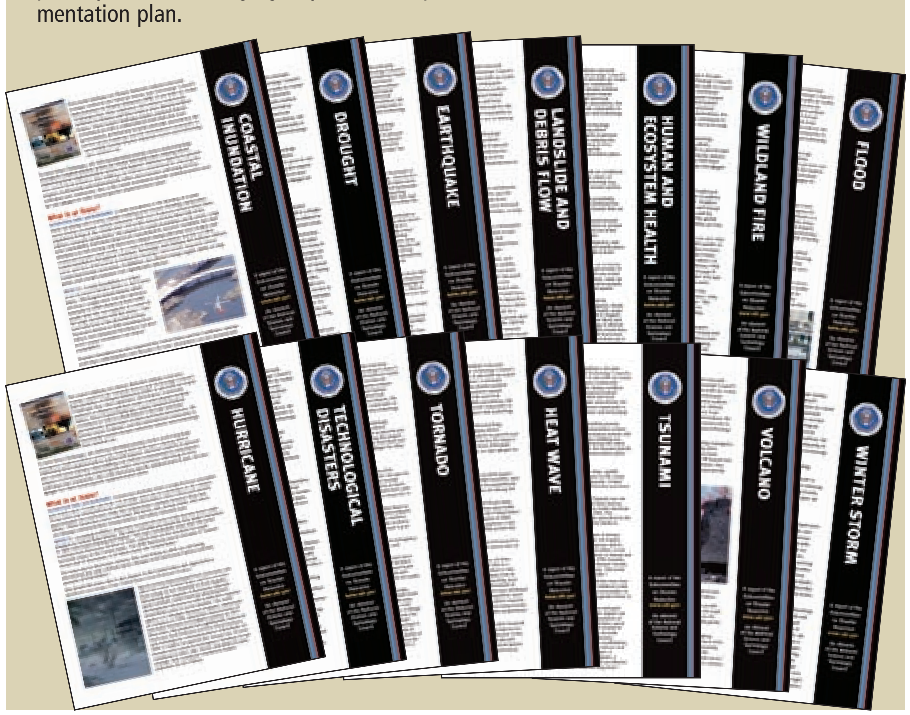
The Subcommittee on Disaster Reduction (SDR) is charged with establishing clear national goals for Federal science and technology investments in disaster reduction; promoting interagency cooperation; and advising the Administration about relevant resources and the work of SDR member agencies.

SDR published a 10-year strategy titled *Grand Challenges for Disaster Reduction*. This document provides a framework of key scientific and technological advances that will improve the Nation's ability to face disasters. The subcommittee identified the following six grand challenges:

1. Provide hazard and disaster information where and when it is needed.
2. Understand the natural processes that produce hazards.
3. Develop hazard mitigation strategies and technologies.
4. Recognize and reduce the vulnerability of interdependent critical infrastructure.
5. Assess disaster resilience using standard methods.
6. Promote riskwise behavior.



In 2008, to begin addressing the grand challenges, SDR published 14 hazard-specific implementation strategies (coastal inundation, earthquakes, drought, etc.) for disaster reduction planning at the Federal level. Every participating Federal agency has a role either as the primary or contributing agency in each implementation plan.



Louisiana Department of Transportation and Development

Wave-induced forces during Hurricane Katrina lifted and misaligned these multiple spans of the I–10 twin bridges over Lake Pontchartrain.

U.S. Department of Transportation (USDOT) and FHWA support this initiative and, together with other SDR member agencies, carry out research and development (R&D) to address the six grand challenges.

The following overview of FHWA's hazard mitigation R&D program describes the threats to highway bridges and their vulnerabilities, and demonstrates how the program is reducing risks for the Nation's transportation infrastructure. Subsequent articles in future issues of PUBLIC ROADS will detail ongoing R&D related to four specific hazards: flooding and scour, wind, earthquakes, and terrorism.

Recognizing Vulnerabilities

The highway system in the United States includes approximately 4 million miles (6.4 million kilometers) of roads, including 47,000 miles (75,600 kilometers) of interstates and 117,000 miles (188,300 kilometers) of other National Highway System roads, plus approximately 600,000 highway bridges and 366 tunnels. Certain links in this network—that is, bridges on essential routes—are critical in that their incapacitation would cause great physical and economic disruption. The vulnerability of bridges depends on their design, location, and material properties.

Highway bridges are engineered to carry specific loading needs that have evolved over time. Over the years, bridge engineers have drawn on individual experience combined with scientific and engineering principles to develop designs that address specific situations. With each new event, engineers reevaluate the parameters, modifying codes and standards accordingly.

The load that a structure experiences and the load path vary, based on its design type and the hazard event. Bridge foundations, columns, and pier caps are critical when addressing seismic loadings because earthquake forces are generated from the ground up. On the other hand, long-span, slender bridges are more susceptible to wind loadings, making aerodynamic stability the critical factor for those structural types. As with seismic loadings, substructures are vulnerable when dealing with scour. The Nation has thousands of highway bridges with unknown foundations, which increase uncertainties about vulnerability to scour.

A bridge of any size, length, or shape, over water, can be susceptible to flooding. Wave-induced forces can lift a span off its bearings, as happened during Hurricane Katrina with New Orleans' I–10 bridge over Lake Pontchartrain. Because of the waves, 38 spans fell off their bearings and 170 others misaligned on the eastbound bridge, and 303 spans misaligned and 26 others were lost on the westbound bridge.

In addition to design, location is critical to vulnerability. For example, bridges over navigable waterways are vulnerable to vessel collisions, which impart high-energy loading at the point of contact. In recognition of this vulnerability, and also as a result of actual incidents, measures are used in heavily trafficked rivers to protect piers in navigation channels against ship and barge impacts. Most bridge failures that have occurred due to collision were the result of errant vessels hitting unprotected piers. In March 2009, a towing vessel pushing eight barges slammed into a bridge pier in Biloxi, MS, causing a section of the bridge to collapse into Biloxi Bay. Fortunately, there were no vehicles on the bridge, which normally carries 35,000 average daily traffic.

As with design and location, the strength and durability of bridge materials are critical. Concrete and steel are the major materials used for bridge construction. Other less commonly used materials are wood, aluminum, and fiber-reinforced polymers. Increasingly, higher strength and more durable steel and concrete are used on newer bridges. Researchers have yet to explore the behavior of materials under hazard loadings, especially the newer materials.

All structural materials used today are subject to damage by fire because heat can change the properties of any material. Recently, the National Cooperative Highway Research Program initiated efforts to assess bridge fire risk and to develop guidelines for bridge owners. Blasts produce high-intensity loadings in a timeframe of milliseconds, and the impact of explosive loadings on material performance needs to be studied further. The threat level of fire and blast is uncertain in terms of magnitude and probability of occurrence, so developing and implementing design and retrofit solutions presents a major challenge. Nevertheless, in recent years fire has damaged high-profile structures, such as the MacArthur Maze in the San Francisco Bay area on April 29, 2007.

FHWA Hazard Mitigation R&D Program: Focus Areas

In addition to the six grand challenges, SDR identified 14 implementation plans for major hazards. Although various programs within FHWA's offices deal with those SDR issues and hazards that affect transportation, the focus of the current R&D effort within the Office of Infrastructure R&D at TFHRC is on addressing the grand challenges for the following hazards as they affect bridges:

- Flooding and scour
- Coastal inundation
- Wind, including hurricanes
- Earthquakes
- Technological hazards, including terrorism

Although the SDR document does not consider security and terrorism issues, the FHWA program does address this hazard.

Flooding and Scour, Coastal Inundation

Flooding and scour are the leading cause of bridge failures in the United States. About 83 percent of the structures listed in the National Bridge Inventory cross waterways.

The failures of the Schoharie Creek Bridge in New York State in 1987 and the Hatchie River Bridge in Tennessee in 1989 led bridge engineers to an increased focus on flooding and scour issues, with advancements in foundation and pier design. With recent hurricanes, focus has expanded to include inundation of coastal bridges, damage due to wave forces, and tidal flow scour.

The Nation's coastal counties contain more than half of the U.S. population but only 13 to 17 percent of the total land area. These areas are prone to coastal hazards such as permanent inundation, temporary flooding, hurricanes, and tsunamis.

The hydraulics research program, conducted largely at the J. Sterling Jones Hydraulics Research Laboratory at TFHRC, carries out studies to advance understanding of the effects of flooding, scour, and coastal inundation on bridges to ensure that those structures are reliable and sustain minimal or no damage during extreme hydrodynamic events. Over the years, the hydraulics laboratory has developed, tested, and implemented multiple countermeasures to protect bridge piers from scour and superstructures from flooding and inundation.

The laboratory consists of a physical and a numerical modeling facility. The physical facility features a tilting flume, a force-balance flume, a wave tank, particle image velocimetry testing stations, and a culvert test facility. The numerical modeling facility includes systems to conduct simulations based on computational fluid dynamics. Researchers can use these numerical simulations in concert with physical experiments to address questions regarding coastal, inland, and environmental hydraulics with an emphasis on bridge scour.

Some of the studies in the hydraulics research roadmap include the following:

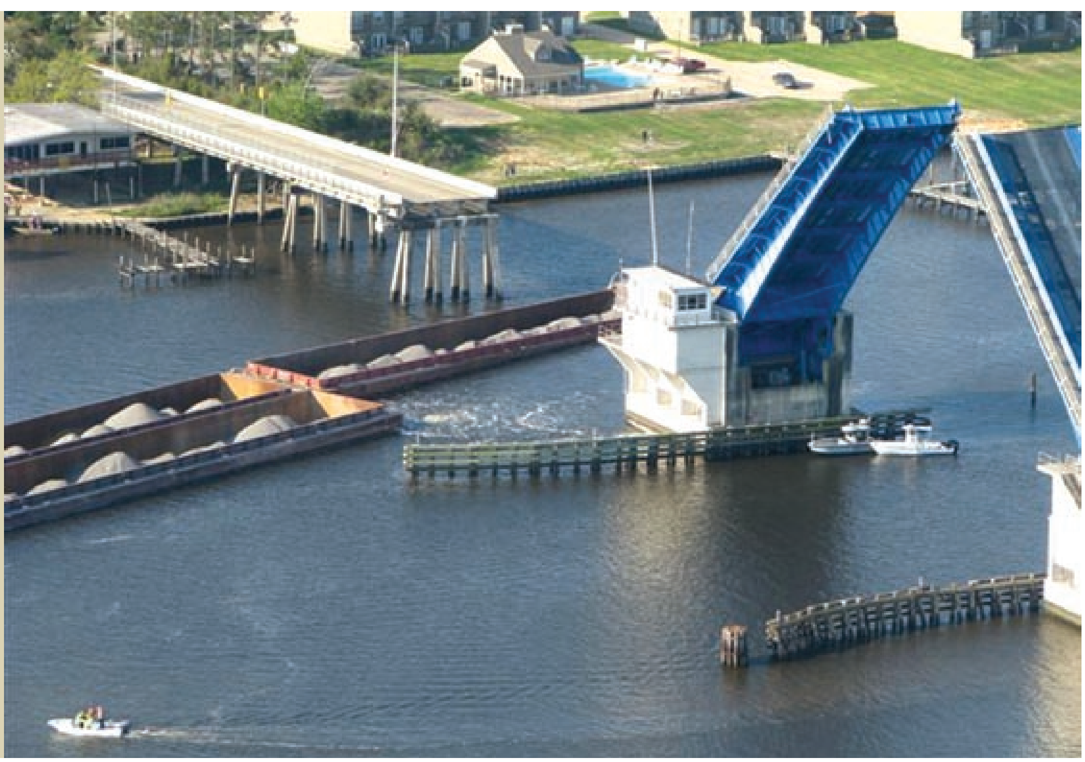
- Studies on bottomless, that is, three-sided culverts
- Lift-and-drag forces on bridge decks
- Optimum bridge deck shapes to minimize pressure flow scour
- Pressure flow scour for live bed situations where river sediment is moving rapidly from the upstream area of a bridge
- Scour in cohesive soils
- Scour in coarse bed material
- Computational fluid dynamics modeling
- Buoyancy forces on culverts

The laboratory's capabilities include testing the hydraulic properties of submerged bridges and highway drainage structures. Researchers can use the laboratory's equipment to solve stream stability problems, develop design standards for bridges in high-flood-risk areas, and contribute to design standards for scour around piers and submerged decks.

Wind Hazards

The aerodynamic stability of bridges began receiving attention after the collapse of the Tacoma Narrows Bridge near Tacoma, WA, in 1940. Since then, the wind engineering

Shown is Popps Ferry Bridge near Biloxi, MS, after a ship collision in 2009 that sunk a section of the bridge. One span of this movable bridge was open for the barge, which missed the channel and hit a side span and pier, causing the collapse.



U.S. Coast Guard

John Huseby, Caltrans

In the San Francisco Bay area, CA, on April 29, 2007, a tanker truck crash and explosion created a gaping hole in the "MacArthur Maze." This portion of the I–80 eastbound to I–580 eastbound connector ramp collapsed onto I–80 westbound and the I–880 southbound connector ramp.

field has evolved and matured while addressing the many issues associated with the interaction of wind and the built environment.

FHWA's aerodynamics research program aims to advance understanding of wind effects on transportation structures to ensure they maintain a high level of performance in normal wind conditions and are reliable and sustain minimal or no damage during extreme wind events. The researchers at TFHRC's Aerodynamics Laboratory, through wind tunnel modeling and field testing and monitoring of actual structures, have developed and implemented a number of measures to address wind/structure interaction and control bridge vibrations caused by wind. As new designs evolve, new issues arise, such as deck vibrations and wind- and rain-induced vibrations of bridge cables, that require further study.

The Aerodynamics Laboratory is the only wind tunnel facility in the United States that is dedicated solely to the study of wind effects on transportation structures. It houses a large, low-speed wind tunnel and a small-scale smoke tunnel for flow visualization.

Ongoing research at the Aerodynamics Laboratory includes the following:

- Bridge geometric details and their aerodynamic significance
- User comfort and serviceability criteria for wind loading on bridges
- Measurement of dynamic properties of stay cables on Prospect-Verona (ME), Leonard P. Zakim Bunker Hill (MA), and Bill Emerson Memorial (MO) bridges
- Optimization of bridge deck cross sections for enhanced aerodynamic performance
- Evaluation of aerodynamic performance of innovative bridge designs
- Monitoring of wind conditions and bridge behavior at select sites to evaluate performance of new design details and retrofit countermeasures

The laboratory has taken part in the design of stay cable damping systems; evaluation of performance problems and design of retrofits; and static, dynamic, and aerodynamic analysis of long-span bridges. In addition, the TFHRC researchers participate in a Wind Hazard Reduction Working Group that coordinates Federal research on wind hazards.

Earthquakes

According to a U.S. Geological Survey circular, "Requirement for an Advanced National Seismic System," 75 million Americans in 39 States face significant risk from earthquakes. FHWA has been involved in seismic research since the aftermath of the 1971 San Fernando earthquake in California. However, it was the 1989 Loma Prieta earthquake that put a national emphasis on this hazard. Seismic research has led to numerous advances in the understanding of earthquake-resistant design, construction, and retrofit of highway bridges.

The focus of earthquake-resistant designs includes foundations, columns, and pier caps, as these represent critical components for this hazard type. To ensure superstructure stability during an earthquake, the FHWA seismic program has supported the development and implementation of improved bearing systems, restrainers (cables that hold the superstructure components in place), and shear keys (short stubs built into the abutment seats to keep the girders from sliding off). Understanding the effects of ground motion on bridges has increased as well through the use of sophisticated finite element analysis and comparisons with post-earthquake field observations from seismic events in the United States and abroad.

Ongoing studies include the following:

- Improving the seismic resilience of bridges
- Addressing accelerated bridge construction issues in high seismic areas
- Developing innovative seismic protective devices
- Refining seismic ground motion and fragility curves for bridge types in the central United States

FHWA's seismic research program focuses on experimental testing and physical modeling, plus analysis and numerical modeling. The TFHRC researchers collaborate with a number of international partners to advance seismic technology and are active in the National Earthquake Hazards Reduction Program coordinating activities with other Federal agencies to reduce earthquake hazards.

Security and Human-Induced Events

Designing for security became an issue after the events of September 11, 2001. Shortly afterwards, a blue ribbon panel convened by FHWA and the American Association of State Highway and Transportation Officials (AASHTO) developed recommendations on ways to address this new hazard. In a parallel effort, FHWA conducted outreach to stakeholders, including convening a workshop to identify research gaps and needs. This effort was the basis of a plan described in the FHWA publication *Multiyear Plan for Bridge and Tunnel Security Research, Development, and Deployment* (FHWA-HRT-06-072).

In conjunction with State DOTs and other infrastructure owners, plus the U.S. Department of Homeland Security, FHWA has been collaborating with the U.S. Army Corps of Engineers on a number of efforts to address security measures. Researchers have concentrated on developing protective systems for vulnerable components of bridges and developing design aids such as computer programs. Installing barriers, fences, gates, lighting, and cameras also can reduce vulnerability, but alone they are not always effective against all threats. The focus to date of FHWA's security research program has been to develop innovative solutions for retrofitting existing structures.

Next Steps

Research conducted at TFHRC is helping build a resilient transportation system—one that functions in normal times and during and after hazard events. The emphasis is on the engineering aspects of building disaster resiliency into the transportation infrastructure for ease in response and recovery.

Researchers are developing workable solutions for several hazards that can affect the system. Each event imparts loads on a structure of different magnitude, direction, and location, so one solution will not always satisfy all hazard requirements. Designing bridges for reduced vulnerability to multiple hazards, however desirable, might not always be practical. A solution for one hazard is not necessarily applicable to another and in some cases actually can increase the bridge's structural vulnerability to that other hazard. For instance, increasing the robustness of a structure to withstand blast loadings may negatively affect its performance during wind or seismic events. Similarly, solutions for one system are not necessarily applicable to another system; that is, a solution to protect a building may not be effective for a bridge.

The R&D effort underway focuses on single hazards, develops solutions, and then ensures the solutions are compatible with other hazards before implementation.

By addressing the SDR's grand challenges, USDOT, FHWA, and other SDR member agencies aim to develop a disaster-resilient America.

"A more disaster-resilient America recognizes and understands the relevant hazards, so communities at risk know when a disaster is imminent," says David Applegate, chair of SDR. "We need to be able to warn the right people in the right place at the right time. We need to ensure services are still accessible after an event. If communities are better prepared, we can minimize the risks of property loss and death, and reduce disruptions to life and the economy."

Sheila Rimal Duwadi, P.E., is a team leader in FHWA's Office of Infrastructure R&D at TFHRC, responsible for R&D of bridge technologies and methodologies for extreme events and specialty materials. She represents USDOT on the SDR and chairs the American Society of Civil Engineers' (ASCE) Structural Engineering Institute's Bridge Technical Activities Committee. She was the past associate editor for ASCE's *Journal of Bridge Engineering.* Duwadi is a registered professional engineer in Virginia.

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Side view of support-column failure and a collapsed upper deck of the Cypress Freeway in the San Francisco Bay area after the 1989 Loma Prieta earthquake.

H.G. Wilshire, U.S. Geological Survey

Greener Alleys

Chicago shares insights on use of permeable pavements and other eco-friendly strategies to create more sustainable transportation infrastructure.

by Janet L. Attarian

(Above) As part of a pilot project by the Chicago Department of Transportation's Green Alleys program, this paving crew is using a roller to compact a permeable asphalt pavement placed in an alley in the Beverly neighborhood of Chicago. (Inset) The completed pavement is shown 2.5 years after installation. *Photos: CDOT.*

Water, in its many forms—rain, snow, ice—is a traditional enemy of roads and bridges. From pooling and icing to frost heaves and corrosion, water causes myriad challenges for departments of transportation. In response, road managers employ design and management strategies to move water off and away from paved surfaces as quickly and efficiently as possible.

In Chicago, IL, the public right-of-way includes more than 3,775 miles (6,075 kilometers) of streets and 1,900 miles (3,058 kilometers) of alleys. Representing roughly one-quarter of the city's land area, streets and alleys make a significant contribution to urban runoff. An overabundance of nonporous surfaces, such as pavements and buildings, can exacerbate localized flooding and lead to overflows into natural water bodies from any sewers that are combined with storm drains. Overflows occur when the volume of wastewater exceeds the capacity of the sewer system or treatment plant, causing discharge of rainwater runoff, domestic sewage, and industrial wastewater into nearby bodies of water.

Most of Chicago's alleys do not have sewer infrastructure. They were designed to divert stormwater toward the center of the alleys and then out into the streets, where the water enters the combined sewer system through catch basins. Over the last 100-plus years, however, many of these alleys deteriorated, or their flowlines changed or were interrupted. According to David Leopold, project manager of the Chicago Department of Transportation's (CDOT) Streetscape and Sustainable Design Program, this leads to frequent requests from aldermen, property owners, and businesses to address flooding. Until recently, he says "the typical response was to either resurface or reconstruct the alley, usually adding a sewer and catch basin."

But in 2004, CDOT began looking at the flooding problem differently. The department wanted to expand the available solutions and offer more sustainable options. Toward that end, CDOT launched a pilot project to test three permeable pavements: pervious concrete, pervious asphalt, and porous pavers. The pilot entailed developing prototype alley designs, formulating and testing new pavement materials, and working with staff and contractors on new construction techniques and quality assurance and control.

The lessons learned prompted additional pilots, and now the city is reshaping the way it designs alleys and applying this knowledge to larger projects, including parking lots and streets. With its new Green Alleys program and a public outreach document, *The Chicago Green Alley Handbook*, CDOT is expanding its toolkit of pavement solutions and leading the city toward a more sustainable future.

Pervious Pavements

Before embarking on the pilot project, CDOT staff and consultants, suppliers, and contractors had limited or no previous experience with permeable pavements. "Local producers and contractors saw no need to research and develop [pervious] mix designs," says Cindy Williams, CDOT's quality assurance manager. "The Illinois Department of Transportation [IDOT] did not have specifications for the production or placement of such materials and, therefore, quality control and quality assurance guidelines did not exist either. Development of mix designs and testing procedures by CDOT was critical to be able to define and specify what was needed."

To overcome this obstacle, the department led an aggressive design and investigative process that involved collecting best practices and sample specifications from around the country. CDOT developed its own specifications through a collaborative process involving CDOT staff, the design team, and a materials testing consultant. Together, they established a series of goals, tested the ideas in a laboratory, and then reviewed the results until the final mix designs, materials, and methods were solidified. For both pervious concrete and asphalt, the testing focused on finding the right balance between strength and permeability, given the composition and unit weights of local aggregates.

The department set several overall design criteria for the two materials. In addition to being permeable, the new pavements would need to contain recycled content. Because the end use would be alley applications, the pavements would need to handle average daily traffic consisting of 200 passenger vehicles, 2 single-unit trucks, and 1 multiunit truck. Plus, the pavements would need to incorporate materials available to contractors in the Chicago area and adhere to relevant IDOT specifications.

In addition, the mix designs for the pervious portland cement concrete (PCC) would need to have high albedo (reflectivity) to minimize the urban heat island effect. They would require a unit weight between 110 and 125 pounds per cubic foot (1,762 and 2,002 kilograms per cubic meter) and a 28-day compressive strength of 1,700 pounds per square inch, psi (11,720 kilopascals, kPa). Typically, CDOT uses a 14-day compressive strength of 3,500 psi (24,132 kPa) and a unit weight of 150 pounds per cubic foot (2,403 kilograms per cubic meter) for streets. With the large amount of air voids and reduced fines required to achieve pervious pavement mix designs, lower weights and strengths are usually specified, and 1,700 psi (11,720 kPa) appeared to be a reasonable goal based on the literature review.

For the pervious hot-mix asphalt (HMA), the mix designs would need to have stability comparable to the Superpave® N50 design. A product of the Strategic Highway Research Program, Superpave predicts the performance for various

CDOT reconstructed this alley in the Andersonville neighborhood using pervious pavers, a solution that helps reduce urban runoff and prevent localized flooding.

CDOT

(Top) Prior to reconstruction, this alley experienced frequent flooding, as shown here with snowmelt leaving large pools of standing water. (Right) After reconstruction with porous pavers in 2006, the alley no longer retains water.

CDOT

combinations of asphalt binder and mineral aggregates in HMA. Based on the literature review, CDOT determined that the criteria for N50 appeared to be appropriate for pervious HMA given the anticipated loading and expected durability.

PCC is usually designed with only a few percent entrained air voids, which helps increase freeze-thaw resistance, a major concern in the development and longevity of these materials in the climate of the Upper Midwest. For the pervious PCC, however, CDOT is designing for as much as 20 percent interconnected air voids. Similarly, the pervious HMA could include as much as 25 percent air voids.

"The downside of the extra void space in the pervious PCC, however, is reduced strength," Williams says. In the research phase, CDOT developed several mix designs, all incorporating ground granulated blast furnace slag, air entrainment, and a water-reducing admixture. Two mixes met the design criteria, one with a predominantly smaller aggregate (about 0.75-inch, or 1.9-centimeter, crushed, washed stone) and one with a predominantly larger aggregate (about 1-inch, or 2.54-centimeter, crushed, washed stone). Although the larger aggregate provided slightly greater strength, the smaller aggregate produced a lower unit weight, and CDOT decided to go with the latter design because of its more uniform appearance and to address concerns about public acceptance.

The pervious HMA, like the PCC, contains little or no sand. To compensate, pervious HMA often contains polymer-modified asphalt cement (AC) and fibers to prevent drain-down. Although the research team did develop a successful mix design with these additives, using an AC modified with recycled ground tire rubber proved much more cost effective, and "to the best of our knowledge, represented the first time a pervious asphalt mix design contained ground tire rubber," Leopold says. This switch solved the drain-down problem without the use of fibers, which are expensive to purchase and blow into the mix. The liquid ground tire rubber enhances the ability of the AC to adhere to the aggregate matrix, saves money, incorporates a recycled material, and increases the temperature range under which the pavement can resist rutting and thermal cracking.

In terms of the porous pavers, at the time of the pilot, CDOT had little experience using these. The pavers themselves are manufactured from an impermeable, high-density, high-strength concrete. Openings between the pavers are filled with an open-graded aggregate, usually a 0.25-inch (0.6-centimeter) crushed and washed stone, to allow water to infiltrate into the setting bed and soil below. The green alley pilots used 3.15-inch (8-centimeter)-deep L-shaped pavers, 10.24 inches (26 centimeters) by 10.24 inches (26 centimeters) wide, with 0.47-inch (12-millimeter) open joints. The pavers use lugs on the sides to maintain the proper spacing and, along with the interlocking "L" shapes, to help provide lateral stability, because the friction of a tight sand joint is not present.

Pilot Projects

After developing the mix designs, in 2006, CDOT launched five pilot projects at selected alleys that experienced flooding and required reconstruction. The original designs for the five pilot alleys all had reverse crowns (meaning water would flow toward the center of the alley) to provide positive flow if clogging occurred. The pilots featured the following characteristics:

- An alley paved in full width and length with pervious PCC.
- An alley paved in full width and length with pervious HMA.
- An alley paved in full width and length with porous pavers and a high-albedo PCC collar.
- An alley paved in full width and length with nonpervious high-albedo PCC.
- A 4-foot (1.2-meter)-wide pervious PCC trench paved along the entire length of the centerline with nonpervious high-albedo PCC in the wheel paths. (The researchers used the center trench design to address urban conditions where infiltration needs to be set back from adjacent buildings to prevent water damage.)

All the alleys had 12 inches (30.5 centimeters) of class A, washed, open-graded aggregate (both crushed and uncrushed were tested) beneath them, except for the alley with the center trench, which had 5 feet (1.5 meters) of aggregate below the trench, with the sides lined in a waterproof membrane.

The pilots revealed a number of lessons in the development and installation of the pervious pavements. For example, with the pervious HMA, the researchers learned that a blend of at least two aggregate gradations should be required for plant control. Also, the addition of fibers is unnecessary if using ground tire rubber. The researchers also found that no more than two lifts (asphalt layers) should be placed in a single production day to avoid causing deformation due to rolling too quickly.

On the pervious PCC alleys, CDOT officials determined that hydration stabilization additives work better than water-reducing and water-retarding admixtures (and this switch was made prior to construction) and that a minimum 28-day compressive strength of 2,000 psi (13,790 kPa) could be achieved and specified. They also found that creating an inverted profile (where the low point of the cross section is in the center of the street) was challenging, as was achieving consistent compaction throughout the specified 8-inch (20.3-centimeter)-thick pavement cross section, particularly within the confines of an alley.

Porous pavers could be installed relatively quickly with mechanical installation, which also helped reduce labor costs. However, achieving an inverted crown with porous pavers presented some challenges.

The breakthroughs and successes from these pilots provided an immediate increase in the department's confidence in pervious pavements. Initial doubts were replaced by well-tested specifications and on-the-ground examples.

According to Leopold, the change brought about within the industry was equally transformative. Although suppliers originally expressed skepticism, after the pilots, many began developing their own mix designs and instituting training classes. Contractors too, Leopold says, went from wary at first to willing to try new techniques.

"All of these changes enabled CDOT to add the newly developed materials to a term contract for alley reconstruction that was going out for public bid in early 2007," Leopold says. "The city received several competitive bids, saw a drop in cost for many of the items, and in one stroke turned an innovative pilot into a program."

Since then, every alley CDOT has reconstructed has been a green alley, using one or more of the materials tested in the original five pilots.

Green Alley Handbook

To help ensure public acceptance of the new approach, CDOT developed *The Chicago Green Alley Handbook*. The handbook is a primer explaining how the department defines a green alley, how a green alley works, and why the city is implementing these new designs. The document clearly explains the toolkit of techniques used in designing green alleys, including proper pitching and grading, permeable pavements, high-albedo pavements, and recycled construction materials. Also explained is another component of the green alley program: dark sky-compliant lighting fixtures, which are designed to direct light downward, reducing light pollution.

"[The handbook] explains the green alley pilot approaches to design as well as dos and don'ts for adjacent property owners," Leopold says. "It lays out a series of best management practices that adjacent owners can implement to further enhance the performance of their green alleys and help make Chicago a greener and more sustainable place." For example, the owners can use rain barrels, rain gardens, and green roofs to help reduce runoff from their buildings.

CDOT distributed copies of the handbook to property owners adjacent to all the pilot green alleys, as well as to every city alderman. Copies also are available at city hall and on CDOT's Web site. The handbook, in conjunction with public meetings, proved a powerful selling tool to ensure public acceptance of the new designs. Being able to clearly articulate the goals, methods, and outcomes of the testing and research for the program was critical.

Field and Maintenance Testing

CDOT tested the pilot green alleys for several factors over a 3-year period between fall 2006, when they were installed, and summer 2009. The researchers tested for pavement strength; albedo and solar reflective index; permeability, based on lab tests on 6-inch (15.24-centimeter) cores; and infiltration, based on single-ring infiltrometer tests performed in the field. (For the single-ring infiltrometer test, the researchers used a metal ring open at the top and bottom with an area of 1 square foot, or

CDOT

A maintenance worker is using a broom-only streetsweeper to clean the center trench in this alley paved with pervious concrete.

0.09 square meter, secured to the surface being tested with plumber's putty. They poured a defined amount of water into the ring, usually 3 gallons, or 11.4 liters, and measured the rate of infiltration with a stopwatch.) In addition, researchers performed permeability tests in the field on the subbase material. The tests showed that all the permeable pavements piloted had reduced levels of infiltration in the first year and that void size, ratio of impermeable to permeable, and the presence of trees all influenced performance.

In conjunction with these tests, CDOT staff looked at maintenance equipment and procedures to determine their impact on infiltration. They tested the following pieces of equipment: a regenerative vacuum sweeper (a low-cost but relatively inefficient impeller-driven vacuum system), standard broom-only streetsweeper, sweeper/vacuum combination, power washer, sweeper/vacuum truck, walk-behind vacuum/brush device, and another sweeper with a powerful vacuum. The researchers tested infiltration before and after cleaning in all cases.

The data from these tests indicate that green alleys can experience significant clogging. However, if the pavements are cleaned periodically, before they become too clogged, maintenance staff can restore them to serviceable levels fairly easily. Based on this finding, CDOT developed a maintenance protocol specifying that the alleys should be swept by a streetsweeper, with its water jets turned off, once in the spring and once in the fall at a minimum. Furthermore, CDOT found that porous pavers require replacement of the stone matrix between the pavers after each cleaning or run the risk of becoming deeply clogged and difficult to clean.

Two observations drove these conclusions. First, the lower that CDOT allowed the infiltration rates to fall prior to cleaning, the more difficult it became to restore permeability. Second, debris was particularly prevalent in the spring, due to snowmelt, and in fall, due to leaf matter. The researchers determined that the broom-only streetsweeper, which was relatively successful at restoring infiltration and is standard equipment available in every city ward, should be sufficient if maintenance is performed regularly. Although traditional alleys are not swept regularly, all city streets are usually swept once a month; therefore, CDOT determined that adding the green alleys to the existing routes was a cost-effective solution. On the other hand, although the city has the means to replace the stone matrix in the porous pavers, this activity is more challenging logistically.

More Pilot Projects

Building on the lessons learned from the first round of pilots, in summer 2009, CDOT installed a new full-width pervious PCC alley in the Logan Square neighborhood. The researchers designed this pilot specifically to address two issues they observed in the earlier pilots. First, a more open pore structure appeared to allow for easier maintenance, particularly using the broom-only streetsweeper. Second, achieving an inverse crown on a full-width pervious PCC alley is labor intensive because it must be done in halves and handtrucked into place.

"To address these problems, the department developed a new mix design that contains fibers and utilizes a blend of two different gradations of course aggregates," Williams says.

The crew placed the pervious PCC pavement using a full-sized paver with the vibrating screed engaged and then rolled it with a 48-inch (122-centimeter) roller in the static mode. This design achieved average strengths of 2,607 pounds per square inch (17,970 kilopascals) and average infiltration rates of 799 inches (20.3 meters) per hour, and it has a more consistent void structure throughout the depth of pavement. Further, going forward the design can save labor costs by enabling the crew to pour the full width of the pervious PCC pavement while incorporating an inverse crown.

Applying Lessons Learned

Even before CDOT had gathered all the long-range monitoring data, the initial successes of the green alley pilot project changed the way the department and the Streetscape and Sustainable Design Program in particular do business. The successful design and installation of permeable pavements tipped the balance from asking "Why?" to "Why not?" Although the green alleys methods require further research and development, they added a whole new set of tools to the department's arsenal. To continue learning how and where to use these materials, the department began installing porous pavers in parkways and parking lots, pervious HMA in parking lanes, and pervious PCC in plazas.

With regard to cost, CDOT found that as a market began to develop for permeable pavements, costs began to come down, allowing for more cost-effective design solutions. For example, with permeable concrete, the price for the original product mixed onsite dropped by more than two-thirds in less than 6 months. When sewer infrastructure is not present, green alleys become cost competitive, because they often do not require any new pipes or catch basins. Costs that need to be analyzed closely include increased excavation fees, higher aggregate costs, and increased labor costs, some of which stem from contractors' unfamiliarity with using permeable pavements. On the plus side, recycled content tends to reduce material costs, which could further reduce costs over time.

In fact, the pilots inspired even greater use of recycled materials. "CDOT continued to experiment and develop pavements with higher amounts of reclaimed asphalt pavement, or RAP, and recycled aggregates, as well as to include ground tire rubber in both residential and arterial street resurfacing projects," Williams says.

The department also began to investigate the solar reflectance index values of pavements and high-efficiency white light sources and dark sky-friendly lighting fixtures, another feature of the green alley pilots.

One subsequent project that benefited from the lessons learned is the Maxwell Street Market. The project consisted of a streetscape and adjacent parking lot used once a week for a flea market. The parking lot was a brownfield site with tier one exceedances of polynuclear aromatic hydrocarbons and the presence of lead and arsenic in surface soils. The site also had no existing sewer infrastructure but had good soils for infiltration. Due to the contamination, 26,000 square feet (2,415 square meters) of the approximately

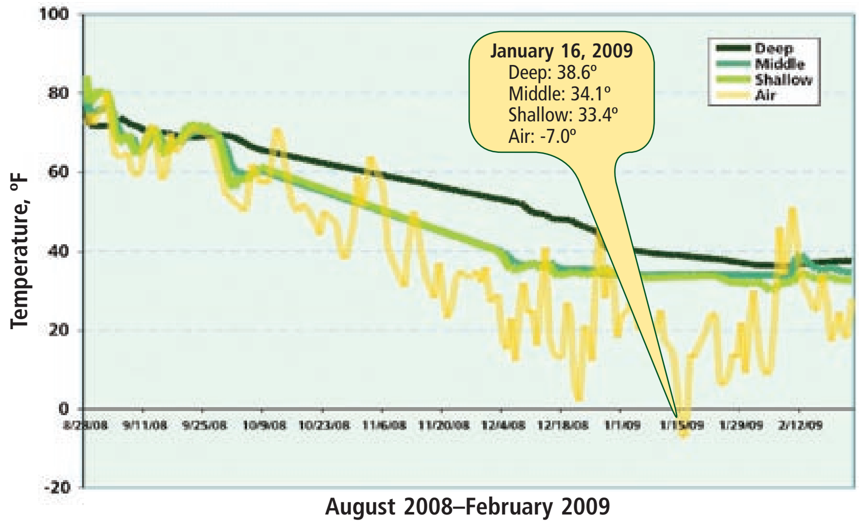
1-acre (0.4-hectare) site had to be remediated to a depth of 2 to 3 feet (0.6 to 0.9 meter). Taking these conditions into account, CDOT decided to replace the remediated soil with open-graded aggregate, pave the surface with porous pavers, and install an adjacent bioswale (a concave landscaping feature that reduces the volume and rate of surface runoff and improves water quality). In addition, CDOT had identified the area as an urban heat island hot spot, so the department installed pavers with a solar reflectance index greater than 0.29 (where 0 is a black surface and 1 is a white surface).

Due to the contamination at the site, the U.S. Environmental Protection Agency was interested in using the project as a pilot to examine the effects of stormwater infiltration on groundwater quality in urban conditions and to assess the effectiveness of porous pavers. To help shed light on these issues, researchers installed piezometers with water level loggers, monitoring wells, temperature probes, and a data-logging rain gauge onsite.

Although EPA is still processing the data, Leopold says one of the most exciting things to come out of the project is confirmation of something observed but not actually monitored on the green alley pilot projects: the effect of freeze-thaw on permeable pavements. Temperature probes placed at various depths in the subbase recorded in situ temperatures, while an aboveground thermometer measured the ambient air temperature.

The results show that even when air temperatures dropped below zero, the temperatures in the subbase usually remained above freezing. "This is not only good for the longevity of the pavement," Leopold says, "it also shows that permeable pavements can still be effective during winter months and reduce the amount of snow and ice present compared to traditional pavements." With ground temperatures a few feet below the surface maintaining a constant 55 degrees Fahrenheit (12.8 degrees Celsius), convection created within the interconnected air voids keeps temperatures within the cross section above freezing. This situation allows for water infiltration even in the winter and helps prevent structural damage due to freeze-thaw cycles.

Temperature Data from Maxwell Street Market



This graph compares air temperature data recorded at the Maxwell Street Market with temperatures measured at various depths below the pavement. The callout highlights the readings from January 16, 2009, showing that even though the air temperature was well below freezing, the temperatures below the pavement were above freezing. Infiltration, therefore, can continue even through the winter, helping prevent structural damage due to freeze-thaw cycles. *Source: U.S. EPA.*

Sustainable Streets Program

Another initiative that has grown out of the green alley pilots is CDOT's Sustainable Streets Program. This too began as an innovative pilot project that became a program even before the pilot was completed. CDOT officials describe the scale of the sustainable streets pilot as much more comprehensive than earlier efforts. The project is located on the near-southwest side of Chicago and totals 2.13 miles (3.43 kilometers) along two arterial streets. One street is a five-lane truck route with no onstreet parking and 10- to 15-foot (3- to 4.6-meter)-wide sidewalks. The other is a five-lane truck route with street parking and 20-foot (6.1-meter)-wide sidewalks. Both streets act as dividers between a dense residential neighborhood and an industrial district along the south branch of the Chicago River. Adjacent land uses include a public park, a high school, a coal-fired power plant, small shops, and produce distributors.

The pilot established several sustainable performance categories and goals commonly associated with the U.S. Green Building Council's (USGBC) Leadership in Energy and Environmental Design (LEED)-certified buildings, but not typical in streetscape design and construction. Where possible, CDOT prioritized integrated design solutions that maximize environmental synergies.

Recycled content. The project aims to recycle at least 90 percent of the construction waste (excluding landscape debris) based on total weight or volume, similar to USGBC's LEED for New Construction criteria. The sum of postconsumer recycled content plus one-half of the preconsumer content must constitute at least 10 percent (based on cost) of the total value of the materials in the project.

Energy conservation. The project will reduce energy use by a minimum of 40 percent below the baseline for new construction of a typical streetscape, use reflective surfaces on sidewalks and roadways, and use dark sky-friendly lighting fixtures. CDOT also will use materials or products that have been extracted, harvested, recovered, or manufactured within 500 miles (805 kilometers) of the project site, for a minimum of 40 percent (based on cost) of the total materials' value, similar to LEED for New Construction criteria.

Stormwater management. The project will divert 80 percent of the typical average annual rainfall and at least two-thirds of the rainwater that falls within the catchment area using stormwater best management practices. These techniques and strategies will promote infiltration, provide water for new landscaping, improve water quality, and reduce the volume of stormwater that enters the combined sewer system.

Urban heat island mitigation. The project aims to reduce ambient summer temperatures on streets and sidewalks through the use of permeable and high-albedo pavements and coatings on roadways and sidewalks, use of trees for shading, and increased landscaping.

Alternative transportation. CDOT will improve bus stops with signage, shelters, and lighting where possible and facilitate use of bicycles with the addition of new bike lanes. The department also will take steps to enhance pedestrian mobility with new fully accessible sidewalks and improved crosswalks.

Beauty and community. The project will create appealing public spaces that are beautiful and promote community interaction and observation of the natural world.

Water efficiency. CDOT will eliminate use of potable water sources for irrigation, instead specifying native or climate-adapted, drought-tolerant plants for all landscaping.

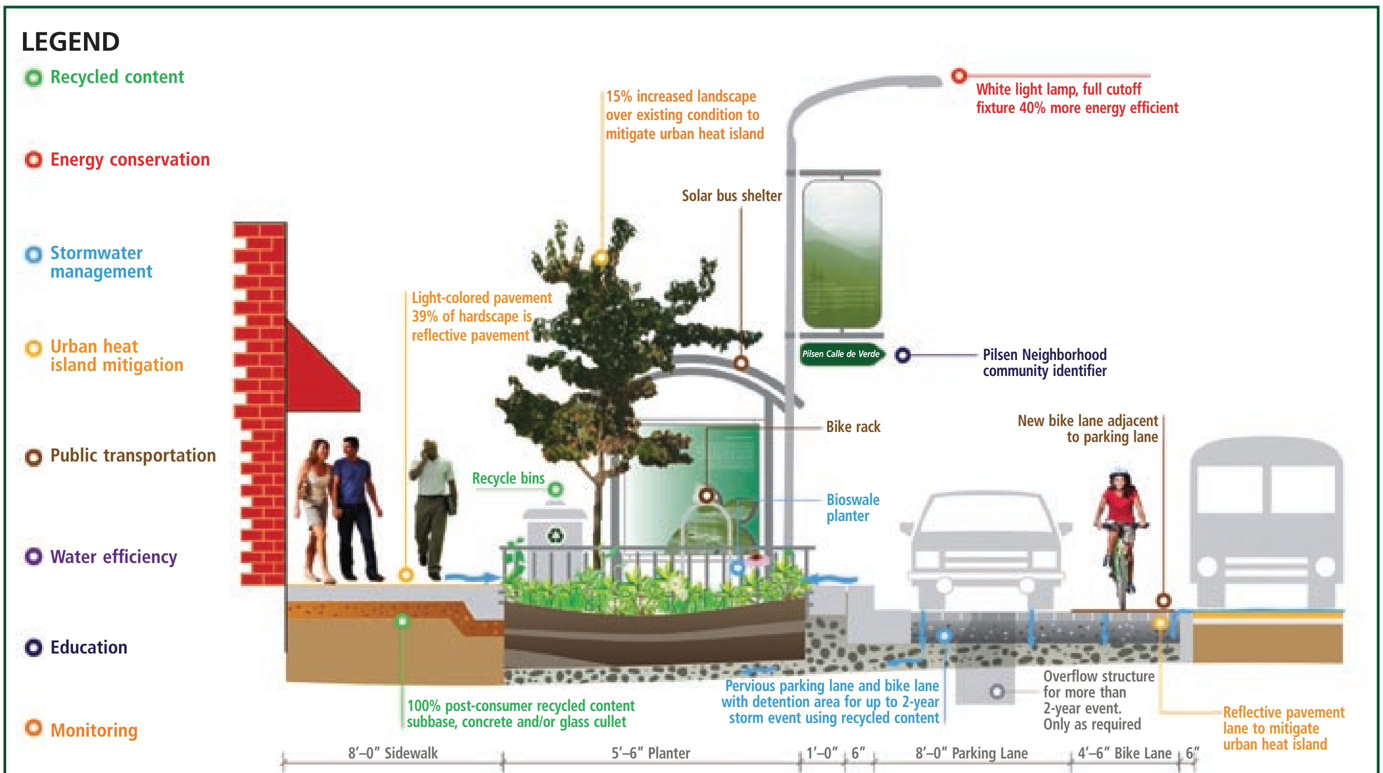
Education. The project will feature public outreach materials and a self-guided tour brochure to highlight innovative, sustainable design features of the streetscape.

Commissioning. CDOT, in partnership with the Metropolitan Water Reclamation District of Greater Chicago, will model and monitor various aspects of the project, including stormwater initiatives and air quality. Researchers will gather data before and after construction to determine the efficacy and long-term performance of these initiatives.

A few of the innovative designs developed for this project to achieve the above goals include a stormwater-fed water feature, a nearly 0.75-mile (1.2-kilometer)-long bioswale interconnected between cross streets, and bike and parking lanes with permeable pavers. Another feature is a stormwater plaza on an adjacent parcel filled with interconnected rain gardens that form a new gateway into the community and provide seating as well as education and public art opportunities.

CDOT is using a number of innovative materials on the project as well, including high-albedo permeable pavers with a photocatalytic cement face mix; a high-albedo, microthin concrete overlay; and PCC with 30 percent recycled aggregate, ground granulated blast furnace slag, and recycled wash water. The project also features warm-mix asphalt with recycled asphalt pavement, light-emitting diode lighting fixtures, and community identifiers with solar- and wind-powered lights and educational signage.

An example of the synergistic design incorporated into this project is the use of high-albedo permeable pavers with a photocatalytic cement face mix in the new bike lanes and adjacent parking lanes. The photocatalytic cement, which uses sunlight and a titanium dioxide catalyst to break down pollutants both on its surface and in the adjacent air, helps improve air and water quality. The pavers' high-albedo surface helps mitigate the urban heat island effect, and their permeability addresses stormwater management.



This graphic helps illustrate how the sustainable streets pilot project integrates sustainable principles throughout the design. This proposed cross section through Blue Island Avenue shows bike and parking lanes surfaced with porous pavers and highlights which elements address the project's sustainability goals. *Source: CDOT.*

These workers are installing pervious concrete in a reconstructed alley in the Hegewisch neighborhood. The concrete incorporates recycled slag, which helps increase albedo and reduces the urban heat island effect. Due to the alley's tight constraints and the need to create an inverted profile, the workers poured the pavement for one half of the alley at a time.

CDOT

Plus, the pavers' high reflectivity and ability to maintain that reflectivity over time improves lighting uniformity, allowing installation of lower wattage lighting fixtures to achieve higher lighting standards and promote energy conservation.

Pedestrian and bicyclist accessiblility also is a factor. Because of the heavy truck traffic, vehicles often park on the existing sidewalk to avoid sideswipes. By narrowing the 20-foot (6.1-meter)-wide sidewalks to 15 feet (4.6 meters) midblock, CDOT found it could add bike lanes and parking, with the sidewalks widening back to 20 feet (6.1 meters) at the intersections. This improves pedestrian accessibility and provides for alternative modes of transportation.

As part of the design and commissioning of the project, CDOT developed a hydraulic model of the stormwater best management practices. The model facilitates evaluating design decisions and provides detailed modeling of green infrastructure that CDOT can apply to a larger model of the city's entire sewershed. These low-impact development strategies can be scaled up, so department staff can assess their impact across sewersheds, allowing for meaningful comparisons of gray versus green solutions. The comprehensive modeling before and after the project's construction will gather important data about the innovative designs and materials specified and enable researchers to calibrate the model with real data to provide more accurate analyses and comparisons. The data also will help the department develop additional maintenance protocols and test their effectiveness.

Inspiring Innovation

As in many transformations, pilot projects provide an opportunity to incubate new approaches and lead by example. Through its Green Alleys program, CDOT staff got its feet wet by applying green infrastructure approaches on small, discrete sites. Today, the department is applying the lessons learned to larger and more complex projects.

The successful techniques developed during the green alley pilot projects are quickly becoming integrated throughout the department. Through the Streetscape and Sustainable Design Program, CDOT is promoting the use of pervious pavements in the city's riverwalks, bicycling facilities, and streetscapes. And larger scale highway and bridge projects too are incorporating permeable pavements and stormwater best management practices, such as in the reconstruction of U.S. 41 and the relocation of Torrence Avenue. The experience using innovative materials in pavement designs also led the department to explore use of recycled roof shingles in HMA on another recent project.

In addition to driving its own internal improvements, CDOT is sharing its green alleys strategies with other cities around the country and internationally. Through the deployment of green urban infrastructure and use of the public right-of-way to create sustainable public spaces, CDOT is not only reshaping business as usual, but perhaps turning the DOT's old enemy—stormwater—into a community ally.

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For more information, visit www.cityofchicago.org/transportation or contact Janet Attarian at 312–744–5900 or janet.attarian@cityofchicago.org.

Detecting Motorcyclists and Bicyclists at Intersections

by David R.P. Gibson, Bo Ling, and Spandan Tiwari

A new multisensor system differentiates vehicles on the road, which could save lives.

According to the National Highway Traffic Safety Administration (NHTSA), the number of U.S. traffic fatalities in 2008 reached its lowest level since 1961. Despite an overall improvement in safety, however, motorcyclist deaths continued their 11-year increase, reaching 5,290 in 2008, accounting for 14 percent of all highway fatalities. Bicyclists, too, face disproportionate dangers on the Nation's roadways. Although bicycle trips accounted for less than 1 percent of all trips in 2008, bicycle riders represented 2 percent of all traffic fatalities.

Statistics for intersection crashes are similarly disproportionate. Based on 2008 data from NHTSA's Fatality Analysis Reporting System, 270 (or 3.5 percent) of the 7,772 intersection fatalities were bicyclists, while another 1,441 (or 18.5 percent) were motorcyclists. Another way of looking at motorcyclist and bicyclist fatalities at intersections is to compare the proportion that occurred at intersections with the proportion that occurred elsewhere. For example, in 2006, 2007, and 2008, a total of 4,283 motorcyclists were killed in intersections, representing 16.9 percent of all fatalities at intersections. Over the same period, of all motorcyclist fatalities on U.S. roads, a total of 28 percent occurred at intersections. Similarly, bicyclists accounted for 786 intersection fatalities during those 3 years, representing 3.1 percent of all intersection fatalities. Intersections, the data reveal, were the site of 36 percent of all bicyclist fatalities.

Further still, per vehicle miles traveled (VMT), NHTSA estimates

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Shown here is a prototype motorcycle classifier, a multi-instrument sensor designed to detect cyclists at intersections. The sensor includes an infrared-visible light stereo camera (top left), an infrared thermal camera (right), and an acoustic sensor (below left).

that motorcyclists are now about 34 times more likely than passenger car occupants to die in a motor vehicle crash. But these estimates are highly dependent on the accuracy of VMT estimates for motorcycles, which is challenging to determine using existing traffic sensors. Intelligent transportation system (ITS) technologies typically use inductive loop and magnetometer sensors to detect cars and trucks, but the sensors are not as effective at detecting and classifying motorcycles and bicycles. These sensors detect the effects that electrically conductive materials have on electromagnetic fields, but both motorcycles and bicycles have low conductive masses. Loop detectors require that bicyclists be near the pavement markings for the sensors to trigger, and the detectors' sensitivities are difficult to set to avoid false detections. With regard to motorcycles, loop detectors only can detect their presence, not their types. In fact, participants at a 2007 Motorcycle Travel Symposium sponsored by NHTSA and the Federal Highway Administration (FHWA) cited transportation infrastructure and how it detects and counts two- and three-wheeled vehicles as a key problem area for traffic engineers.

According to Dan Stewart, manager of the Maine Department of Transportation's (MaineDOT) Bicycle and Pedestrian Program, accurate detection is critical for intersection control devices to ensure that red and green traffic signals respond appropriately to motorcyclists and bicyclists and keep all modes of traffic flowing safely. "This problem is only increasing for motorcycles as they are made with less steel, making them harder for conventional systems to detect," he says. "It's frustrating for riders to obey the rules of the road when a traffic signal will not recognize a person on a bike or motorcycle."

Spurred by the 2007 symposium, FHWA and a traffic engineering firm embarked on a multiphase research project to develop a system to detect and classify two- and three-wheeled vehicles more effectively. Phase I of the project, now complete, focused on developing an accurate detector. The result is a multi-instrument device for detecting these vehicles at intersections and ultimately for improving safety for riders.

Benefits of Better Detection

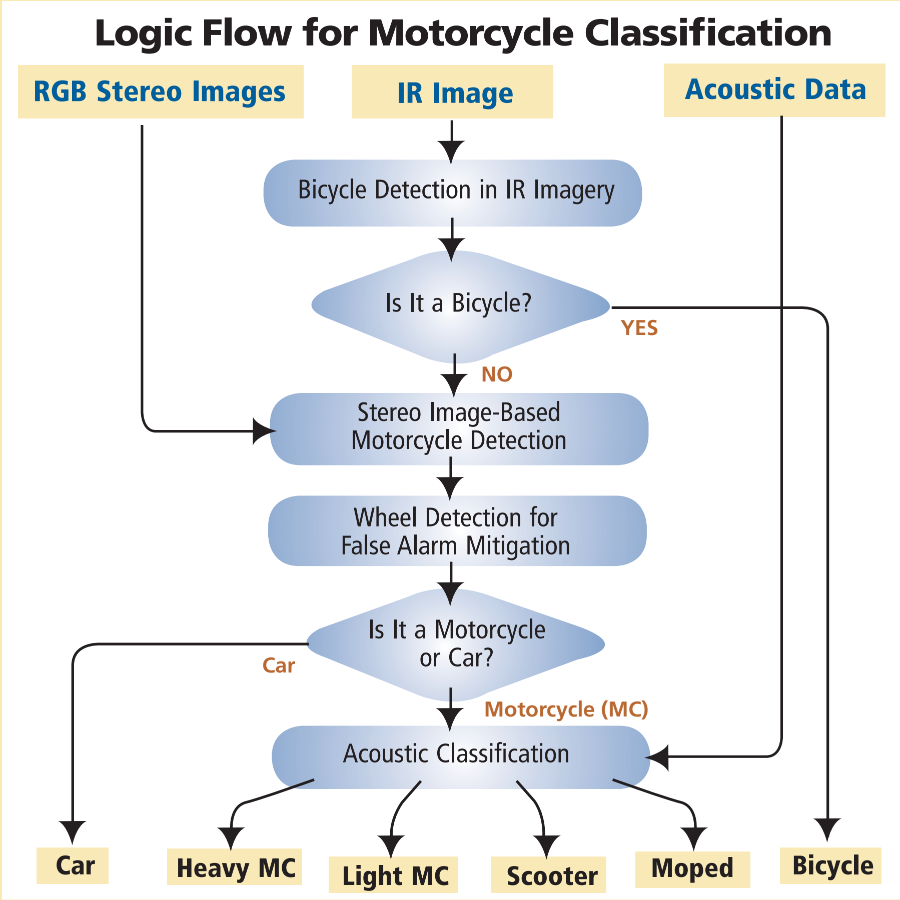
Developing improved sensors to detect cyclists at intersections could produce a number of benefits. Detection and classification technologies improve safety by enabling signal control systems to lengthen signal times for slower moving traffic, such as pedestrians and bicycles, and shorten signal times for faster moving motorcycles and automobiles. More accurate detection systems would enable ITS technologies to sense motorcyclists and bicyclists traveling alone—that is, unaccompanied by larger motor vehicles nearby to trigger a detection—and provide green lights, safety messages, and other cues to riders.

Sensors also can play an important role in traffic monitoring. ITS technologies installed at high-traffic locations can supply useful, continuous monitoring data on traffic demand and vehicle classification, while accomplishing their primary safety and operations objectives. Improved detection systems could benefit transportation planners by collecting more accurate data on demand levels to inform present traffic control needs and planning for future improvements. Improved vehicle classification also could help States meet FHWA requirements for reporting on two- and three-wheeled vehicles as described in FHWA's *Travel Monitoring Guide* (FHWA-PL-01-021).

"The city of Cambridge [MA] supports bicycles, mopeds, scooters, and motorcycles as part of our comprehensive climate protection plans," says Adam Shulman, a transportation planner with the city's Traffic, Parking & Transportation Department. "In just the past 6 years, bicycling has increased by 100 percent in Cambridge. If a new tool is created that can accurately and inexpensively count bicycles, we could better monitor our successes and help plan and prioritize additional ways to encourage these smaller, health-promoting, and less gas-dependent vehicles."

Getting Started

The researchers knew that the ideal sensor, which they termed "motorcycle classifier," would have to detect and classify motorcycles and bicycles in real-world roadway environments. The sensor would need to work in a variety of weather, lighting, and time-of-day conditions, including sunrise,



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sunset, noon, night, sun glare in the spring and fall, fog, drizzle, rain, and snow. This need for an over-roadway sensor that works in a variety of conditions led the researchers to select a multiple-technology rather than single-technology sensor.

At left are two consecutive images of pedestrians crossing a street as photographed by a stereo camera. To the right are the corresponding disparity maps rendered by the algorithm. The shapes of the pedestrians are clearly visible popping out from the gray background in the disparity maps.

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Because of the inaccuracy of traditional ITS technologies for detecting two- and three-wheeled vehicles, the researchers focused on using infrared (IR) and visible light cameras. Specifically, the researchers chose an IR-visible light stereo camera to identify the riders on two- and three-wheeled vehicles, an IR thermal camera to distinguish cars and motorcycles from bicycles, and an acoustic sensor to distinguish classes of cycles such as large motorcycles versus mopeds.

The researchers designed their new motorcycle classifier based on a multisensor device previously developed as a pedestrian detector. (See "Detecting Pedestrians" in the September/October 2009 issue of PUBLIC ROADS.) Using an IR-visible light stereo camera, the pedestrian detector focuses on the unique shapes of people, as distinct from other three-dimensional (3–D) objects in the roadway environment, to detect pedestrians crossing intersections. Similarly, two- and three-wheeled vehicles, with human riders, have distinctly different shapes than cars and trucks. So, the researchers applied the same technology to detect riders on two- and three-wheeled vehicles.

Logic Flow

The logic flow (underlying programming in the detection system) of the motorcycle classifier uses the different sensors in sequence to detect a vehicle and progressively zero in on its classification. The sequential sensors also provide some overlap for redundancy, facilitating error checking.

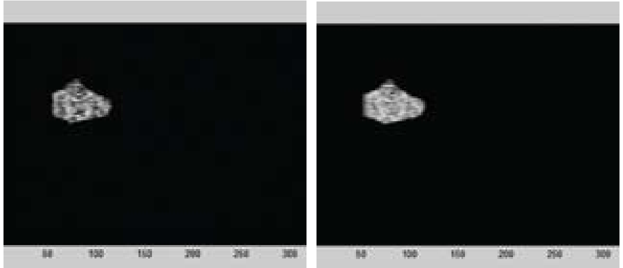
The logic flow is as follows. (1) Using the IR thermal camera, ask, "Is it a bicycle?" If yes, classify it as a bicycle. (2) If it is not a bicycle, use the IR-visible light stereo camera and ask, "Is it a car or a motorcycle?" If a car (note that in this context a car might mean car, truck, or bus), classify it as such. (3) If the vehicle is not a bicycle or a car, it must be some kind of two- or three-wheeled motorized vehicle. (4) Using the acoustic sensor, ask, "What kind of two- or three-wheeled vehicle is it?" Then classify it as a heavy motorcycle, light motorcycle, moped, scooter, or motor tricycle.

Stereo IR-Visible Light Sensor

The key to this approach is using the stereo camera (the pedestrian detector from the earlier research) to identify people as riders and therefore distinguishing the two- and three-wheeled vehicles from cars, trucks, and buses. The sensor uses a computer algorithm to build a 3–D disparity map (which provides depth information on objects in an image) and identify the profile of a human body. The term "disparity" comes from describing the 2–D vector between the positions of corresponding features seen by the left and right lenses of a stereo camera. The equipment can compute a map from the disparity coordinates (x, y, d) to a 3–D position, where x is the horizontal axis, y the vertical axis, and d the depth. Instead of detecting pedestrians, in this application the sensor detects cyclists through their 3–D body features in the disparity map.

When applying the pedestrian disparity technique to detecting cyclists, the researchers needed to address several issues. The first was the difference in speed between pedestrians and cyclists, and the need to capture two consecutive frames of the same object in relatively the same location. The speed of motorcyclists and even bicyclists ranges from 20 miles per hour, mi/h (32 kilometers per hour, km/h) to more than 60 mi/h (97 km/h), whereas pedestrians travel at the leisurely rate of 1–4 mi/h (1.6–6.4 km/h), or perhaps faster if running. At a speed of 20 mi/h (32 km/h), or 30 feet per second (9 meters per second), a

The IR-visible light stereo camera took these photos of a motorcyclist, the left-hand image by the left lens and the right-hand image by the right lens.



Algorithms rendered the motorcyclist photos into these disparity maps. The revised algorithm produced the right-hand image, which has a more completely filled-in disparity map.

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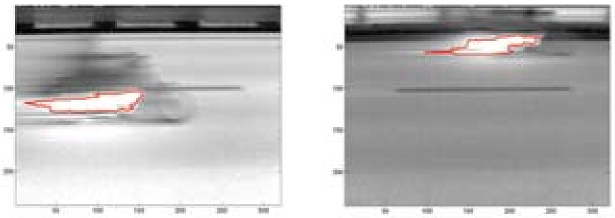
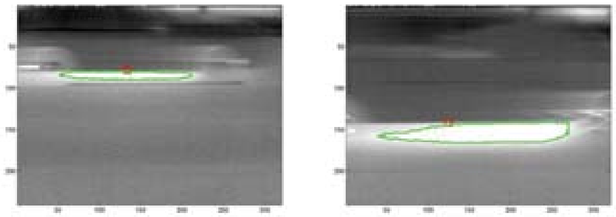


These photos show the distinguishing thermal shape of a motorcycle as captured by the IR thermal camera, with the hot spots outlined in red. Note that the hot spots for motorcycles appear within the vehicle image. The motorcycle on the left is closer in range, and its hot spot associated with the engine and exhaust pipe is relatively isolated. The motorcycle on the right is farther away from the camera, and its engine and exhaust pipe show a relatively larger hot spot compared to the motorcycle's body.



These photos depict the IR images of cars, with the morphological shapes of hot spots outlined in green. Note that the hot spots of cars appear beneath the vehicle images, unlike those of motorcycles, which appear within the body of the motorcycle's profile. The researchers found that hot spots underneath cars can have different thermal shapes, which makes the classification more challenging, so they are developing algorithms to overcome this problem.

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5-foot (1.5-meter)-long motorcycle will not occupy the same frame location long enough for the camera to shoot consecutive photos for comparison in the disparity map. To compensate, the researchers increased the sampling rate to 5 shots per second, far above the rate used in pedestrian detection.

The second issue is that although distinguishing a walking pedestrian alone is relatively simple, imaging a body hunched over riding a motorcycle is more complex. However, because the peak point (vertically) of a motorcycle detection is almost always a human body—the rider's head—the researchers could window in on the motorcyclist and positively detect him or her. (The same holds true for two riders on a single motorcycle.) The researchers had to revise the original pedestrian detection algorithms significantly to allow for the increased complexity of the disparity maps that would be analyzed. The revised algorithms yield a more completely filled-in disparity map, facilitating a more accurate detection and classification.

Bicycle, Motorcycle, and Car Wheel Detection

As noted earlier, the first step in the logic flow is using the IR thermal camera to distinguish bicycles from other vehicles. To detect a bicycle, the camera is keyed to the unique thermal signature of bicycle wheels: They are much clearer and more readily distinguished than those of motorized vehicles. Unlike motorcycle wheels, which usually move more rapidly, bicycle wheels are better articulated and relatively sharp because they are not partially surrounded by a motorcycle or automobile body.

Similarly, the shapes and characteristics of the thermal signatures of motorcycles and cars help to distinguish between those vehicles. The camera renders the IR images in gray scale, with white being the hottest areas and black being the coolest. The bright IR regions of motorcycles and cars are located in different parts of the vehicle image (such as the engine and exhaust pipes) and are of somewhat different shapes. Researchers can select a region of the image and look at its thermal threshold and shape to determine with some certainty if the image shows a motorcycle. In addition, a closer look for the shapes of car undercarriages can help prevent misclassification of cars as motorcycles.

Because the IR camera technique might confuse cars with motorcycles, another sensor, the visible light stereo camera, then comes into play. The motorcycle classifier examines the red, green, blue (RGB) digital image from the camera and windows it to locate the vehicle wheels.

The key for the classifier to distinguish motorcycles from cars is the shape of the area around the front wheel. A motorcycle's front wheel typically protrudes alone, unlike its rear wheel and the front and rear wheels of a car or truck, which are at least partially enclosed within the vehicle's body. The front wheel therefore helps create a distinct image signature for a motorcycle, partially surrounded by a background of pavement instead of the nearby sheet metal of a vehicle body. This element of the logic flow completes the redundant error checking in the classification of a vehicle as a two- or three-wheeled motorcycle versus a car or truck.

Subclassification of Motorized Two- and Three-Wheeled Vehicles

At this point in the logic flow, only vehicles classified as "motorcycles" remain (which includes scooters and mopeds). All motorcycles are shaped about the same from the point of view of IR and visible light images. The researchers could have performed the subclassifications using a digital single lens reflex-type camera, but this would have been prohibitively expensive. Instead, they chose a simpler approach based on acoustics.

Motorcycles, scooters, and mopeds have distinct sound signatures due to differences in their engines and typical operating speeds. The researchers used digital signal processing with phase analysis of the sound to measure the spectrum features for each of the motorized two- and three-wheeled vehicle classes.

Classifying vehicles by acoustic or sound signature is straightforward logically but computationally intensive in its internal algorithms. First, the motorcycle classifier determines whether the sound is that of a motorcycle engine or scooter-moped engine. If the sound is coming from a heavier, more powerful engine, the system employs a second logic set that determines whether the source is a heavy or light motorcycle. If the acoustic pattern is that of a light engine, the system further examines whether the engine has the characteristics of a scooter engine or moped engine.

System Deployment And Results

The researchers selected an outdoor test site near a major highway in Walpole, MA. They pointed both the stereo and IR cameras toward the highway, which is frequently traveled by vehicles and motorcycles. They placed a microphone near the cameras to record the sound signals. The researchers recorded data, including stereo images, IR images, and sounds, continuously from 9 a.m. to 5 p.m. To collect more motorcycle data, researchers deployed the system at the test site for more than 1 week under different weather conditions.

For the system test, the researchers manually scanned through all of the datasets and selected all the motorcycles and randomly selected vehicles. Because there were no bicyclists on the highway at the site during the test period, the researchers rode bicycles themselves and recorded the data.

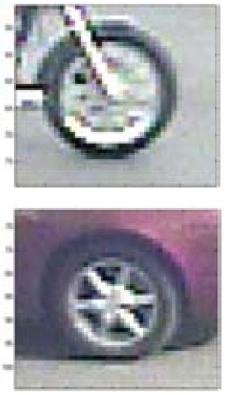
During phase I, the researchers collected a total of 45 vehicle samples and found the performance of the multisensor motorcycle classifier promising, even though it misclassified vehicles on several occasions. Out of 12 cars, the system classified 1 as a heavy motorcycle and 1 as a light motorcycle. Out of 14 heavy motorcycles, the system classified 3 as cars. Out of 4 light motorcycles, the system classified 1 as a car. Out of 9 bicycles, the system classified 1 as a car. The system classified all 3 mopeds correctly, but classified 1 of 3 scooters as a light motorcycle.

The researchers conclude that the main reasons for the misclassifications are motion blur in the IR images and less-than-ideal acoustic quality. Development is underway to reduce the motion blur and improve the acoustic features using a microphone array.

A Promising Approach

MaineDOT's Stewart is optimistic about the motorcycle classifier's early showing. "This research has the potential to save lives and dramatically improve the transportation system," he says.

Next up: The researchers will continue to refine the tool in the second phase of the project, now underway with a 24-month project period. Phase II involves two multi-instrument sensors, one for bicycle detection at intersections and the other for detection and classification of motorcycles at intersections. The researchers will place the IR camera and stereo camera in one enclosure for better image alignment. The stereo camera will use high-resolution lenses. A microphone array will be embedded in the enclosure at strategic locations to reduce the impact of background acoustic noises such as wind. The algorithms will be further improved to enhance the image quality and explore new thermal and disparity features. The researchers also plan to separate the mixed acoustic signals to better classify different motorcycles traveling in a group. The sensors will be able to work as stand-alone detectors or be integrated into existing ITS installations. Phase II also will gauge the level of detections in inclement weather.



The IR-visible light stereo camera captured these images of the front wheels of a motorcycle (top) and car (bottom). A motorcycle's front wheel, as photographed, is typically surrounded mostly by pavement, while a car's front wheel is surrounded mostly by sheet metal. These differences help the researchers differentiate motorcycles from cars.

Migma Systems, Inc.

Correct and Incorrect Vehicle Classifications

Classified as ▶ / Dataset ▼	Bicycle	Heavy Motorcycle	Light Motorcycle	Car	Moped	Scooter
Bicycle	8	0	0	1	0	0
Heavy Motorcycle	0	11	0	3	0	0
Light Motorcycle	0	0	3	1	0	0
Car	0	1	1	10	0	0
Moped	0	0	0	0	3	0
Scooter	0	0	1	0	0	2

Source: Migma Systems, Inc.

David R.P. Gibson, P.E., is a highway research engineer on the Enabling Technologies Team in FHWA's Office of Operations Research and Development. He has a master's degree in transportation from Virginia Tech. His expertise includes traffic sensor technology, traffic control hardware, modeling, and traffic engineering education.

Bo Ling earned his M.S. in applied mathematics in 1990 and Ph.D. in electrical engineering in 1993 from Michigan State University. He has served as principal investigator for numerous government-funded research projects. Dr. Ling is cofounder, president, and chief executive officer of Migma Systems, Inc. He became a senior member of IEEE in 1998 and is a part-time faculty member of the Department of Electrical and Computer Engineering at Northeastern University in Boston.

Spandan Tiwari received his M.S. in 2003 and Ph.D. in 2007 in electrical engineering from the Missouri University of Science and Technology. He has more than 7 years of experience in computer vision, pattern recognition, image processing, automatic target recognition, signal processing, machine learning, and intelligent processing. He joined Migma Systems in 2007. Dr. Tiwari is a member of IEEE and the International Society of Artificial Life.

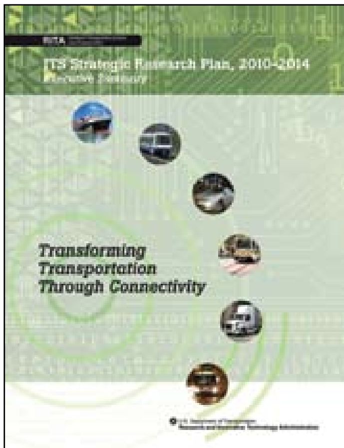
For more information, contact David Gibson at 202-493-3271 or david.gibson@dot.gov, or Bo Ling at 508-660-0328 or bling@migmasys.com.

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

ITS Strategic Plan Sets Stage for Next 5 Years



USDOT's Research and Innovative Technology Administration recently released a 5-year intelligent transportation systems (ITS) strategic research plan for 2010–2014. The plan explores the potentially transformative capabilities of wireless technology to make surface transportation safer, smarter, and greener, and ultimately enhance livability for Americans.

At the core of the research plan is a program called IntelliDrive℠, a multimodal initiative that uses wireless communications to provide connectivity between vehicles, between vehicles and roadway infrastructure, and among vehicles, infrastructure, and wireless consumer devices. Researchers will examine how to deliver warnings to motorists to enhance overall safety and minimize driver distraction. The research plan also provides funding for technology transfer and training for ITS professionals.

To view the strategic plan, visit www.its.dot.gov/strat_plan.

FHWA Revises Rules to Make Highways Safer

In December 2009, USDOT released a comprehensive update to the *Manual on Uniform Traffic Control Devices* (MUTCD). Administered by the Federal Highway Administration (FHWA) since 1971, the MUTCD is the national standard for all traffic control devices, including signs, pavement markings, signals, and any other devices used to regulate, warn, or guide traffic. Ensuring uniformity of traffic control devices across the Nation—from their messages and placement to their sizes, shapes, and colors—helps to reduce crashes and traffic congestion. This is the first comprehensive update to the manual since 2003.

The following are among the new provisions in the 2009 edition:

- Replacing highway signs with brighter, larger, and more legible ones that are easier to understand at freeway speeds. States should begin using the newer signs as existing ones wear out.
- Changing the formula used to calculate crosswalk times to give walkers more time.
- Identifying electronic toll collection requirements on signs using the color purple—the first time purple has been sanctioned for use on highway signs.

Most changes are a result of extensive research; however, several changes stem from recommendations from the National Transportation Safety Board. States must adopt the 2009 MUTCD as their legal State standard for traffic control devices within 2 years.

For more information, visit http://mutcd.fhwa.dot.gov.

Technical News

New Resources Cover FWD Calibration Procedures

Falling weight deflectometers (FWDs), used to conduct structural testing for pavement, require careful calibration to ensure their effectiveness in the field. In 2009, the American Association of State Highway and Transportation Officials (AASHTO) published new guidelines for calibrating FWDs: AASHTO R 32-09, Standard Recommended Practice for Calibrating the Load Cell and Deflection Sensors for a Falling Weight Deflectometer. The new guidelines are the result of years of enhancements made to the calibration procedures by FHWA's Long Term Pavement Performance (LTPP) program in collaboration with State highway agencies. Researchers now can use the new guidelines at all FWD calibration centers across the country for projects supported by the

A new FHWA report and video explain how to calibrate FWDs, such as the one shown here.

LTPP program and other pavement-related research. To help transportation professionals learn the new FWD calibration procedure, FHWA recently produced a report and video on the topic.

The report, *FWD Calibration Center and Operational Improvements: Redevelopment of the Calibration Protocol and Equipment* (FHWA-HRT-07-040), provides information on how the new FWD calibration procedure was developed and how to calibrate an FWD according to the new procedure. The report compares the old and new procedures and explains the updates and improvements, and is available at www.pooledfund.org by searching under study number TPF-5(039).

The related video, "Calibrating the Falling Weight Deflectometer," demonstrates the new procedure, explains the preparations needed to perform a successful calibration, and describes how calibration improves the quality of back-calculated data and the impact on overlay design. The video is available at www.fhwa.dot.gov/pavement/ltpp/index.cfm.

For more information, contact Jane Jiang, FHWA highway research engineer, at 202–493–3149 or jane.jiang@dot.gov.


WSDOT

Here, WSDOT installed a guardrail that measures 31 inches (79 centimeters) high.

Improved Software Helps Build Better Concrete Pavements

FHWA recently released an updated version of its High Performance Concrete Paving (HIPERPAV®) software called HIPERPAV III. First developed in 1996 and then updated with the release of HIPERPAV II in 2005, the free software is a simulation tool for determining the early age (that is, during the first 72 hours following placement) behavior of portland cement concrete pavement. Available for download at www.hiperpav.com, the software was designed for use by State and local highway agencies, contractors, suppliers, researchers, and academia.

Improvements in HIPERPAV III make the software even more robust and user friendly, including enhanced temperature predictions for the heat of hydration. With the new moisture modeling features, users can more realistically compare the effect of various curing strategies and environmental conditions, resulting in improved predictions of critical stresses, material strengths, and drying shrinkage. Other new features include a batch mode that enables users to analyze several strategies at once, a quick-compare tool that can be used to view the differences between up to four strategies simultaneously, and a sensitivity comparisons tool that helps users discern differences in the effects of environmental, design, materials, and construction variables on strength gain, stress development, and cracking risk.

For more information or to obtain a copy on CD, contact Fred Faridazar, highway research engineer with FHWA's Office of Infrastructure Research and Development, at 202–493–3076 or fred.faridazar@dot.gov.

Washington State Studies Guardrail Height

The Washington State Department of Transportation (WSDOT) recently evaluated whether a clear correlation exists between guardrail height and penetration of the guardrail by vehicles. Specifically, WSDOT reviewed datasets available for Washington State and explored whether guardrails with heights of 27 inches (68.6 centimeters) and lower experience more through, over, or under penetrations than those measuring 28 inches (71.1 centimeters) and higher.

WSDOT researchers used a total of 10.25 years of collision data from 1999 through the first quarter of 2009. The data included 1,806 collisions recorded by the WSDOT Transportation Data Office. Overall, the researchers found no clear trends or indicators that the studied guardrail heights reduce or increase the number of collisions. WSDOT explains its methodology and detailed findings in the report *Through, Over, or Under Guardrail Penetration by Guardrail Height* (WA-RD 742.1).

For more information or to download the report, visit www.wsdot.wa.gov/research/reports/fullreports/742.1.pdf.

WSDOT

Public Information and Information Exchange

Now Available: Screening Tool for Senior Drivers

The AAA Foundation for Traffic Safety has developed a free online screening tool designed to measure the physical and mental abilities shown to be the strongest predictors of crash risk among older drivers. Roadwise Review™ Online: A Tool to Help Seniors Drive Safely Longer provides feedback to users about their ability to continue driving safely.

Developed by AAA and transportation safety researchers, the Roadwise Review tool gives seniors and their family members an opportunity to assess an older driver's eight necessary functional abilities: leg strength and

AAA Foundation for Traffic Safety, www.seniordrivers.org

Shown here is a screen capture from Roadwise Review, an online self-assessment tool that helps older drivers assess abilities deemed critical to safe driving.

general mobility, head/neck flexibility, high-contrast visual acuity, low-contrast visual acuity, working memory, visualization of missing information, visual search, and visual information processing speed. The tool leads the user through a series of screening exercises, such as a timed walking evaluation that measures general mobility. The software then uses an integrated data system that provides users with confidential feedback about screening results.

Roadwise Review is based on research sponsored by the National Highway Traffic Safety Administration and the National Institute on Aging that indicates individuals who exceed measured levels of decline in key safe driving predictors are 2–5 times more likely to be involved in a motor vehicle crash.

To access the screening tool, visit www.seniordrivers .org or www.aaaseniors.com.

AAA Foundation for Traffic Safety

Transportation TV Covers Industry Highlights

In 2009, AASHTO launched "Transportation TV" as part of a national marketing campaign to generate dialogue on the importance of preserving and modernizing the Nation's transportation system. Transportation TV provides online video content about the industry.

As of early 2010, the site had logged more than 24,000 page visits to view nearly 100 videos posted on the site. The Web site features weekly newscasts on current transportation issues and special reports on topics such as the Car Allowance Rebate System (also known as "Cash for Clunkers") and the 2009 National Roadway Safety Awards.

Available exclusively at www.transportationtv.org, Transportation TV offers six distinct channels: Transportation TV News, The Briefing Room, View from the Hill, View from the Administration, Transportation TV State to State, and Transportation 101. Together, these channels offer State and national news, insights, and analysis from transportation decisionmakers, members of Congress, and State DOTs.

For more information, visit www.transportationtv.org.

AASHTO

FHWA, Oklahoma State University Study Motorcycle Crashes

Despite years of steady improvement in highway safety and historically low numbers of roadway fatalities, motorcycle riders remain one of the highest risk groups on U.S. roadways. Nearly 5,300 motorcycle riders died in roadway crashes in 2008, accounting for 14 percent of all traffic fatalities, and 96,000 were injured. As one approach to improving safety, researchers at FHWA and the Oklahoma State University are conducting a new study to improve the highway community's understanding of the causes of motorcycle crashes.

Required by a provision in the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users, the motorcycle crash causation study will be the Federal Government's first major indepth analysis of motorcycle safety in nearly three decades. Researchers will evaluate data from hundreds of motorcycle crashes to identify common factors, such as road configurations, environmental conditions, and rider experience. The study will look at how these factors might be affected by countermeasures that, if implemented, could prevent or reduce the severity of motorcycle crashes.

Missouri Increases Number of Rest Areas and Truck Parking Spaces

The Missouri Department of Transportation (MoDOT) continues to add to the State's inventory of rest areas and parking facilities, even while other States close theirs. In addition, the number of parking spaces for trucks increased from 587 to 853 between 2002 and 2009, a 45 percent jump. MoDOT cites safety for commercial motor vehicle drivers and the public as motivation for increasing the number of rest areas and availability of truck parking.

According to one MoDOT official, "MoDOT understands that for professional drivers to perform at their best, good rest is important. Truck drivers work long days and deserve places along our roadways to park, relax, and feel safe."

Two welcome centers and more converted truck parking areas will create an additional 146 spaces in 2010. According to MoDOT, the increase in parking spaces is vital for truck drivers who, under Federal law, must leave the road and rest once they record a 10- to 11-hour workday.

MoDOT

EPA Updates Mobile Source Emissions Model

The U.S. Environmental Protection Agency (EPA) recently released the final version of its Motor Vehicle Emission Simulator (MOVES) model. MOVES2010 is a tool to help estimate air pollution from cars, trucks, and other mobile sources. The model also can calculate the emissions reduction benefits from a range of mobile source control strategies, such as inspection and maintenance programs and local fuel standards.

MOVES2010 replaces EPA's previous model for mobile source emissions, MOBILE6.2. According to

EPA, MOVES2010 is a significant improvement over its predecessor for estimating greenhouse gas emissions from the transportation sector. EPA will publish a *Federal Register* notice of availability in the near future to approve MOVES2010 for meeting official State implementation plans and transportation conformity requirements. EPA intends to provide a 2-year grace period for using MOVES2010 for purposes of transportation conformity.

FHWA and EPA are planning a series of Web conferences and hands-on training sessions focused on MOVES2010. To be notified about upcoming training, sign up for the EPA-MOBILENEWS listserv at www.epa.gov/otaq/models/mobilelist.htm.

For more information, visit www.epa.gov/otaq/models/moves/index.htm.

Measuring Progress in Linking Planning and the Environment

FHWA's Planning and Environment Linkages program developed a resource to assist transportation agencies in creating programs to evaluate success in integrating transportation planning and environmental analysis. The document, *A Guide to Measuring Progress in Linking Transportation Planning and Environmental Analysis*, helps agencies address complex social, economic, and environmental challenges early in the planning process and minimize impacts on natural and cultural resources.

An integrated approach to transportation planning recognizes the ongoing need for State and local governments to link their transportation planning with the planning processes of natural and cultural resource agencies. This approach enables planners and the public to consider the costs and benefits of decisions in a comprehensive manner.

Traditionally, transportation agencies measured performance based only on system conditions or operations, such as accessibility, mobility, safety, and operational efficiency. To date, many agencies have underutilized measures to track successes on other goals, such as integrated transportation planning and environmental streamlining and stewardship.

For more information or to download the guide, visit http://environment.fhwa.dot.gov/integ/meas_progress.asp.

Now Available: Safety Materials in Spanish

The National Highway Traffic Safety Administration (NHTSA) now offers Spanish language pedestrian and bicycling safety materials—downloadable resources and classroom curriculum—to teach Hispanic adults safe behaviors to prevent traffic-related fatalities and injuries when walking and bicycling. Hispanic immigrants often rely on walking and bicycling as their primary means of transportation, but some are unfamiliar with U.S. traffic signs, signals, and practices, putting them at higher risk of being involved in crashes.

For adults in English as a Second Language (ESL) classes, NHTSA developed a pedestrian and bicycling safety curriculum for teachers. Designed with the understanding that ESL teachers use real-life applications to teach adults, this curriculum, in English, includes two modules on the basic principles of pedestrian and bicycle safety. Each module includes a teacher's guide and student workbook for an intermediate-level student.

NHTSA

NHTSA offers pedestrian safety materials in Spanish, such as this poster that advises pedestrians to be alert and follow the signals.

NHTSA's downloadable materials include posters, brochures, and radio public service announcements. NHTSA intends for local, State, and national traffic safety advocates to use the materials to help educate Hispanic immigrants on pedestrian and bicycle safety in the United States.

For more information and to download the materials, visit www.nhtsa.gov/links/ped_bike_sp.html. For printed copies, send a fax to 301-386-2194 with your name, address, phone number, and preferred number of copies (up to 25 maximum for each). For additional information, contact paula.bawer@dot.gov.

NHTSA

Internet Watch

by Alicia Sindlinger

Freight Web Site Receives Makeover

Freight transportation is critical to the Nation's economy because it links businesses with suppliers and markets throughout the country and the world. According to the Federal Highway Administration's (FHWA) Freight Analysis Framework, which estimates commodity flows and freight transportation activity, the U.S. transportation system moved an average of 53 million tons of freight worth $36 billion per day in 2002. To help transportation professionals manage moving such a large quantity of freight, FHWA recently improved its Freight Management and Operations Web site at http://ops.fhwa.dot.gov/freight and the portal to freight-related Web pages throughout the U.S. Department of Transportation at www.freight.dot.gov.

The improved Freight Management and Operations Web site contains updated content, new resources, and most important, an entirely new, easier-to-use navigation structure. Prior to the update in fall 2009, the overall organization of the site was based on the organizational structure of FHWA's Office of Freight Management and Operations. Now, a topic-based navigation structure makes it easier for *all* freight transportation professionals to find the information they need.

"We received feedback from users that finding information on our site was not as straightforward as they would like," says Tony Furst, director of FHWA's Office of Freight Management and Operations. "We made changes based on what made the most sense to users and the site is now organized by topic so they can more easily find and access information."

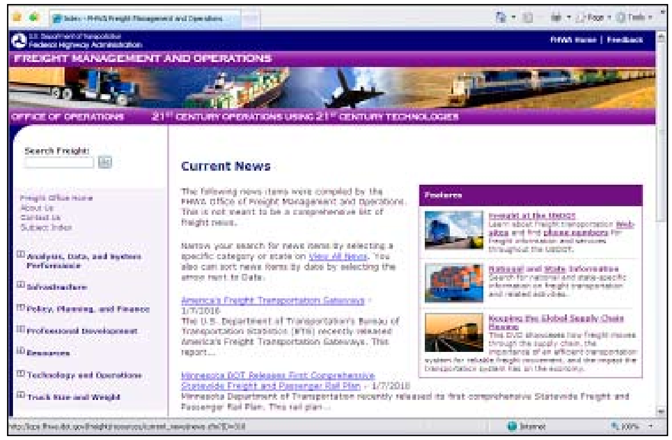
A Topic-Based Solution

When the Office of Freight Management and Operations decided the Web site needed a complete overhaul, the project team thoroughly researched and tested its options. During the redesign, FHWA conducted two rounds of user testing and utilized the feedback to make adjustments.

In the first round of testing, staff from the Office of Freight Management and Operations met individually with freight professionals from FHWA, State departments of transportation (DOTs), and metropolitan planning organizations (MPOs). Through these meetings, the FHWA staff quickly realized that although the site hosted a lot of information, users had difficulty finding it. In the second round of testing, FHWA collected user feedback on a preliminary set of topic-based categories and subcategories for the site content.

"We engaged our site users and they provided us with feedback on everything from how to best organize the information to what content to include on the pages," Furst says.

With a solid set of categories and subcategories, FHWA then fine-tuned them through several internal meetings. As a result, the site now is organized into seven freight-related categories: analysis, data, and system performance; infrastructure; policy, planning, and finance; professional development; resources; technology and operations; and truck size and weight. Each category is represented on the site's left-hand navigation bar and, when clicked, displays subcategories within that topic. For example, when a user clicks the link "Analysis, Data, and System Performance," a dropdown menu of 11 subcategories appears, including links to data sources, information by State, and national statistics and maps. The subcategories link to the respective areas on the site, making it easier for the user to go directly to the desired information from any page within the site.



New Resources and Other Improvements

Upon visiting the home page, users will notice additional changes. Although the home page still displays current freight-related news, it also prominently displays a "Features" section that alerts visitors to new or important resources on the site. From the home page, users also can access a searchable "News Archive" with all previously posted freight-related news items.

Another new section, called "Freight Solutions," lists real-world examples from State DOTs, MPOs, and other agencies. The examples are divided into 10 topical areas: economic development, environmental guidance, freight plans, freight studies, funding and financing, intermodal connectors, performance measures, programming and selection criteria, public involvement and outreach, and public and private sector cooperation.

In addition, site visitors now can find freight-related publications and resources more easily on the reorganized "Publications" page, which includes FHWA publications, a video, and a virtual library of freight documents "that should be on every freight practitioner's bookshelf," the site says.

"Overall, the new freight site is much more streamlined," says Chris Smith, intermodal policy and program manager with the American Association of State Highway and Transportation Officials. "The topic-based organization makes it much easier to find what I need because everything on a specific topic is grouped together. It's a valuable resource for the freight transportation industry."

Alicia Sindlinger is a contributing editor for PUBLIC ROADS.

Training Update

NATIONAL HIGHWAY INSTITUTE

by Amanda Moss and Diana Duvall

Bridge Inspection Training Hones Critical Techniques

Inspection and maintenance of the Nation's bridges are essential to the safety and mobility of the highway system. Proper bridge inspection requires not only an eye for intricate detail, but also knowledge of common problems. To ensure that all bridge inspectors are armed with the proper techniques, the Federal Highway Administration (FHWA) developed the National Bridge Inspection Standards (NBIS).

According to the NBIS, each inspection must be conducted by at least one team leader. To be certified as a team leader, an inspector must complete an FHWA-approved comprehensive training program. The National Highway Institute (NHI) course Safety Inspection of In-Service Bridges (FHWA-NHI-130055) is one training program that potential team leaders can use to fulfill this requirement.

"We developed this NHI course to meet the requirements of law, raise the national level of understanding, and provide more uniform bridge safety inspections and ratings," says Gary Moss, a senior structural engineer at FHWA who helped develop the course.

About the Course

The 10-day NHI course teaches Federal, State, and local highway agency employees and contractors proper bridge inspection techniques. Participants learn to evaluate a variety of bridge types and determine the critical areas for inspection. They are taught the common points of deterioration, including underwater portions, and learn to evaluate the deterioration.

As part of the course, participants visit and inspect at least two bridges. This hands-on portion is critical, as it allows participants to apply the knowledge they gained in the classroom. Participants practice assigning evaluations according to coding guidance developed by FHWA, the American Association of State Highway and Transportation Officials, or State highway agencies. The course also teaches participants to recognize when it is necessary to recommend further inspection or even bridge closure. Because of the level of detail and the importance of the material covered, the course attracts engineers and inspectors of all levels, not just those looking to become team leaders.

"It's amazing—many of the participants will tell me they never knew that bridges have so many defects," says Tom Ryan, project manager at a professional engineering company and a course instructor/developer. "This course provides participants with many 'aha!' moments. It opens their eyes to pertinent details and defects they may have overlooked before. You can almost see the light bulb… when they grasp a particular concept that reinforces the inspection techniques we present in class."

Tom Ryan, Michael Baker Jr., Inc.

A researcher at TFHRC demonstrates ground penetrating radar during a facility tour for participants in the NHI course Safety Inspection of In-Service Bridges.

Safety Inspection of In-Service Bridges is one of NHI's most popular offerings and has been presented to thousands of participants. NHI is updating the course curriculum to include the latest inspection techniques, such as nondestructive evaluation.

TFHRC Labs Enhance Training

Participants in the August 3–14, 2009, session of the course participated in a unique, hands-on learning opportunity—a tour of the laboratories at FHWA's Turner-Fairbank Highway Research Center (TFHRC) in McLean, VA. For a half day, course participants visited various labs, including the Nondestructive Evaluation (NDE) Center.

The NDE Center develops and tests nondestructive evaluation technologies that assess the condition of in-service highway bridges. Researchers evaluate existing technologies and develop new tools to improve the state of the practice for bridge (and pavement) inspection. The center is dedicated to advancing NDE technologies for highway bridges and works closely with State departments of transportation to identify and solve inspection challenges.

Visiting the TFHRC labs taught participants a variety of special skills, such as ways to determine the condition of steel coatings and how to determine whether concrete is deteriorating simply by hitting it with a hammer and listening to the noise it makes.

"NHI truly enjoys collaborating with TFHRC," says Louisa Ward, training program manager at NHI. "In fact, we also developed a 1-day seminar together with the TFHRC NDE Center, Bridge Inspection Non-Destructive Evaluation Showcase [(BINS) (FHWA-NHI-130099)]," she adds. BINS is a demonstration-based seminar that exposes bridge inspectors to more efficient and more effective inspection tools and techniques.

NHI continues to work with many partners, including TFHRC, to develop and enhance training for bridge inspectors. For more information or to register for courses, visit www.nhi.fhwa.dot.gov.

Amanda Moss is a contractor for NHI.

Diana Duvall is a contractor for FHWA.

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 Turner-Fairbank Highway Research Center's Web site at www.tfhrc.gov, the National Transportation Library's Web site at http://ntl.bts.gov, or the OneDOT information network at http://dotlibrary.dot.gov.

Design and Evaluation of Jointed Plain Concrete Pavement With Fiber Reinforced Polymer Dowels Publication No. FHWA-HRT-06-106

Highway departments commonly use steel dowel bars as load transferring devices in concrete pavement, but these bars can cause corrosion and loosening of the connection between the dowel and the pavement, among other issues. This study evaluates fiber reinforced polymer (FRP) dowel bars as an alternative to steel in jointed plain concrete pavement (JPCP) under the American Association of State Highway and Transportation Officials' (AASHTO) HS-25 static and fatigue wheel loads and compares their response with JPCP using steel dowels.

The report, *Design and Evaluation of Jointed Plain Concrete Pavement with Fiber Reinforced Polymer Dowels*, details laboratory and field evaluations of JPCP with FRP and steel dowels, analytical modeling of dowel response, and field rehabilitation of JPCP using FRP dowels. Researchers collected field data through an automatic data acquisition system, which captured strain and joint deflections used for assessing joint load transfer efficiency (LTE), joint relative deflection, and pavement performance. The report provides theoretical calculations through different examples for JPCP with FRP and steel dowels by varying dowel diameters, spacing, dowel material properties, joint width, and base material properties.

In conclusion, the study found that JPCP with FRP dowels provides ample LTE up to and beyond 90 percent, which exceeds criteria set by AASHTO and the American Concrete Pavement Association. JPCP with FRP dowels also has proven to hold up in the long term, providing sufficient LTE after 5 million cycles of fatigue tests under HS-25 loading.

Printed copies of the report are available from the PDC.

Time-Frequency Analysis: Mathematical Analysis of The Empirical Mode Decomposition (Fact Sheet) Publication No. FHWA-HRT-10-029

Mathematical Analysis of the Empirical Mode Decomposition is a 3-year study sponsored by the FHWA Exploratory Advanced Research Program and awarded to Princeton University to develop a mathematical foundation for empirical mode decomposition (EMD). Invented more than 10 years ago, EMD provides a nonlinear time-frequency analysis with the ability to evaluate nonstationary signals. Transportation-related applications of EMD could include detecting early signs of fatigue in vibrating metal components and locating cracks or loss of rigidity in reinforced bridge columns. This fact sheet discusses EMD's origins, mathematical challenges, and potential benefits to the transportation industry.

Over the past decade, EMD has been used in a wide range of fields, including biology, geophysics, ocean research, radar, and medicine. Although researchers have fine-tuned the algorithm and extended it to a variety of different applications, little is known about EMD's mathematical properties. This research, therefore, aims to explore the theoretical foundations of this empirical tool and develop new software tailored to specific applications.

The fact sheet is available at www.fhwa.dot.gov/advancedresearch/pubs/10029/index.cfm. Printed copies are available from the PDC.

Double Crossover Diamond Interchange (TechBrief)
Publication No. FHWA-HRT-09-054

Today's traffic volumes and travel demands often lead to safety problems that are too complex for conventional intersection designs to handle properly. Consequently, FHWA released *Alternative Intersections/Interchanges: Information Report (AIIR)* (FHWA-HRT-09-060), which highlights four alternative intersection designs and two interchange designs that offer substantial advantages over conventional at-grade intersections and grade-separated diamond interchanges. This TechBrief summarizes information on one of the alternative interchange designs, the double crossover diamond (DCD) interchange.

The DCD interchange, also known as a diverging diamond interchange, is a new interchange design that is similar to the design of a conventional diamond interchange. The main difference is the way left and through movements navigate between the cross street intersections with ramps. The DCD design accommodates left-turning movements onto arterials and limited-access highways while eliminating the need for a left-turn signal phase at signalized ramp terminal intersections. On the cross street, the traffic moves to the left side of the roadway between the signalized ramp intersections. Drivers on the cross street who want to turn left onto the ramps can continue do so without conflicting with opposing through traffic and without stopping. The DCD interchange offers benefits over conventional interchange designs, including lower costs, fewer conflict points, increased throughputs, reduced delays, decreased speeds, and reduced environmental impacts.

The document is available at www.fhwa.dot.gov/publications/research/safety/09054/index.cfm. Printed copies are available from the PDC.

Displaced Left-Turn Intersection (TechBrief)
Publication No. FHWA-HRT-09-055

This TechBrief summarizes information on the displaced left-turn (DLT) intersection, one of the alternative intersection designs featured in the FHWA report *Alternative Intersections/Interchanges: Information Report (AIIR)* (FHWA-HRT-09-060).


TECHBRIEF
Displaced Left-Turn Intersection

The DLT intersection, also known as the continuous flow intersection or the crossover displaced left-turn intersection, moves left-turn movements from the main intersection to an upstream signalized location. Traffic that would turn left at the main intersection in a conventional design now must cross opposing through lanes at a signal-controlled intersection several hundred feet upstream and then travel on a new roadway parallel to the opposing lanes. From this new roadway, the left-turning traffic executes the left turn onto the perpendicular roadway simultaneously with the through traffic at the main intersection. Traffic signals at the left-turn crossovers and the main intersection are operated in a coordinated mode so vehicles do not stop multiple times in the intersection area. The primary benefit of the DLT intersection is the reduction in the number of traffic signal phases and conflict points with consequent improvements in operations and safety.

The document is available at www.fhwa.dot.gov/publications/research/safety/09055/index.cfm. Printed copies are available from the PDC.

Displaced Left-Turn Interchange (TechBrief)
Publication No. FHWA-HRT-09-056

This TechBrief summarizes information on the displaced left-turn (DLT) interchange, the other alternative interchange design featured in the FHWA report *Alternative Intersections/Interchanges: Information Report (AIIR)* (FHWA-HRT-09-060).

The DLT interchange design has similarities to both the at-grade DLT intersection and the double crossover diamond interchange. The main feature of the DLT interchange is that left-turning traffic crosses opposing through lanes several hundred feet upstream of the main intersection and then proceeds on a new roadway situated between the opposing through lanes and a roadway that carries right-turning traffic from the ramp. From this new roadway, the left-turning traffic completes its maneuver onto the on-ramp. The DLT interchange offers benefits over a conventional diamond interchange with its efficient and simplified two-phase operation that typically results in increased capacity, reduced delays, and separated conflict points.

The document is available at www.fhwa.dot.gov/publications/research/safety/09056/index.cfm. Printed copies are available from the PDC.

Median U-Turn Intersection (TechBrief)
Publication No. FHWA-HRT-09-057

This TechBrief summarizes information on the median U-turn (MUT) intersection, another one of the alternative intersection designs featured in the FHWA report *Alternative Intersections/Interchanges: Information Report (AIIR)* (FHWA-HRT-09-060).

Roadway designers can implement MUT intersections as either full MUTs—where direct left turns from both the major and minor approaches are eliminated from the main intersection—or as partial MUTs—where direct left turns from only the major approaches are eliminated. On the major road, drivers who want to turn left must travel straight through the at-grade main intersection, make a U-turn at the median opening downstream of the intersection, and then turn right onto the cross street. On the minor street, drivers who want to turn left onto the major road must turn right at the main intersection, execute a U-turn at a downstream median opening, and proceed straight through the main intersection. The benefits of the MUT intersection include increased capacity and safety.

The document is available at www.fhwa.dot.gov/publications/research/safety/09057/index.cfm. Printed copies are available from the PDC.

Quadrant Roadway Intersection (TechBrief)
Publication No. FHWA-HRT-09-058

This TechBrief summarizes information on the quadrant roadway (QR) intersection, another one of the alternative intersection designs featured in the FHWA report *Alternative Intersections/Interchanges: Information Report (AIIR)* (FHWA-HRT-09-060).

A QR intersection works by rerouting all four left-turn movements at a four-legged intersection onto a road that connects the two intersecting roads. The location of the connector road depends on traffic flow and availability of right-of-way. All four of the left-turning movements are rerouted over the connector road. This design prohibits all left turns at the main intersection and therefore allows a simple two-phase signal to process the remaining through and right-turn movements. The QR intersection increases operational efficiency through a congested intersection by moving the left turns away from the main intersection.

The document is available at www.fhwa.dot.gov/publications/research/safety/09058/index.cfm. Printed copies are available from the PDC.

Restricted Crossing U-Turn Intersection (TechBrief)
Publication No. FHWA-HRT-09-059

This TechBrief summarizes information on the restricted crossing U-turn (RCUT) intersection, another one of the alternative intersection designs featured in the FHWA report *Alternative Intersections/Interchanges: Information Report (AIIR)* (FHWA-HRT-09-060).

The RCUT intersection, also referred to as the superstreet intersection or J-turn intersection, is characterized by the prohibition of left-turn and through movements from side street approaches. Instead, the RCUT intersection accommodates these movements by requiring drivers to turn right onto the main road and then make a U-turn maneuver at a one-way median opening 400–1,000 feet (122–305 meters) after the intersection. Drivers execute left turns from the main road approaches in a manner similar to left turns at conventional intersections. The benefit of the RCUT intersection is that it reroutes minor street left-turn and through movements to a median U-turn crossover, which provides major advantages such as reduced delay and congestion for through traffic on the major road and reduced opportunities for crashes compared to conventional designs.

The document is available at www.fhwa.dot.gov/publications/research/safety/09059/index.cfm. Printed copies are available from the PDC.

Conferences/Special Events Calendar

Date	Conference	Sponsors	Location	Contact
August 15–18, 2010	APWA International Public Works Congress and Exposition	American Public Works Association (APWA)	Boston, MA	Dana Priddy 816-595-5241 dpriddy@apwa.net www.apwa.net/congress
August 28–September 1, 2010	SASHTO 69th Annual Meeting	Southeastern Association of State Highway and Transportation and Highway Officials (SASHTO)	Little Rock, AR	Ralph Hall 877-727-4861 www.sashto.org/Contact.aspx www.sashto.org/sashto2010
September 9–12, 2010	Preserving the Historic Road	Federal Highway Administration (FHWA), National Park Service, Paul Daniel Marriott + Associates, U.S. Forest Service, and U.S. National Committee of the International Council on Monuments and Sites	Washington, DC	Gloria Scott 916-653-1029 gloria_scott@dot.ca.gov www.historicroads.org
September 15–17, 2010	International Conference on Sustainable Concrete Pavements: Practice, Challenges, and Directions	FHWA and National Concrete Pavement Technology Center	Sacramento, CA	Shiraz Tayabji 410-997-9028 stayabji@aol.com www.fhwa.dot.gov/pavement/concrete/2010acptpconf.cfm
September 22–24, 2010	34th IABSE Symposium	Organized by the Italian Group of the International Association for Bridge and Structural Engineering (IABSE)	Venice, Italy	Symposium Secretariat +39 041 2571301 or +39 041 614185 iabse2010@iuav.it www.iabse.org/venice2010
September 27–October 1, 2010	IENE International Conference on Ecology and Transportation	Infra Eco Network Europe (IENE)	Velence, Hungary	Anna Maria Wremp +46 18 67 13 94 info@iene.info www.iene.info
October 10–13, 2010	National Conference on Access Management	Mississippi Department of Transportation, Transportation Research Board's (TRB) Access Management Committee, and TRB Joint Intersection Subcommittee	Natchez, MS	Jeffrey Altman 601-359-7675 AMConference@mdot.state.ms.us www.accessmanagement.info/conference.html
October 28–November 2, 2010	AASHTO Annual Meeting	American Association of State Highway and Transportation Officials (AASHTO)	Biloxi, MS	Monica Russell mrussell@aashto.org www.transportation.org

International Conference on

Sustainable Concrete Pavements

Strategies from Raw Material Production to Long-Term Service

The conference will highlight current practices, challenges, and future directions. In addition to nearly 40 peer-reviewed papers, selected presentations, and practice-oriented forums, the conference will share studies from U.S. and international highway agencies and industry organizations. Topics:

- Optimized procedures for concrete mixture and pavement design
- Effective use of local and recycled materials
- Construction practices
- Preservation, rehabilitation, and recycling strategies
- Adoption and implementation of eco-efficiency and environmental life-cycle assessments
- Sustainable concrete pavements in the urban environment
- Next-generation materials and techniques

September 15–17, 2010
Sacramento, CA
Organized by the Federal Highway Administration and National Concrete Pavement Technology Center

U.S. Department of Transportation
Federal Highway Administration

For conference updates, visit
www.fhwa.dot.gov/pavement/concrete/2010acptpconf.cfm.

To register online, visit
http://registeruo.niu.edu/iebms/wbe/wbe_p1_main.aspx?oc=40&cc=WBE4010454.

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