JULY–AUGUST 2012
NUMBER 281

TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES

TR NEWS

Adapting to Climate Change

Building a Network of Solutions

- State, Regional, and Local Initiatives
- Learning from Severe Weather Events
- Solar, Green, and LED-Lit Highways
- The Ready Benefits of Ecodriving
- Scenario Planning for Priorities

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TR NEWS

NUMBER 281 JULY–AUGUST 2012

ADAPTING TO CLIMATE CHANGE: BUILDING A NETWORK OF SOLUTIONS

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COVER: Maxwell Bridge in Napa, California, after installation of LED streetlights. The California Department of Transportation is converting streetlights on state-maintained roads in one of many measures to conserve energy and reduce emissions. (Photo: Pacific Gas and Electric)

TR NEWS

features articles on innovative and timely research and development activities in all modes of transportation. Brief news items of interest to the transportation community are also included, along with profiles of transportation professionals, meeting announcements, summaries of new publications, and news of Transportation Research Board activities.

***TR News* is produced by the Transportation Research Board Publications Office**
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TR News (ISSN 0738-6826) is issued bimonthly by the Transportation Research Board, National Research Council, 500 Fifth Street, NW, Washington, DC 20001. Internet address: www.TRB.org.

Editorial Correspondence: By mail to the Publications Office, Transportation Research Board, 500 Fifth Street, NW, Washington, DC 20001, by telephone 202-334-2972, by fax 202-334-3495, or by e-mail jawan@nas.edu.

Subscriptions: North America: 1 year $55; single issue $10. Overseas: 1 year $80; single issue $14. Inquiries or communications concerning new subscriptions, subscription problems, or single-copy sales should be addressed to the Business Office at the address below, or telephone 202-334-3216, fax 202-334-2519. Periodicals postage paid at Washington, D.C.

Postmaster: Send changes of address to *TR News*, Transportation Research Board, 500 Fifth Street, NW, Washington, DC 20001.

ALSO IN THIS ISSUE:

COMING NEXT ISSUE

Highway safety tools and procedures are the focus of the September–October issue of TRB's magazine, including an overview of the *Highway Safety Manual* and its applications; a national strategy to prevent highway fatalities, Toward Zero Deaths; the expected safety benefits from the SHRP 2 naturalistic driving study; and an opinion piece on building and training the safety workforce. Additional articles cover strategic highway safety plans, research on fatigue and safety, building a safety culture, the Interactive Highway Design Model, safety analysis and assessment, safety data needs, and more.

PHOTO: VIRGINIA DOT

Response teams clear a truck accident on a Virginia Interstate.

INTRODUCTION

Implementing Climate Change Policies

State and Local Innovations to Mitigate and Adapt to Climate Change

ROBERT B. NOLAND AND CYNTHIA BURBANK

This theme issue of *TR News*, assembled at the initiative and guidance of the TRB Special Task Force on Climate Change and Energy, highlights a variety of innovative approaches that state and local transportation agencies are implementing to mitigate and to adapt to climate change. Meeting the challenges of climate change requires innovation and experimentation—applying the concept of state and local governments as "laboratories of invention." Aimed at reducing greenhouse gas (GHG) and other harmful emissions, mitigation strategies span an array of initiatives in the transportation sector.

◆ In one article, Ronald Killian explores the benefits of ecodriving, an approach that reduces fuel consumption and GHG emissions while promoting health and safety. Primarily a modification of driver behavior, ecodriving represents a unique and virtually no-cost mitigation opportunity that is being employed around the world.

◆ Washington State has reaped the benefits of its commute trip reduction program, in place since the early 1990s. The article by Keith Cotton, Kathy Johnston, Kathy Leotta, and Seth Stark of the Washington State Department of Transportation (DOT) showcases the coordinated efforts of state, local, and regional public agencies and private-sector employers to reduce GHG emissions and meet other transportation, economic, and societal goals.

◆ Brant Arthur's article on the launch of the Climate Initiatives Program by San Francisco's Metropolitan Transportation Commission explores a myriad of pilot projects, including efforts to promote ridesharing, the deployment of electric taxis, and bicycling, to reduce GHG emissions.

Other mitigation-related innovations discussed in this issue include Tennessee DOT's incentives for the development of alternative fuel stations; Washington State's efforts to create a series of electric-vehicle recharging stations along the Interstate 5 corridor; Vermont's programs to encourage electric vehicles and transit ridership; California's plan to convert its lighting to LEDs to save energy and money—and to reduce its carbon footprint; and Oregon's initiatives to install solar panels on available rights-of-way, to offset Oregon DOT's energy consumption.

Adapting to climate change is a major challenge. Many state agencies are making strides to prepare for the future:

◆ Michigan DOT is taking operational steps to adjust to climate change and has identified opportunities and issues that other states may find valuable. Michigan DOT's Gregory C. Johnson, Niles Annelin, and Kristin Schuster discuss the impacts of increasingly variable precipitation events and temperature extremes on transportation infrastructure.

◆ Benjamin L. Rasmussen, Lindsey Morse, and David Perlman of the John A. Volpe National Transportation Systems Center describe a pilot project in scenario planning for climate change. Funded by the Federal Highway Administration, the project developed a collaborative planning process to consider and address the consequences of climate change and to minimize the potential impacts.

◆ Gina Campoli of the Vermont Transportation Agency (VTrans) draws lessons from the recent major damage in the state from Hurricane Irene and its aftermath—large sections of the road network washed away, leaving many towns completely isolated. VTrans recognizes that the risk of future events is high and is working closely with the Vermont Agency of Natural Resources to avoid disruptions.

This theme issue offers highlights from a new TRB Transportation Research Circular, *Climate Change and Transportation: Summary of Key Information*, assembling important facts and significant issues related to climate change and transportation, with links to more extensive discussions. In addition, an overview of the Climate Change Resource Center website, created by the American Association of State Highway and Transportation Officials, cites several of the model and exemplary activities that are under way throughout the nation.

Noland is Professor and Director, Voorhees Transportation Center, E. J. Bloustein School of Planning and Public Policy, Rutgers University, New Brunswick, New Jersey, and Chair of the TRB Special Task Force on Climate Change and Energy. Burbank is Vice President, Parsons Brinckerhoff, Washington, D.C.

Note: The *TR News* editorial board expresses appreciation to the Special Task Force on Climate Change and Energy, to Robert B. Noland and Cynthia Burbank for their leadership and contributions in assembling this issue, and to Ann R. Purdue and Christine L. Gerencher, TRB Senior Program Officers, for their assistance as liaisons.

Climate Change and Transportation

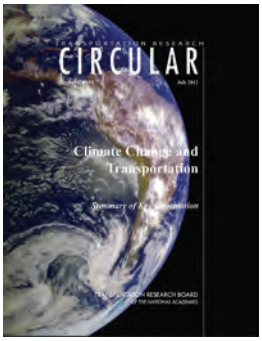
Summary of Key Information

CYNTHIA BURBANK

The author is Vice President, Parsons Brinckerhoff, Washington, D.C.

"A strong, credible body of scientific evidence shows that climate change is occurring, is caused largely by human activities, and poses significant risks for a broad range of human and natural systems."

—National Research Council of the National Academies, *Advancing the Science of Climate Change: America's Climate Choices*, 2010



The TRB Special Task Force on Climate Change and Energy has released its second circular, presenting key information for the transportation sector.

Climate change is a complex and daunting issue for transportation executives and professionals. Reports and articles on the topic have proliferated in the past five years, creating a cacophony of perspectives from continually evolving information. Nevertheless, transportation is a major contributor to the greenhouse gas (GHG) emissions associated with increased global temperatures, and transportation assets and operations worth billions of dollars are vulnerable to the impacts of climate change.

To help beleaguered executives and professionals in the transportation sector make sense of the findings, issues, and challenges, the TRB Special Task Force on Climate Change and Energy charged three members—Cynthia Burbank of Parsons Brinckerhoff; Daniel Sperling of the University of California, Davis; and Joyce A. Wenger of Wenger and Wenger Consulting—to prepare a summary highlighting the most important information for the transportation sector. The result is TRB Circular E-C164, *Climate Change and Transportation: Summary of Key Information*.

The document draws on major reports of the National Research Council, the Transportation Research Board, and other organizations. The key findings are as follows:

1. Carbon dioxide and other GHG emissions and levels have been rising.
2. Global climate systems are changing as a consequence of human activity.
3. Climate change presents many risks to humans, causing many scientific organizations to recommend significant reductions in GHG emissions by 2050.
4. Many companies in the private sector, along with states, local governments, and the U.S. military, are moving forward with plans to reduce GHG emissions and to adapt to a changing climate.
5. The transportation sector produces nearly 30 percent of U.S. GHG emissions.
6. Transportation GHG emissions may be reduced through a variety of strategies that address vehicles, fuels, vehicle miles traveled (VMT), operational efficiency, and construction, maintenance, and agency operations.
7. Pricing can be a powerful motivator to reduce GHG, through parking charges, pay-as-you-drive insurance, congestion pricing, carbon pricing, and fuel taxes.
8. Growth in travel could present a challenge in meeting GHG reduction targets. Even if the VMT per person remains at the current level, the total VMT for the United States may increase because of population growth.
9. In the longer term, the alignment of transportation and land use planning may support the achievement of emissions reduction goals. In particular, compact land use development may reduce VMT, thereby reducing GHG emissions.
10. Freight GHG is growing at a rate three times that of passenger GHG; controlling emissions from freight sources may require special efforts.
11. Adaptation to the effects of climate change will require significant efforts from the transportation sector. As climate change increases, the risks and impacts on transportation systems, facilities, and operations also will increase.

Although light-duty vehicles generate 60 percent of transportation-related GHGs, freight-related emissions are rising rapidly and require special attention.

PHOTO: OREGON DOT

The online circular provides citations for each of these findings, as well as supporting information and graphics. The document is posted at http://onlinepubs.trb.org/onlinepubs/circulars/ec164.pdf.

Photo: Michigan DOT

Climate Change Adaptation in Michigan

Preparations, Strategies, and Examples

GREGORY C. JOHNSON, NILES ANNELIN, AND KRISTIN SCHUSTER

Johnson is Chief Operations Officer; Annelin is Environmental Policy Specialist; and Schuster is Environmental Section Manager, Michigan Department of Transportation, Lansing.

(*Above*:) Michigan DOT is developing stronger contingency plans for responding to severe winter storms. Some studies indicate that warmer lakes and less ice cover may cause more lake-effect snows.

Climate has become increasingly variable throughout the world. Michigan and other states in the interior of the continent face different climate-related changes from those of the coastal states. In ocean coastal states, sea-level rise and hurricanes are concerns. In the Midwest, questions about climate involve the increased variability of precipitation and temperature extremes. These changes are likely to have negative and unexpected impacts on industry and infrastructure across the region.

Climate and Economy

Michigan is located in the heart of the Great Lakes, which influence the state's climate. No location in Michigan is more than 85 miles from one of the lakes, and with 3,000 miles of shoreline—second only to Alaska—water is important to the state's economy. Economic activity related to the Great Lakes accounts for 823,000 jobs, or approximately one-quarter of Michigan's payroll. The lakes contribute to the state's tourism, transportation, manufacturing, and agricultural industries.

Photo: Michigan DOT

Freighters passing through the Soo Locks between Lake Superior and Lake Huron in Michigan. The Great Lakes are vital to the state's economy—and a major influence on its climate.

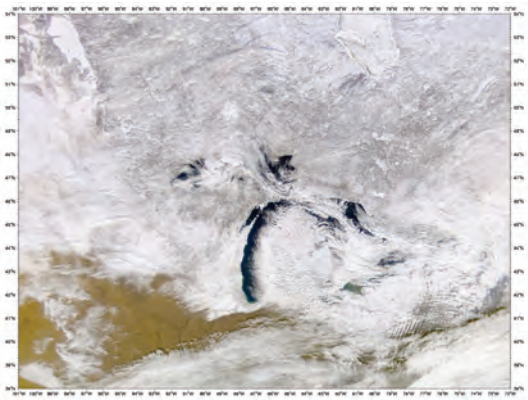


Photo: National Aeronautics and Space Administration

Satellite photo of lake effect over Lake Michigan: clear dry air moving eastward from Wisconsin picks up moisture in crossing the lake, forming dense clouds as it reaches the eastern shore. Downwind areas often experience heavy snowfalls.

Lake Conditions

The health of the lake ecology and the impacts of climate variability therefore are a concern to Michigan residents and businesses. As global temperature rises, the water level in the lakes could decrease, and the average water temperature could increase. Lower lake levels would have a negative effect on the state's waterborne freight industry, which handles approximately 95 million tons of bulk cargo annually. The Detroit–Wayne County Port Authority generates more than 10,000 direct and indirect jobs and $550 million in personal income for state residents.

This industry is linked to freight operations throughout the country; maintaining operation with shallower shipping lanes would require reductions in the weight of cargo loads, making shipping in the Great Lakes less effective and less efficient. The U.S. Army Corps of Engineers spends more than $80 million annually to dredge the harbors and waterways of the Great Lakes to maintain functional depths for ports and channels.

Changing lake conditions also could influence local weather patterns. The surface area of the lakes, as well as the considerable volume of water, moderates Michigan's weather. In the winter, the overnight low temperatures are often warmer than temperatures in Wisconsin, for example, because of the insulating effect of the water.

The lakes also generate heavy lake-effect snows in downwind areas. Some studies indicate that warmer lakes and less ice cover in the winter will increase evaporation and precipitation, potentially causing more snow in areas prone to lake-effect snow. In addition, warmer winter weather can cause more rapid deterioration of roadways through more frequent freezes and thaws of the soil.

Effects on Infrastructure

The Great Lakes are important to Michigan tourism and to the transportation network that supports the tourism industry. Changes that affect the lakes as a tourist attraction also would affect travel on Michigan roadways.

More frequent and intense rainfall events are expected, posing a significant threat to the transportation network. Road washouts raise safety concerns, and restoration is expensive for the responsible transportation agency and for the local economy. Closure of a typical freeway section during peak traffic periods can lose up to $200,000 in economic activity per hour. In addition, the potential for changes in the water table would require an analysis of the structural integrity of much of the state's infrastructure.

Michigan is predicted to experience higher summer temperatures lasting for longer periods. Prolonged high temperatures can increase the rate of deterioration of road and rail infrastructure and can cause rutting, buckling, and other pavement damage. On June 8, 2011, after several days of warm weather, the pavement buckled on a southbound section of I-69 in Calhoun County. Worker safety is another key concern during high temperatures, and a strategy to protect workers needs to be developed.

Case-by-Case Approach

Michigan DOT is managing its system to increase motorist safety, protect the infrastructure, address changing conditions, and communicate with system users about weather events. The department is tackling these issues case by case, taking into account site conditions, costs, and changes over time.

Michigan DOT is preparing for altered climate conditions throughout the state. For example, to minimize infrastructure damage from intense precipitation events, changes are needed in the design of drainage systems and bridges. Bridges over waterways may require larger hydraulic openings. Designing structures to avoid scour-critical features and installing pump stations with greater capacity for below-grade freeways and culvert systems are on the agenda for increased attention—including monitoring and maintenance—as are modifications to culvert sizes, locations, and numbers.

Photo: Michigan DOT

An intense heat spell caused pavement to buckle on a section of I-69 in southern Michigan. Higher summer temperatures and other effects of climate change pose new challenges for transportation infrastructure.

Fighting Slope Erosion

With funding from the American Recovery and Reinvestment Act (ARRA), Michigan DOT recently undertook a project to address ongoing slope erosion in sections of below-grade freeway on I-696, which crosses Oakland and Macomb Counties in suburban Detroit. Steep slopes and high volumes of traffic make this section of the road difficult to maintain. In addition to the slope instability problems, intense rain events have damaged the freeway, and heat and drought have caused loss of vegetation.

The department explored options beyond the selection of turf species to address the poor growing climate and the high maintenance costs from the difficult access for mowing. The department required a vegetation mix that would provide a variable-depth root structure to stabilize the slopes, would reduce runoff volume and velocity, and would trap and filter sediment and pollutants.

To accomplish these goals and still provide an attractive roadside, Michigan DOT selected 55,000 trees, plants, shrubs, and vines capable of withstanding heat, drought, and adverse roadside conditions. The ARRA-funded project has stabilized more than 9 miles of steep slopes and has improved water quality by incorporating green technologies and infrastructure. The department will monitor the pilot project to gain information for managing other steep slopes.

Construction Challenges

Michigan DOT also is considering how climate changes may affect construction practices. The strategy will address the need to protect motorists, workers, and the environment from hazards created in work zones by extreme weather events. For example, stronger specifications can require contractors to develop response plans to protect work under way from flooding.

Concrete Materials

The department also is concerned about the integrity of construction materials during days of prolonged high temperatures and will encourage conducting different phases of construction at night or during cooler periods. For example, Michigan DOT already uses night pours for bridge decks on steel beams because the daytime temperature of the steel beams is warmer than that of the adjacent concrete. Pouring at night, when the steel has cooled to the temperature of the concrete, allows for a better bridge deck.

Altering workday hours for paving operations also may be necessary, to stagger the peak hydration temperature of newly finished concrete in relation to the peak ambient temperature. This would help minimize the risk of early and excessive tensile stress cracking in the pavement.

PHOTO: MICHIGAN DOT

Michigan DOT conducts some construction activities—such as bridge concrete pours—at night, when temperatures are cooler.

The temperatures during various phases of pavement construction can affect the outcome of a project significantly. For example, high temperatures can cause slab curling during construction and in service, and the loss of moisture in the earliest stages can cause warping in concrete pavements. If fluctuations in daily temperatures increase, the response reaction in the pavement from the edge stresses of curling could accelerate decay, increase fatigue, and raise the likelihood of load-related cracking.

Other pavement issues related to higher temperatures include plastic shrinkage cracking and the instability of fresh concrete mixtures. These may jeopardize the effectiveness of the entrained air void system, making the pavement susceptible to early deterioration from freezing and thawing.

The department also may have to monitor the moisture content of the aggregates more closely during concrete production, as well as the temperature of the fresh concrete during placement, to ensure the levels are not detrimental to the quality of the finished product. Although more costly, innovative materials that have the potential to render concrete less sensitive to extreme fluctuations in temperatures should be investigated.

Asphalt Mixtures

Hot-mix asphalt pavement can be susceptible to rutting if temperatures after construction are high. During construction, high temperatures may cause delays in opening to traffic while the new pavement cools to a temperature ideal for achieving density. Agencies may try warm-mix asphalt to avoid the negative outcomes associated with asphalt paving during excessively warm periods. Warm-mix asphalt also reduces the energy input for construction—as well as the greenhouse gas emissions.

Roadside weather information systems increase the accuracy of traveler information systems and allow more efficient management during weather events.

Photo: Michigan DOT

System Operation

System operation is a critical activity of transportation departments; closing roads because of infrastructure damage, snow, or flooding hurts local, state, and national economies. In the winter of 2011, 40 miles of Canada's 402 Highway—a critical link between Toronto, Southwest Ontario, and Michigan—was closed for parts of three days because of a blizzard. The inability to reroute traffic cost days of delay and hurt industries that depend on just-in-time delivery.

The closure of Michigan roadways for one day would cost the state's economy approximately $250 million. Michigan DOT's strategy is to continue to improve real-time traveler information systems to inform motorists about risks and closures and to minimize economic loss.

To improve the effectiveness of traveler information systems, Michigan DOT is investing in roadside weather information systems (RWIS). Remote sensors and weather equipment have been installed in key locations throughout the Upper Peninsula and the Northern Lower Peninsula.

The RWIS sensors collect real-time information that enables the department to react appropriately and rapidly to changing road and weather conditions. The system ensures that the department can dispatch the correct maintenance vehicles to plow or to treat the roadways as needed, reducing waste and boosting efficiency.

With this information, Michigan DOT also can develop stronger contingency plans for responding to severe winter storms. During heavy snowfalls, for example, more frequent snow removal is needed along roadside barriers, which can create a hazard as snow accumulates. A major issue, however, is the inability to fund a maintenance budget that supports response to multiple snowstorms in accordance with public expectations.

Even routine maintenance activities, such as ditch and drainage structure cleanout, are difficult with stretched budgets. Nonetheless, completing these activities can reduce the likelihood of failure during an intense rainfall. Removal of vegetation, debris, and sediment that can build up and hinder function allows the department to maintain the effective, efficient conveyance of water through the right-of-way.

US-41 Relocation

Erosion produced by long-term fluctuations in lake levels threatens some coastal routes in Michigan. A section of US-41 along Lake Superior was located on an 80-ft sandstone cliff approximately 7 miles north of Baraga in Michigan's Upper Peninsula. Cliff recession had advanced to undercut the guardrail system and was threatening the stability of the highway. Contributing phenomena included the following:

- Rock weathering,
- Surface water from highway runoff eroding the top of the cliff,
- Groundwater flowing through the permeable sandstone above less permeable layers within the cliff rock, and
- Removal of weathered cliff materials, known as talus material, at the base of the cliff by longshore currents and wave action.

The necessary relocation of US-41 away from the lake's edge cost $3 million and placed several planned construction projects on hold.

Photo: Michigan DOT

Unable to address the various contributors to the cliff recession, Michigan DOT relocated the two-lane roadway in 2010, moving it more than 100 feet inland for 2 miles at a cost of approximately $3 million dollars. Because of the urgency of the project, the region had to adjust its planned construction program.

Michigan Route 25 on the east side of the Lower Peninsula, along Lake Huron, is facing similar threats from erosion caused by long-term lake level fluctuations and the consequent instability. A 40-mile stretch of Route 25, located along a 30- to 40-ft cliff, is being undercut. In the 1990s, Michigan DOT closed a park along the road because of the instability of the shoreline. Many measures have been taken at another roadside park to slow the rate of localized erosion.

The department is monitoring the conditions and is commissioning a study to explore how the rate of erosion affects the road and to identify measures that can slow the erosion and allow the roadway to remain in place. The long-term solution is unclear, and the funds necessary to address the stability of the roadway have yet to be determined.

Risk Assessment

Michigan DOT is continuing to explore the risks from extreme weather events for infrastructure and operations. This will require an analysis of a regional climate model and detailed information about the location and condition of state transportation assets. These asset management data are available for Michigan's major infrastructure but are incomplete for many of the roadside features that potentially are at risk. Elements such as culverts and stormwater management infrastructure, for example, will need to be inventoried to determine the points of greatest risk to the transportation system.

Michigan DOT is participating in a National Cooperative Highway Research Program project to examine risk assessments related to climate change.[1] The project is using Michigan Route M-222 as a case study in developing a risk assessment tool. M-222 passes along a slope above a sharp bend in the Kalamazoo River, which reaches high velocities during peak flow. Scouring of the toe of the slope has caused deterioration, intensified by river migration and possibly by dam operations. Aerial photographs revealed slope recession for many years; although identified in 2006, the problem was mistakenly believed to be caused by a culvert outlet eroding the slope.

[1] NCHRP Project 20-83 (05), Climate Change and the Highway System: Impacts and Adaptation Approaches, http://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=2631.

Photo: Michigan DOT

Erosion of cliffs near Baraga, Michigan, threatened US-41; Michigan DOT moved the road more than 100 feet inland.

In 2011, Michigan DOT determined that the slope had become unstable. Slope failure would damage the roadway and would affect travel around the City of Allegan; M-222 is a primary arterial road to the city from the east. Closure of the route would have had huge economic impacts for the city and would have impeded access to many residences. In 2009 the receding slope had damaged a home that the city later removed for safety reasons; as part of the project to restore the slope's stability, another home had to be razed.

The NCHRP project expects that data on the natural factors affecting the safety of the M-222 roadway can be integrated into the predictive model for the impacts of increased precipitation events on roadways.

Implementing Strategies

As these various examples from Michigan show, extreme weather events can have a significant impact on the transportation system of an entire state or region, causing the interruption of commerce locally—and sometimes nationally and internationally. Transportation agencies must investigate, plan, design, construct, and operate their systems recognizing the risks and applying proactive strategies to mitigate extreme impacts.

A robust knowledge of transportation assets and their vulnerability to extreme weather events is a key to implementing adaptation strategies that balance risk while recognizing budget realities. Discussions with state and regional climatologists have proved to be vital to Michigan DOT in planning for adaptation strategies.

Agencies also should create an organizationwide awareness of long-term climate trends for their jurisdictions and for the surrounding regions. This awareness is indispensable in developing adaptation strategies that sustain local and regional commerce during an extreme event.

State Activity on Climate Change and Energy

A Whirlwind Tour

CYNTHIA BURBANK

The author is Vice President, Parsons Brinckerhoff, Washington, D.C.

PHOTO: TOM SAUNDERS, VIRGINIA DOT

(Photo above:) *In-place pavement recycling on I-81 is part of Virginia DOT's Green Initiatives program. Other measures include LEED-certified rest areas and enhanced signal timing for efficient traffic flow.*

To find out what state departments of transportation (DOTs) are doing related to climate change and energy, take a quick tour of the interactive U.S. map posted on the website of the Transportation and Climate Change Resource Center of the American Association of State Highway and Transportation Officials (AASHTO).[1] Selecting a particular state on the map provides access to a variety of information and documents. Some examples follow:

- Colorado: "Assessment of Colorado DOT Rest Areas for Sustainability Improvements and Highway Corridors and Facilities for Alternative Energy Source Use";
- Massachusetts: "Interagency Transportation, Land Use, and Climate Change: Cape Cod Pilot Project";
- Michigan: "Climate Change Adaptation Issues in Highway Operations";
- Missouri: "Alternative Energy Resources for Missouri DOT";
- New York: "Climate Change and Energy Efficiency Initiative of the New York State DOT";
- Oregon: "ODOT Solar Highways";
- Pennsylvania: "Pennsylvania Climate Adaptation Report: Risks and Practical Recommendations";
- Tennessee: "Tennessee DOT Biofuel Green Corridor Network";
- Virginia: "Green Initiatives in Virginia Transportation"; and
- Washington: "WSDOT Sustainable Transportation Folio."

The map was launched in 2011, and is updated continually. Nonetheless, the map represents only a portion of the climate change and energy activities undertaken by state DOTs. Many climate adaptation, energy conservation, and greenhouse gas mitigation activities by state transportation agencies are not recorded in documents that are web-accessible. The AASHTO map is a work in progress that is evolving as new activities unfold and information becomes available. A "contact us" feature on the website allows states to provide additional material for the map; states also can send new information and updates via e-mail to climate-change@aashto.org.

In addition to the interactive map, the Transportation and Climate Change Resource Center website contains a wealth of information for state DOTs, metropolitan planning organizations (MPOs), and other transportation professionals interested in climate change and energy. The site is well populated with research reports, a calendar of meetings and events, and other topical information, covering key topics such as

- Federal actions and legislation;
- State, local, and MPO activities;
- GHG mitigation;
- Climate adaptation;
- Climate science;
- Energy;
- Communications and public opinion;
- Litigation;

[1] www.transportation.org/tools/state_by_state.

◆ Future research; and
◆ Web links.

The website home page displays recent activities at a glance under Current Topics and Events.[2] This feature is updated monthly with timely information relevant to DOTs.

Links are provided to the briefing materials from the climate change workshops at 17 state DOTs, along with links to 12 national climate change webinars sponsored by AASHTO and the Federal Highway Administration. The site also provides resources for members of AASHTO's Sustainable Transportation: Energy, Infrastructure, and Climate Solutions Technical Assistance Program, including the monthly *Climate Briefing* newsletter and a peer-to-peer forum.

AASHTO is working to keep the site practical and useful for state DOTs and others and solicits suggestions and material from users to ensure that the posted information maintains its freshness and value.

[2] http://climatechange.transportation.org.

The AASHTO Transportation and Climate Change Resource Center's website features an interactive map of the climate change–related measures employed by state DOTs.

Climate Change and the Highway System

Project Explores Impacts and Adaptation Approaches

The potential impacts of climate change on the highway system are many. Higher greenhouse gas concentrations are likely to increase the Earth's average temperature and to alter patterns of precipitation and the incidence and severity of storms. According to a 2007 report from the Intergovernmental Panel on Climate Change, the recent increases in coastal erosion and flooding are results of sea-level rise caused by climate change; global mean sea level is projected to rise by 0.09 to 0.88 meters between 1990 and 2100.

Research is needed to provide a sound foundation for practitioners to address the impacts of climate change on the highway system for the period 2030 to 2050. National Cooperative Highway Research Program (NCHRP) Project 20-83(05) is working to produce the first layer of information necessary for assessing potential impacts, identifying vulnerable infrastructure by region, and recommending institutional arrangements and technical tools that can address the future interactions of climate change and highway systems.

The objectives of the research are as follows:

◆ Synthesize the state of knowledge worldwide to ascertain the probable impacts of climate change on highway systems by U.S. region for the period 2030 to 2050;

◆ Recommend institutional arrangements, tools, approaches, and strategies that state departments of transportation can use in system planning, design, construction, operations, and maintenance to adapt infrastructure and operations; and

◆ Identify research and activities needed to close gaps in knowledge and to implement effective adaptive management.

The research team is led by Michael D. Meyer of PB Americas, Inc. Randell Iwasaki, Executive Director of the Contra Costa Transportation Authority, chairs the project advisory panel. Two interim reports are available for download:

◆ *Review of Key Climate Impacts to the Highway System and Current Adaptation Practices and Methodologies*[a] and

◆ *Synthesis of Information on Projections of Change in Regional Climates and Recommendation of Analysis Regions.*[b]

The final report for the project is expected in late 2012.

[a] http://onlinepubs.trb.org/onlinepubs/nchrp/docs/NCHRP20-83%2805%29_Task2-3SynthesisReport.pdf.
[b] http://onlinepubs.trb.org/onlinepubs/nchrp/docs/NCHRP20-83%2805%29_Task2-4TechnicalReport.pdf.

The Transportation and Climate Initiative

An Innovative State Collaborative

LOIS NEW

The Transportation and Climate Initiative (TCI) is a regional collaboration of transportation, energy, and environment officials in 11 Northeastern and Mid-Atlantic states and the District of Columbia. The initiative seeks to promote a clean energy economy and reduce greenhouse gas emissions in the transportation sector. Specifically, TCI focuses on the following tasks:

1. Developing clean vehicles and alternative fuels,
2. Creating sustainable communities,
3. Adopting innovative communication technologies, and
4. Advancing more efficient freight movement.

The initiative was launched in June 2010 by agency heads in energy, environment, and transportation and already is demonstrating the benefits of regional action.

In fall 2011, participating TCI jurisdictions formed the Northeast Electric Vehicle Network and were awarded a nearly $1 million planning grant from the U.S. Department of Energy to prepare the region for the mass market rollout of electric vehicles. Work on the project, including efforts to remove barriers to the deployment of plug-in cars and trucks, is under way, and the effort has engaged a diverse group of stakeholders—utilities, vehicle and charging manufacturers, fleets, large employers, and other interested parties.

In 2011, the TCI jurisdictions agreed to a set of regional sustainability principles that make sustainable development a top transportation goal. TCI work groups have commissioned several substantive research projects to inform further action. The projects include the following:

- A literature review on removing barriers to the deployment of electric vehicles;
- A survey of what TCI jurisdictions are doing to achieve sustainable community outcomes;
- A workshop and report on potential metrics of progress toward the goals for sustainable communities;
- A series of webinars with leading experts on developments in information and communication technologies; and
- A report on freight flows within the TCI region.

TCI also offers an innovative model for collaboration among states and jurisdictions. At a time when states are working to overcome budget shortfalls, the initiative fosters important regional strategic planning to maximize environmental benefits, increase energy efficiency, and bolster economic development in the transportation sector.

The heads of environment, energy, and transportation agencies for the 12 TCI jurisdictions convened in June 2012 for an annual summit, during the annual meeting of the Northeast Association of State Transportation Officials in Baltimore, Maryland. Regular operations of TCI are guided by a steering committee of agency staff and managers, who meet biweekly via conference call. Four larger, topic-oriented work groups—corresponding to the four core tasks—involve energy, environment, and transportation staff from all 12 jurisdictions; the work groups meet via monthly conference calls.

PHOTO: TCI

The Transportation and Climate Initiative explores strategies for fuel efficiency, data application, and technology—such as electric vehicle charging stations—to reduce GHG emissions.

Although decision-making within TCI is generally consensus-based, any jurisdiction can choose not to participate in specific efforts or policy deliberations. The four work groups generally develop projects, initiatives, and policy proposals, which are vetted by the steering committee and then directed to the agency heads for review and consideration.

Participating in TCI are Connecticut, Delaware, the District of Columbia, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, and Vermont. The Georgetown Climate Center, housed at Georgetown Law in Washington, D.C., facilitates the initiative. In addition to the grant from the U.S. Department of Energy, the efforts are supported by the Rockefeller Foundation, the Emily Hall Tremaine Foundation, the Rockefeller Brothers Fund, Oak Foundation, and the Barr Foundation.

For more information about TCI, visit www.georgetownclimate.org/tci.

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Facing Up to Climate Change

Planning and Implementation at the Vermont Agency of Transportation

GINA CAMPOLI

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Vermonters have been conservation-minded for decades. Vermont led the nation in banning billboards, requiring bottle deposits, and adopting a statewide land use law. Climate change, the latest environmental challenge facing the state, has been on the agenda since the late 1990s, when Vermont joined the other New England states and Eastern Canadian provinces to set aggressive goals for reducing regional greenhouse gas (GHG) emissions.

Vermont's GHG policies are closely linked to energy policy. The Vermont Agency of Transportation (VTrans) is working with other state agencies through the Vermont Climate Cabinet to implement the Comprehensive Energy Plan (CEP). The CEP sets an ambitious goal of meeting 90 percent of the state's energy demand—including the needs for transportation—with renewable sources by 2050. The state will achieve this goal by focusing on the following objectives:

◆ Increase the share of Vermont-registered vehicles powered by electricity from renewable sources to 25 percent by 2030,
◆ Increase transit ridership by 110 percent,
◆ Quadruple Vermont-based rail passenger trips,
◆ Triple the number of state park-and-ride spaces by 2030, and
◆ Hold per capita VMT to 2011 levels.

The state's commitment to reach these objectives includes the following steps:

◆ VTrans, the Agency of Natural Resources, and the Department of Public Service equally support a staff position as the single point of contact for the state's utilities, car dealers, local officials, and other partners.

PHOTO: VERMONT AGENCY OF TRANSPORTATION

With many transportation facilities adjacent to rivers and streams, VTrans is adapting to mitigate the devastating effects of extreme weather events, such as Tropical Storm Irene in 2011.

PHOTO: LEONORA ENKING

An Amtrak train pulls into the station in Windsor, Vermont. The state has set goals—such as quadrupling the number of passenger rail trips—to decrease the use of nonrenewable energy sources.

◆ Key issues on the policy agenda for the coming year include removing barriers to the deployment of infrastructure for alternative fuels, establishing state incentives to support green vehicle purchases, examining the effects of fuel switching on transportation revenues, and identifying strategies to address revenue losses.

◆ The governor's recommended budget for 2013 increases transit funding by 9 percent and funding for park-and-ride facilities by 27 percent.

◆ More than $52 million dollars obtained in the past two years from federal sources was combined with $15 million in private funding to improve track on the Amtrak *Vermonter* line.

Changing travel demand in a rural state is a difficult task, but Vermont has a strong tradition of concentrated, mixed-use town and village centers of economic growth. These have continued to prosper as job centers, in part because of state programs promoting smart growth; in addition, the centers are amenable to walking, biking, and transit.

VTrans is also planning for climate adaptation. In 2011, Vermont's transportation infrastructure experienced major climate-related impacts with two 500-year flood events. Water levels in Lake Champlain broke all records, with unprecedented spring flooding, and Tropical Storm Irene hammered the state in August 2011. For more than 200 years, much of the state's transportation network had grown along winding valley floors and scenic rivers. More intense and frequent storm events, which scientists associate with a changing climate, are causing the rivers and adjacent mountain streams to wreak havoc on the state's bridges, culverts, roadways, trails, and rail lines.

(continued on next page)

Photo: John Blyberg

Record-breaking water levels at Lake Champlain in 2011 caused extensive flooding and infrastructure damage.

Tropical Storm Irene washed out more than 2,000 roadway segments, undermined more than 1,000 culverts, and damaged more than 300 bridges; the price tag was several hundred million dollars. As VTrans rebuilds and works to make the transportation network more flood resilient, it is pursuing short- and long-term approaches to climate change adaptation.

In the short term, VTrans is evaluating the hazard risk from fluvial floods for roads and bridges, as well as the vulnerability of the transportation infrastructure throughout the state, and is developing a suite of measures to address risk and vulnerability. The measures run the gamut from engineering solutions—such as bridge and culvert retrofits—to wetlands conservation, to keep floodwaters away from developed areas, and include the evaluation of alternative routes.

In the long run, the agency intends to establish flood resiliency criteria to help in prioritizing transportation project funding. In addition, the agency will work with state and federal natural resource agencies to collect data and information to improve understanding of the effects of climate change in Vermont.

VTrans has reinvigorated its relationship with the Natural Resources Agency, recognizing that river science is critical to its work. The agencies are sharing several positions, as well as resources, and executive-level staff are meeting weekly. Vermont cannot afford to forgo this collaborative approach or the preparations for a new weather normalcy.

Photo: Federal Emergency Management Agency

Tropical Storm Irene washed out more than 2,000 roads and damaged hundreds of bridges in Vermont.

Adaptation with Rapid Bridge Replacement

Recovering from the damage of Hurricane Irene in 2011, the Vermont Department of Transportation (VTrans) already is planning for climate change adaptation. When Chris Williams, a senior project manager for VTrans, learned of a new toolkit that speeds bridge design and construction—saving time both for the agency and for travelers—he took prompt action to implement standard bridge designs and construction methods developed by TRB's second Strategic Highway Research Program (SHRP 2).

The SHRP 2 rapid bridge-building toolkit integrates standard concepts for accelerated construction of all bridge components into designs that local contractors can build using their own equipment. During a pilot test of the design toolkit in Iowa, local contractors replaced a three-span bridge in two weeks.

Local resources are important, especially during emergencies. Not only is quick response critical—at a time when arranging for outside constructors and delivery of equipment may not be feasible—but local economies benefit from work done by local businesses. Developing local expertise in applying plans and methods from the toolkit is one way VTrans and other highway agencies can prepare for the challenges of adapting to climate change.

For more information, contact Monica Starnes at mstarnes@nas.edu. For related videos, visit www.trb.org/StrategicHighwayResearchProgram2SHRP2/SHRP2Videos.aspx.

—Linda Mason, SHRP 2

Photo: Volpe Center

Climate Change Scenario Planning

The Cape Cod Pilot Project

BENJAMIN RASMUSSEN, LINDSEY MORSE, AND DAVID PERLMAN

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(*Photo above:*) Participants at a 2010 workshop of the Interagency Transportation, Land Use, and Climate Change Pilot Project discuss transportation and land use development strategies for Cape Cod.

Cape Cod is a scenic and historic region of Massachusetts, with quaint towns and a beautiful coastline. Like many U.S. regions in the coming decades, however, Cape Cod will experience adverse shifts in weather patterns and other impacts associated with climate change.

To reduce greenhouse gas (GHG) emissions in the region and to anticipate the potential effects of climate change on Cape Cod, the Interagency Transportation, Land Use, and Climate Change Pilot Project implemented a scenario planning process from 2010 to 2011, to assemble a multiagency development strategy focused on transportation and land use.[1] The outcomes from the project are informing the region's long-range planning and other related efforts by local, state, and federal agencies.

The pilot project aimed to accomplish the following:

- Incorporate climate change mitigation and adaptation into transportation and land use planning.
- Through scenario planning, consider climate change in the context of transportation and land use planning—and develop a strategy for the future.

Photo: Michaelann Bewsee

Checquessett Neck Road in Wellfleet, Massachusetts, is an example of the many area roadways in low-lying areas, particularly vulnerable to climate change–influenced weather events.

[1] Federal participants in the pilot project included the sponsors—the Federal Highway Administration, the National Park Service, and the Fish and Wildlife Service—along with the Environmental Protection Agency, the National Oceanographic and Atmospheric Administration, the Federal Transit Administration, the Federal Emergency Management Agency, and the Department of Defense. The pilot project received support from the Cape Cod Commission, the Cape Cod Regional Transit Authority, the Massachusetts Department of Transportation, and Cape Cod's 15 towns.

◆ Share resources and expertise among federal, regional, and local stakeholders through interagency coordination and integrate the planning processes.

◆ Establish a process that can be replicated elsewhere.

Scenario Planning

In the context of land use and transportation planning, scenario planning can define a range of possible future conditions (*1*). Before the pilot project, the application of scenario planning to address the issues of climate change had been limited (*2*). The Federal Highway Administration (FHWA) has identified several ways for scenario planning to support the integration of climate change into transportation planning (*3*):

◆ Promote different types of development—for example, transit-oriented development—that are conducive to reducing GHG emissions and improving air quality.

◆ Help the public and elected officials visualize and understand the impacts of growth in accordance with criteria that address the transportation-related causes of climate change, such as vehicle miles traveled (VMT), gallons of gas consumed, or GHG emissions.

◆ Improve decision making about ways to address specific vulnerabilities, such as transportation infrastructure located in low-lying areas.

Data Requirements

Scenario planning is data-intensive. The pilot project depended on robust data for each of its major elements: scenario development, evaluation with performance indicators, and incorporation of climate change considerations. Data were collected from state and other geographic information system (GIS) databases, federal resources, the Cape Cod Commission (CCC), and towns; some data had yet to be gathered.

The model for developing the scenarios required baseline transportation and growth data. The baseline transportation data enabled estimates of the effects that changes in specific factors—such as the density and proximity of housing and employment—would have on VMT. The growth rates projected for the population and employment in 2030 derived from U.S. Census 2000 projections and were held constant across scenarios to allow for direct comparisons. Because of time and resource constraints, the project team—which consisted of staff from the U.S. Department of Transportation's Volpe Center—was not able to estimate the impact of the effects of climate change on the rates of population growth.

Coastal flooding in Cape Cod.

Photo: Putneypics, Flickr

TABLE 1 Indicator Results for 2030 (percentage increases or decreases compared with 2008 conditions)

Indicator	Preliminary Scenarios			Workshop Breakout Group Scenarios				Refined Scenario
	Trend	Dispersed	Targeted	A	B	C	D	
Development in Areas Vulnerable to Sea-Level Rise								
Percentage of new population in vulnerable areas	28.3	28.5	44.0*	37.5	19.1	15.0*	24.9	20.4
Growth in Conservation and Resource-Constrained Areas								
Percentage of new population in critical habitat areas	49.6*	49.6*	20.9	25.7	40.6	31.6	20.7	14.2+
Percentage land area developed (from previously undeveloped or rural)	33.3*	29.9	0.0+	1.9	1.7	0.0+	2.8	4.5
Percentage of new population in undeveloped or rural lands	41.1*	36.4	31.1	15.1	35.7	28.6	15.6	12.4+
Percentage of new population in other high priority conservation areas	64.4*	62.1	31.4	31.5	54.0	38.2	29.9	25.2+
Percentage of new population in historic preservation areas	4.8	5.1	6.4	8.0*	0.4	0.2	1.7	0.1+
Percentage of new population in water resource areas	47.9*	41.4	39.9	21.5+	52.4	43.1	32.0	47.8
Percentage of new population in water resource areas in low-density areas (less than three dwelling units per acre)	41.1*	36.4	31.1	15.1	35.7	28.6	15.6	12.4+
Percentage of new population in wellhead protection areas	33.4	30.1	36.4	15.5+	32.6	32.9	28.1	42.0*
Percentage of new population in wellhead protection areas in low-density areas (less than three dwelling units per acre)	33.3*	29.9	0.0+	1.9	1.7	0.0+	2.8	4.5
Transit Accessibility								
Percentage of new population served by transit	7.2*	Standard: 16.7 Enhanced: 38.1	Standard: 43.1 Enhanced: 50.1+	44.9	18.0	24.1	31.1	24.7
Percentage of new jobs served by transit	24.7	Standard: 21.7 Enhanced: 44.0	Standard: 46.3 Enhanced: 50.8+	47.1	11.6*	13.9	26.4	33.3

+ Best-performing scenario for each indicator.
* Lowest-performing scenario for each indicator.

Performance Indicators

Early on, the planning group of representatives from each federal and regional agency involved in the project selected 12 performance measures aligned with the goals of the project and of the regional agencies (see Table 1, above). The indicators allowed participants to compare the effects of land use and transportation scenarios developed as part of the pilot project.

The planning group considered cost and economic impact to be important indicators. These factors, however, could not be quantified and incorporated into the evaluation of the scenarios, because of other priorities and limited time, resources, and data.

Sea-Level Rise

The project team found that estimates of the effects of regional climate change had not been performed for Cape Cod. The computer-based models that can generate region-level estimates lack specificity at the local level. The project team therefore organized and facilitated a consensus-based expert elicitation with seven local and regional experts in July 2010.

The goal of the expert elicitation was to develop impact projections for rises in sea level for specific areas of Cape Cod at time horizons of 20, 50, and 100 years, and—if feasible—for three scenarios: low, medium, and high estimates of sea-level rise. During

the elicitation, however, the experts determined that this goal was not achievable because of the dynamic conditions that influence sea-level rise at local points on the Cape, a lack of robust data sources, and the infeasibility of completing the analysis and modeling within the scope and scale of the pilot project.[2]

Therefore the experts focused on identifying areas vulnerable to sea-level rise and to other climate-related effects, considering elevation, exposure to storm surge and coastal flooding, erosion, and the impacts of sea-level rise on significant infrastructure and developed areas. The expert workshop produced an indexed map incorporating explanations of the potential vulnerability of each area.

GHG Mitigation Strategies

Working with local and regional stakeholders, the project team developed a list of mitigation strategies from a literature review. In particular, the report *Moving Cooler: An Analysis of Transportation Strategies for Reducing Greenhouse Gas Emissions,* which assesses the potential effectiveness of reduced travel activity or improved vehicle and system operations to reduce GHG emissions, served as a key resource (*4*).

The pilot project's list of strategies focused on what could be implemented at the local level without requiring federal or state action. The strategies were organized into seven categories:

1. *Pricing strategies*—to raise the relative costs associated with some components of the transportation system, to reduce use.

2. *Land use and smart growth strategies*—to create land use that is more transportation-efficient, requiring fewer and shorter vehicle trips.

3. *Nonmotorized transportation strategies*—to encourage walking and bicycling as alternatives to driving.

4. *Public transportation strategies*—to encourage the use of public transportation and to expand its availability.

5. *Regional ridesharing, carsharing, and commuting strategies*—to expand services and provide incentives for alternative options to driving alone.

6. *Operational and intelligent transportation system strategies*—to improve the operation of the transportation system to decrease the GHG emissions per mile and to make better use of available capacity.

7. *Vehicle efficiency and alternative fuel strategies*—to improve the fuel efficiency of vehicles and increase the use of alternative fuels.

The project team considered developing regional estimates of the potential GHG reductions from the mitigation measures presented in *Moving Cooler*. Again, because of the limited data, time, and resources, the team decided not to pursue this direction. The team was able to integrate Strategies 2 and 4 in modeling the scenarios but was not able to integrate the remaining strategies. The other five strategies therefore did not influence scenario performance.

Scenario Development

The project team hired consultants to help in developing scenarios.[3] The consultants used a decision-support software tool, CommunityViz, an extension for the mapping and spatial analysis package ArcGIS, for the scenario development.

The pilot project developed 10 scenarios for 2030:

- Five by the consultant team for comparisons,
- Four by stakeholders during the November 2010 workshop, and
- One refined by stakeholders after the workshop.

All scenarios involved the placement of population and employment in accordance with the growth assumptions described earlier. Digital "chips" were used to represent different quantities of population and employment.

The five preliminary scenarios developed by the project team provided context for the workshop stakeholders. The preliminary scenarios consisted of the trend scenario, which continued historic growth pat-

[2] Focusing more resources on climate change adaptation as a regional priority can make it possible to collect the data for a comprehensive analysis.

[3] The consultant team consisted of PlaceMatters, Inc., and Placeways, LLC.

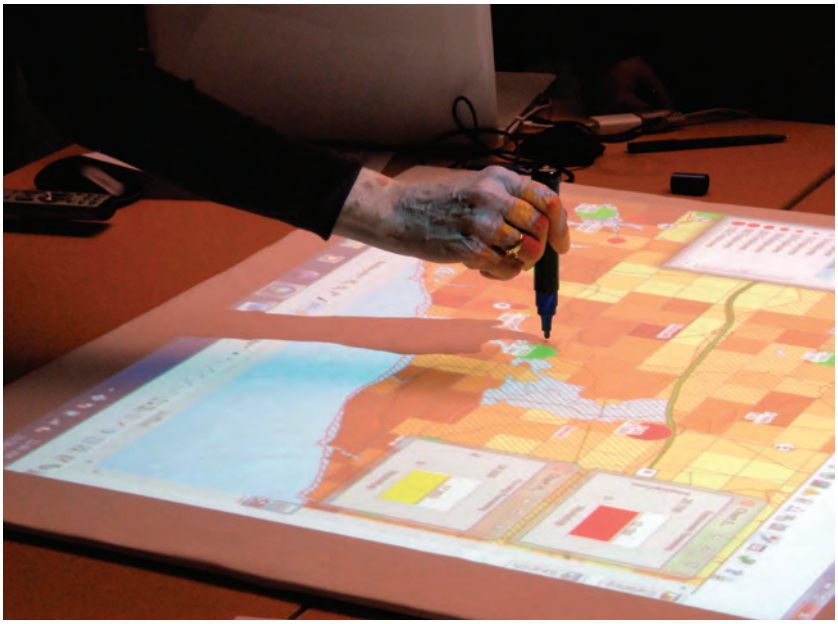

Photo: Volpe Center

Workshop participants navigated a regional map in CommunityViz, allocating new housing and employment units with infrared pens, a Nintendo Wii remote control, and a vertically mounted projector.

terns into the future, and four scenarios that combined two levels of development intensity and two levels of transportation investment.

The two levels of development intensity were intended to demonstrate extreme scenarios. A dispersed, but even, growth scenario followed a spread-out distribution of development, using a random allocation. An intense and focused growth scenario allocated new development in high-density residential areas and commercial and industrial centers, following the town land use vision maps when available or otherwise following the zoning.

The two levels of transportation were (*a*) the standard, consisting of transit plus the improvements then in planning by the Cape Cod Regional Transit Authority (CCRTA), and (*b*) the enhanced, which included unplanned stops and routes determined by areas of population and employment density.

Stakeholders Workshop

A one-and-a-half day workshop was held in November 2010 to facilitate interagency discussion, introduce scenario planning and the software tool, and develop transportation and land use scenarios that could be consolidated into the refined scenario. Invitations were sent to each town administrator, who then selected one or two administrative or planning staff to attend the workshop. Planning group members attended as observers; more than 50 people participated.

At the workshop, stakeholders were divided into four breakout groups, each led by a representative from the consultant team. The consultant group developed and presented a novel interactive display that allowed participants to view and interact with CommunityViz as though it were a tabletop map.

Each of the breakout groups allocated the projected population and jobs for 2030 and then modified Cape Cod's transit system by adjusting the frequency of routes and designating new stops to serve the areas of growth. Participants were able to view several data layers within the GIS interface, including areas vulnerable to climate change effects.

Representatives from the breakout groups began work on the refined scenario at the workshop. The work continued through a series of meetings and exchanges between staff from CCC, the Cape Cod National Seashore, CCRTA, and town planners.

The change from the housing density in 2008 for four of the scenarios—including the refined scenario—is shown in Figure 1 (above, right). Recognizing that the conditions on Cape Cod—and therefore the data—are evolving, participants agreed to use the refined scenario as the foundation for ongoing conversations and future changes but not as an unalterable scenario.

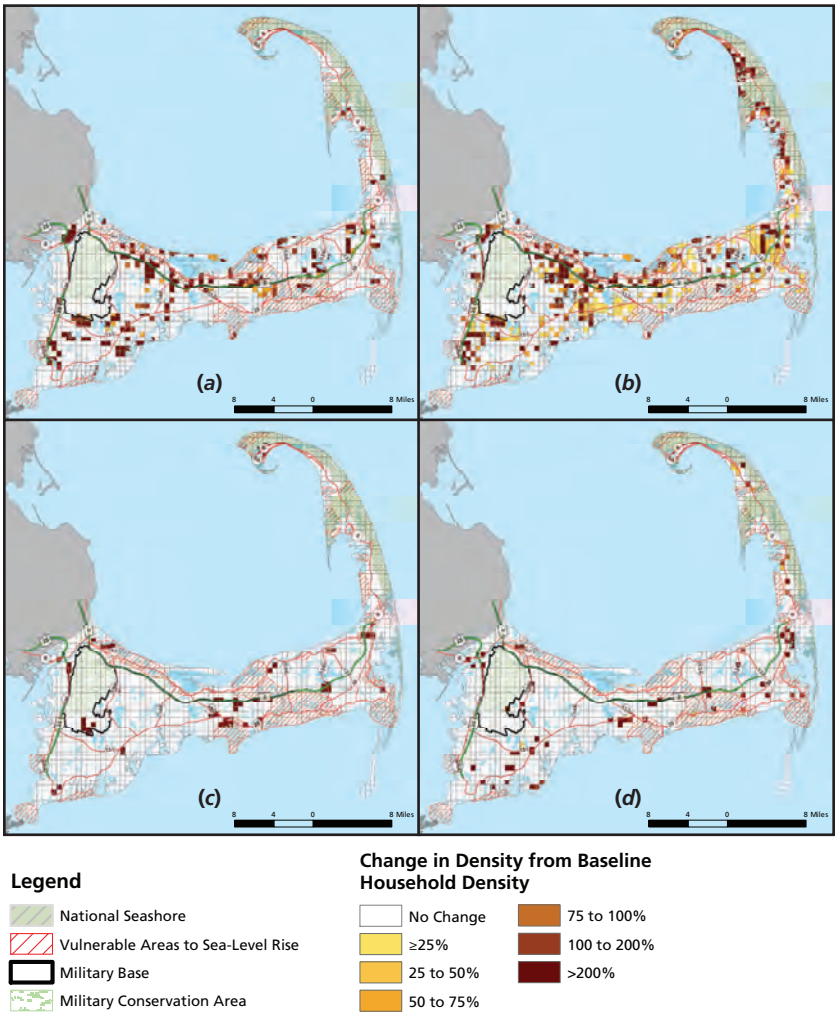

FIGURE 1 Four scenarios demonstrating the 20-year change in housing density from 2008 conditions: (*a*) trend, (*b*) dispersed, (*c*) targeted, and (*d*) refined. (Source: PlaceMatters and Placeways)

Assessing the Scenarios

The 10 scenarios were assessed in terms of the selected performance indicators listed in Table 1. The percentage increases or decreases used 2008 conditions as a baseline, except for changes in VMT and GHG emissions, which were compared to VMT and GHG in 2030 in the trend scenario (see Table 2, page 20). Changes in GHG emissions were equivalent to changes in VMT, because possible changes in technology, fuel, or transportation mode after 2008—whether by enactment or otherwise—were not included in the analysis. The consultant team estimated that under the trend scenario, VMT and GHG emissions would be 24 percent higher in 2030 than in 2008.

The performance of the scenarios underscores the value of the planning process, as well as the trade-offs that stakeholders considered in addressing climate change adaptation and mitigation through land use and transportation planning. In particular, the refined scenario avoided additional development in certain high-density areas identified as vulnerable, improving

TABLE 2 VMT and GHG Indicator Results for 2030 (percentage increases or decreases compared with the trend scenario)

Scenario	Percent Change
Dispersed–standard	–0.8[a]
Dispersed–enhanced	–3.3
Targeted–standard	–6.2
Targeted–enhanced	–6.8
Breakout Group A	–7.8[b]
Breakout Group B	–5.6
Breakout Group C	–6.6
Breakout Group D	–5.8
Refined	–5.3

[a] Worst.
[b] Best.

performance for that indicator at the expense of reductions in VMT and in GHG emissions.

In addition, the refined scenario was constrained by preexisting plans, cost considerations, evaluation by local jurisdictions, and consultation with local entities, including CCRTA, to make realistic and vetted future investments. These constraints differed significantly from the unrestrained scenario-building exercises conducted before and during the workshop.

Results

Action Plans

The project team worked with the Cape Cod National Seashore and CCC to incorporate the pilot project's specific outcomes into action plans. The steps to ensure implementation of project outcomes or recommendations were identified and incorporated into current and future plans and activities of the agencies. The project team is developing an action plan for the Massachusetts Department of Transportation as well.

Attainment of Goals

Climate Change Mitigation and Adaptation

The impact of density, land use mix, and transit access on VMT was modeled and assessed in scenario planning during the pilot project. The resulting reductions in VMT and GHG, however, were relatively small. This underscores the reality that larger reductions will require other and more substantial transportation strategies to align with international GHG targets. Actions that aim to change behavior through pricing, incentives, technology improvements, and other measures are more difficult to model; additional time and resources are needed to integrate the effect of these measures into scenario planning.

In addressing adaptation, the pilot project found that access to robust data—or the time and resources to collect these data and conduct location-specific modeling—is a necessity for developing locally meaningful estimates of the effects of climate change. Without these data, the ability to plan specific climate change adaptation measures is limited.

Although the goals of mitigation and adaptation were treated separately for baseline assumptions and performance indicators, the pilot project found that the goals nonetheless were discussed together—and

PHOTO: WOODLEYWONDERWORKS, FLICKR

The project team evaluated the effects of density, land use, and transit access on vehicle miles traveled, but found that these factors had a relatively small impact on GHG emissions.

should be—because of the potential trade-offs. At times, participants found that development decisions that would reduce GHG emissions through changes in settlement density and in the jobs-and-housing balance also would place new populations in vulnerable areas, because of the location of existing residential and commercial centers. In placing new population in vulnerable areas, participants acknowledged that further study is needed to determine the extent of the vulnerability and to identify the options for mitigating the impacts of climate change.

Scenario Planning

Scenario planning provided participants with an opportunity to explore overlaps of information and to discuss trade-offs. A key benefit of the scenario planning software was that it provided immediate feedback on development and transportation decisions. The software also provided a tool for exploring and testing the implications of different decisions. To realize these benefits, it was important to have the right people in the room and to provide sufficient time to run updates to performance indicators.

Interagency Coordination

Participation by multiple agencies ensures the pooling and sharing of expertise and resources. Including state and federal agencies, as well as local and regional stakeholders and federal land management agencies, was important. Regional or local entities should initiate the process, because they are best positioned to assess the data needs, the status of planning efforts, and the planning priorities for the region.

Replicability

The final goal of the pilot project was to create a replicable process for considering climate change in transportation and land use planning in situations that require interagency coordination. The pilot project has stimulated information sharing and interest across many federal agencies and in a variety of public forums throughout the United States.

Applying the Lessons

The pilot project successfully brought together multiple stakeholders and agencies to consider the effects of climate change and transportation-related adaptation and mitigation. The project confirmed that scenario planning offers a valuable way to incorporate important considerations into the planning processes for transportation and land use.

The pilot project required significant preliminary planning and data collection, as well as stakeholder outreach, and provided an opportunity to engage a variety of people and entities in an informed discussion of trade-offs and priorities. The successes and lessons learned from the pilot project can help others pursue similar efforts and advance the consideration of climate change in transportation and land use planning.

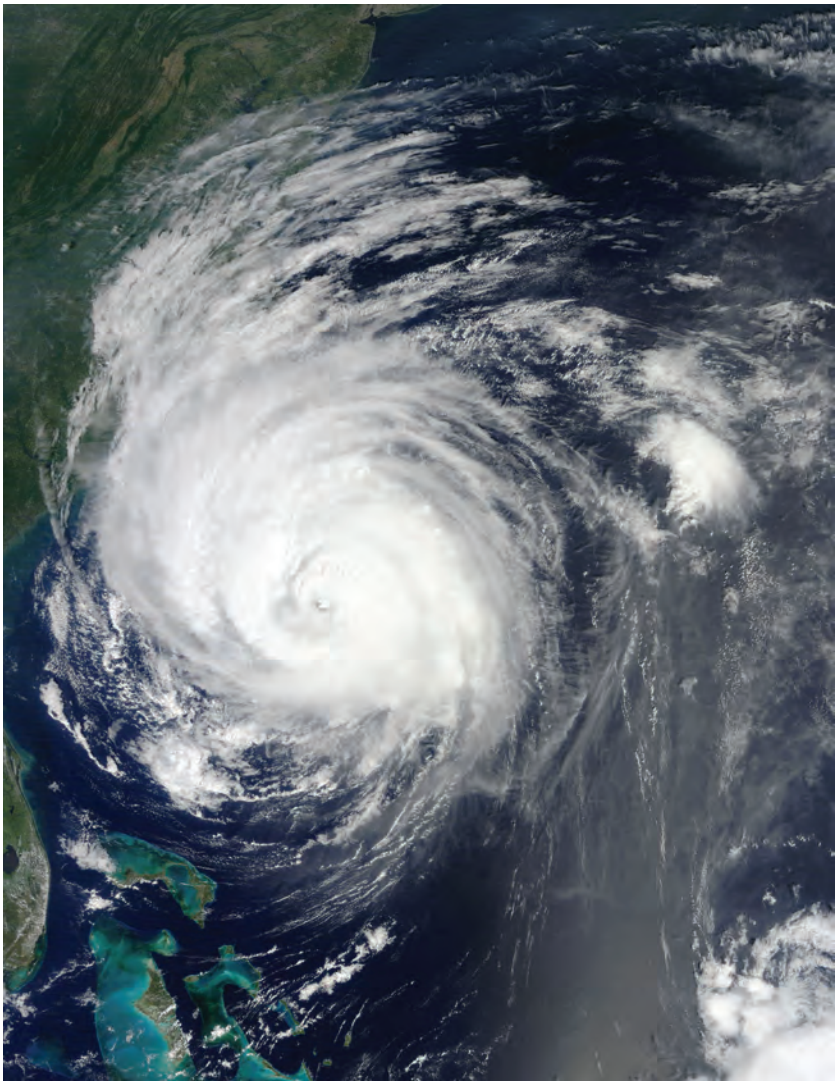

PHOTO: JEFF SCHMALTZ, NASA

Hurricane Earl traveled along the East Coast in fall 2010, causing heavy rains and power loss in Cape Cod. Continued research can better predict consequences of adding new population to vulnerable areas.

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SHRP 2 RESEARCH UPDATE

Incorporating Greenhouse Gas Impacts into Transportation Decision Making

MICHAEL D. MEYER

The second Strategic Highway Research Program (SHRP 2) is completing a collaborative decision-making tool, Transportation for Communities: Advancing Projects Through Partnerships (TCAPP).[1] TCAPP is an online decision support tool that guides users through the key decisions in the processes of long-range transportation planning, programming, and environmental review. The primary audience consists of state transportation agencies and metropolitan planning organizations leading and managing these collaborative processes; additional audiences include federal and state resource agencies and other stakeholders.

The TCAPP web tool is ready for use.

Among its many applications, TCAPP will assist transportation agencies in understanding and incorporating the impacts of greenhouse gas emissions (GHGs) into decision making. The results of research supporting this application will be available soon in print from the TRB bookstore[2] and online through the SHRP 2 website.[3] A practitioner's handbook will be available as a reference guide for considering GHG emissions and energy impacts in various planning and decision-making contexts.

Step-by-Step Analysis

These complementary SHRP 2 products will provide transportation decision makers with

◆ Background information on the connection between GHG emissions and transportation fuel consumption;

◆ Guidance on state-of-the-practice methods of analyzing GHG emissions and energy, including a description of the tools and data required for conducting the analyses;

◆ An overview of the cost-effectiveness of the range of strategies to mitigate GHG emissions; and

◆ Illustrative case studies of GHG emissions analyses from highway and transit project planning.

A technical framework for conducting GHG emissions analyses as part of the decision-making process is outlined in the accompanying table (page 23). The framework consists of five basic, analytic steps, each involving a series of questions. By following this framework, transportation officials can consider the GHG and energy impacts of their choices for infrastructure investment, system management and operations, and demand-management activities.

Strategic Influences

With the online TCAPP tool, users will benefit from accompanying SHRP 2 research on strategies for reducing GHG emissions from transportation. According to the research, most studies on GHG reduction strategies for transportation have focused on fuels and vehicle technology, but most state and local transportation and planning agencies have little direct authority over vehicle and fuel choices.

Factors found to be most directly under the control of agencies include the following:

◆ Design, construction, and maintenance of the transportation infrastructure;

◆ Operation and management of the system, such as technologies to improve traffic flow and pricing policies to manage demand—for example, through congestion pricing or variable tolls; and

◆ Providing transportation services that are less carbon-intensive, such as ridesharing and vanpool programs and improvements to public transit.

The research revealed that transportation agencies can have an indirect—but nevertheless important—role in other areas, such as land use planning; for example, transportation agencies may provide regional coordination, funding, and technical assistance for state and local efforts to develop more efficient land use patterns. Transportation agencies also may be asked to provide analysis support for state-level policy changes in vehicle taxation, mileage-based charges, and congestion charges. The provision of alternative fuels infrastructure also may rest with transportation agencies, which can set an example by purchasing alternative-fuel vehicles for their fleets.

Guidance for Action

Other notable findings are as follows:

◆ Among the most cost-effective investments a transportation agency can make is to maintain its systems in good repair, minimizing the occurrence of lane closures, bridge postings, and major traffic diversions that increase travel distances, congestion, and energy use and create more GHG emissions.

◆ Highway expansion strategies may have a net positive or

[1] www.transportationforcommunities.com.

[2] http://books.trbbookstore.org/.

[3] www.trb.org/StrategicHighwayResearchProgram2SHRP2/PublicationsSHRP2.aspx.

negative effect on cumulative GHG emissions, depending in part on the amount of automotive travel induced. In the same way, the GHG impact of new transit service depends on ridership levels—if ridership does not materialize, the GHG benefit may be negative.

◆ Transportation system management strategies that reduce congestion and improve traffic flow, such as investments in intelligent transportation technologies, may provide modest GHG reductions at a lower cost than physical additions to system capacity. Again, the effect on GHG reductions depends on the magnitude and treatment of the induced demand.

◆ User pricing strategies—such as travel-based fees or congestion pricing—can provide significant GHG reductions, but at relatively high pricing levels. According to the study analysis, a fee of 2 cents to 5 cents per mile is equivalent to a gas tax increase of $0.40 to $1.00 per gallon at today's vehicle fuel efficiency levels.

◆ Individual system management and operations strategies produce generally modest impacts on GHG emissions nationwide. Energy-saving driving behavior, or ecodriving, may have significant potential for reducing GHGs in the near to medium term, although an effective public policy to encourage ecodriving has yet to emerge. Requiring changes in driving behavior through measures such as speed limit reductions can yield significant GHG benefits, but these approaches tend to be unpopular and require aggressive enforcement to achieve the desired behavioral effect.

◆ For freight, rail and marine carriage is considerably more energy-efficient than truck travel, on average. The absolute magnitude of the reductions from shifting freight modes is limited, however, because only certain types of goods—particularly long-haul, non-time-sensitive shipments—can be moved competitively by rail or water.

◆ Land use strategies to affect demand can provide meaningful GHG reductions in the long term, at low cost to the public sector. Modest to moderate changes in land use patterns can be accomplished without significant loss of consumer welfare, but more far-reaching changes may not be popular and may be difficult to achieve in the current political and economic environment.

These and other strategies may prove most useful when combined for synergistic effects, such as when transit investments are coordinated with land use planning, and highway bottleneck reductions are coupled with congestion pricing. More research is needed to identify the best pairings of strategies for longer-term, positive effects in reducing GHG emissions.

To view the TCAPP guidance, Integrating Greenhouse Gas into Transportation Planning, go to www.transportationforcommunities.com/ shrpc01/ghg_application_kdps/26/0.

TABLE 1 GHG Analysis Framework

Analysis Step	Key Questions
I. Determine information needs	1. Which stakeholders should be included in GHG strategy development and evaluation?
	2. What is the scope of GHG emissions analysis?
II. Define goals, measures, and resources	3. Which goals, objectives, and policies relate to GHG reduction?
	4. Which GHG-related evaluation criteria and metrics will be used?
	5. What are the baseline emissions for the region or study area?
	6. What is the goal or target for GHG reduction?
	7. How will GHG considerations affect funding availability and needs?
III. Define range of strategies for consideration	8. Which GHG reduction strategies should be considered?
	9. Are strategies and alternatives consistent with a long-range plan or other relevant plans to meet GHG reduction objectives?
IV. Evaluate GHG benefits and impacts of candidate strategies	10. Which calculation methods and data sources will be used to evaluate the GHG impacts of projects and strategies?
	11. What are the emissions and other impacts of a particular project, strategy, or design feature?
V. Select strategies and document overall GHG benefits and impacts of alternatives	12. Which GHG-reducing strategies should be part of the plan, program, or project?
	13. What are the net emissions impacts for the plan, program, corridor, or project alternatives considered, or for the alternative selected?

Photo: Joe Wolf

Changes in land use patterns—such as transit-oriented development in Carlsbad, California—can lead to significant GHG reductions at a low cost to the public.

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Establishing Biofuel Infrastructure in Tennessee

ALAN JONES

The State of Tennessee developed and initiated an alternative fuels program in 2005 and 2006. A major goal was to increase the availability and use of biofuels, specifically of B20 biodiesel and E85 ethanol blends. In 2005, the Tennessee General Assembly authorized the Tennessee Department of Transportation (DOT) to establish a grant program to help retail fuel stations pay the capital costs of purchasing and installing fuel storage tanks and fuel dispensing equipment for E85, B20, or both.

In 2006, the General Assembly approved $4 million for alternative fuel projects, and $1.5 million was allocated to Tennessee DOT for the grant program. In addition, Tennessee DOT set aside $930,000 in funds from the federal Congestion Mitigation and Air Quality Improvement program to install biofuel pumps in air quality nonattainment and maintenance areas.

Photo: Alan Jones

The author refuels a state flex-fuel vehicle with E85 at a Nashville gas station—a recipient of a Tennessee DOT grant for accessible biofuel stations along the state's Interstate corridors.

Green Islands

With this authorization and funding, Tennessee DOT established the Green Island Biofuel Corridor Grant Program. The program aims to establish a statewide network of publicly accessible B20 and E85 refueling stations—or "green islands"—along Tennessee's Interstate corridors and in communities with significant numbers of vehicles capable of running on biofuels. A major goal was to place the biofuel pumps no more than 100 miles apart along Interstate corridors.

Tennessee DOT held a series of Green Island grant competitions for biofuels infrastructure. A review panel applied the published criteria in evaluating and scoring the proposals. The selection process emphasized the cost-effectiveness of the project, the location of the retail station, the demonstrated potential of the biofuels market, and owner commitment.

Tennessee DOT offered funding of up to 80 percent for the equipment and required a minimum investment of 20 percent from applicants. Grants ranged to a maximum of $45,000 for one E85 or B20 pump—or $90,000 for a station with both fuels. The grant contracts require fuel stations to sell the biofuel for at least four years.

To date, the Green Islands program has provided grants to help establish 21 E85 pumps and 16 B20 pumps. Several fuel stations have installed or converted equipment and are selling biofuels without grant funding. Tennessee currently has a total of 31 E85 pumps and 29 B20 pumps.

Photo: George Hornal, Tennessee DOT

Working with the University of Tennessee at Knoxville, Tennessee DOT planted native switchgrass in Interstate rights-of-way in a pilot project to produce biofuel.

Other Initiatives

In addition to Green Islands, Tennessee DOT is supporting alternative fuels and cleaner transportation in other ways:

◆ Tennessee DOT is storing biofuels at all regional and some district facilities and is using biofuels in fleet vehicles.

◆ In partnership with the University of Tennessee at Knoxville (UTK), Tennessee DOT launched a pilot project to grow switchgrass, a native perennial grass and a feedstock for the production of cellulosic ethanol, in Interstate rights-of-way. Tennessee DOT has planted four 1-acre test plots of switchgrass across the state, maintaining the plots and working with UTK to monitor the results. Ethanol from switchgrass offers a larger net energy gain than ethanol from corn. In addition, the life cycle of switchgrass ethanol is low in greenhouse gas emissions.

◆ Tennessee DOT and other state agencies supported ECOtality North America in implementing a U.S. Department of Energy stimulus project to install 130 Level 2 electric vehicle charging stations at businesses and public facilities in the state's four major urban areas. The project included installation of 12 DC fast chargers at sites along Interstate highways.

◆ Tennessee DOT is working with Clean Cities coalitions to encourage greater use of biofuels. The coalitions hold biofuels workshops and talk about biofuel use to decision makers at companies and agencies that operate vehicle fleets.

◆ Encouraging biofuels use is a theme of Tennessee DOT's "Clear the Air Tennessee" air quality education campaign. Education and outreach are essential in increasing the use of cleaner, sustainable vehicle fuels.

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The Oregon Solar Highway Program

Offsetting Transportation's Carbon Footprint

ALLISON HAMILTON

The Oregon Solar Highway Program came to life in 2007 after I watched a Public Broadcasting System special, *Saved by the Sun*, featuring solar panels along the autobahn in Germany. I thought, "If they can do that there, why can't we do it here?" It turns out that we can.

Transportation departments across the country are tasked with meeting climate change and sustainability policies and goals, including greenhouse gas reduction targets, while facing declining revenues. At the same time, they support the business of moving goods and people in vehicles that are powered almost exclusively by carbon-based fuels. How can a transportation agency reduce its own carbon footprint?

PHOTO: OREGON DOT

Solar panels near the Baldock Safety Rest Area in Oregon. Completed in 2012, the Baldock Solar Highway Project is the largest in the country.

Powering Up

An innovative program at the Oregon Department of Transportation (DOT) encourages partnerships with private industry to expedite project delivery and secure private-sector financing for projects. Through this program, Oregon DOT constructed the nation's first solar highway project in 2008, a 104-kilowatt direct-current array in the middle of one of Oregon's busiest interchanges—Interstate 5 and Interstate 205—just south of Portland. Oregon's second—and the nation's largest—solar highway project was completed in January 2012. The Baldock Project is a 1.75-megawatt direct-current array on 7 acres of land owned by Oregon DOT at the eastern edge of the Baldock Safety Rest Area, approximately 6 miles south of the first project.

The Oregon Solar Highway Program seeks to site renewable energy projects on suitable parcels of publicly owned transportation system rights-of-way—the miles of fallow ground between the drainage ditch and private property. Oregon has 19,000 lane-miles of rights-of-way; solar arrays on less than one percent of that land could offset all of Oregon DOT's annual electricity use with clean, sustainable, home-grown energy. More than 8 million lane-miles of rights-of-way are available across the country.

PHOTO: OREGON DOT

Oregon DOT's first solar highway project, constructed in 2008, is a 104-kilowatt direct-current array located near a busy interchange south of Portland.

Financing and Operation

Solar energy is beautiful, silent, and almost maintenance-free—but today it is expensive. The two Oregon solar highway projects were financed through a public–private partnership with the state's largest utility, Portland General Electric (PGE). PGE's green energy program provides money to build renewable energy projects within its territory, and the company is working to meet a 25 percent Renewable Portfolio Standard by 2025. PGE was willing to take the risk with Oregon DOT to develop the "first in the nation" prototype, as well as the Baldock project.

PGE's green energy program was not the only source of funding. Until recently, Oregon provided a 50 percent tax credit for renewable energy projects; through limited liability partnerships with tax equity investors, PGE was able to take advantage of the tax credit. PGE also applied the federal investment tax credit of 30 percent, the accelerated depreciation, and grant funds from the Energy Trust of Oregon at $1 per watt.

PGE's limited-liability corporation constructed, owns, operates, and maintains the prototype project. PGE constructed, operates, and maintains the Baldock project, which is owned by the tax partner.

The energy produced from both projects feeds into the PGE grid. Oregon DOT buys the energy produced from the prototype project and receives a small annual site license fee and a share of the renewable energy certificates (RECs) for the Baldock project. For the project's estimated 40-year life, Oregon DOT will receive 26 percent of the RECs generated—equivalent to the funds the agency has committed for the project's environmental assessment and permitting activities and for consultant and staff time. Oregon DOT will apply the RECs to its carbon footprint. As solar costs continue to decline, the agency will be able to increase the site license fees, which will provide a revenue stream—and help power the grid with the energy of the future.

For more information and details about the Oregon Solar Highway Program, visit www.oregonsolarhighway.com.

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The West Coast Green Highway Initiative

Cross-Sector Partnerships for Sustainable Transportation Solutions Along Interstate 5

JEFF DOYLE

Transportation accounts for 27 percent of all greenhouse gas (GHG) emissions nationwide (*1*). In Washington State, however, transportation is responsible for nearly half—47 percent—of all GHG emissions and is the largest source of emissions among the sectors of the economy. In 2009, the state legislature passed ambitious GHG reduction goals. These included the aggressive target of a 35 percent reduction in per capita vehicle miles traveled (VMT) by 2035, despite projected 40 percent increases in the state's population and in travel demand for the same period.

Achieving these drastic VMT reduction targets presents an extraordinary challenge, even with a variety of programs to manage travel demand, such as significant increases in fuel prices, the institution of tolling, the expansion of multioccupancy modes, public education, and other initiatives. The challenge of reducing VMT heightens the importance of other potential measures to reduce GHGs—such as clean cars, clean fuels, and the necessary supporting infrastructure. The Washington State Department of Transportation's (DOT's) innovative public–private partnership strategy is focusing on these other measures, in particular through the West Coast Green Highway Initiative.

PHOTO: JEFF DOYLE

Washington State DOT joined with private partners to install a network of quick-charge stations for electric vehicles.

Green Highway Initiative

The West Coast Green Highway Initiative is a multistate partnership of Washington, Oregon, California, and the Canadian province of British Columbia, to showcase sustainable transportation projects and policies along the Interstate 5 (I-5) corridor. In 2008 Washington State DOT's Public–Private Partnerships Office undertook an economic feasibility study (*2*). The study found that state DOTs could spur the development of alternative fueling infrastructure to support biofuels, electricity, and hydrogen fuel cells by leasing state-owned parcels of land along highways for privately operated fueling stations. The study identified electric vehicle charging infrastructure as the best near-term partnership opportunity to promote clean cars and fuels in the I-5 corridor.

After legislative approval of the concept, Washington State DOT crafted a business plan to develop a strategic network of quick-charge stations for electric vehicles. The department altered the study's approach, however, and sought partnerships with the private sector to locate the chargers on private land to be owned and operated by a private partner. This variation avoided potential conflicts with the federal law prohibiting commercial activities at Interstate rest areas. Washington State DOT presented the public–private partnership plan to state and federal officials and won initial seed funding of $1.32 million—but not from transportation sources. The U.S. Department of Energy backed the project for its promise in reducing petroleum dependence.

Private-Sector Leverage

After securing the seed funding, Washington State DOT solicited private-sector partners under a fixed-price, variable scope procurement—the firm that offered the most quick-charging locations, equipment, and supporting services would win the fixed-price contract of $1 million. Six firms submitted proposals, and Washington State DOT selected AeroVironment as its partner.

The department scored the proposal as providing goods and services worth $1.6 million—$600,000 more than the project scope had required. As a result, Washington State now has a continuous network of quick-charging stations for electric vehicles approximately every 30 miles along the 276 miles of I-5, from the Canadian border to the Oregon border.

Multistate Collaborations

Washington State DOT and Oregon DOT have collaborated closely to develop another showcase project, the I-5 Electric Highway network, under the West Coast Green Highway Initiative. The two agencies shared consultant and legal costs in the early feasibility stages; jointly developed minimum requirements for charging stations, to ensure a common driver experience and commercial standards throughout the network; joined forces to develop uniform signage and branding for the Electric Highway; and have continued to collaborate on opportunities to expand the network and encourage greater consumer adoption of electric vehicles.

To expand this collaboration among agencies, Washington State DOT's Public–Private Partnerships Office is leading a Transportation Pooled Fund Study examining new ways for state and local transportation agencies to get ready for electric vehi-

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cles. Arizona, California, North Carolina, Ohio, Oregon, and Wisconsin are participating, with U.S. DOT and the Federal Highway Administration actively involved. The pooled fund study is open to additional participants. For more information, search for TPF-5 (250) at www. pooled-fund.org, or e-mail Partnerships@wsdot. wa.gov.

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1. *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2009*. U.S. Environmental Protection Agency, Washington, D.C., April 2011.
2. PB Consult. *Alternative Fuels Corridor Economic Feasibility Study*. Prepared for Washington State Department of Transportation, January 23, 2009.

Converting to Energy-Efficient Lighting for Roadways and Maintenance Facilities in California

STEPHEN C. PREY

In February 2012, the management of the California Department of Transportation (Caltrans) approved funding to convert all roadway lighting on state-maintained roads—including federal-aid highways—as well as the exterior lighting systems of maintenance facility yards, to light-emitting diode (LED) technologies. The expected benefits of the conversion are significant:

- Energy savings of up to 50 percent for roadway lighting;
- A 15-year warranty and an expected field life of up to 20 years between change-outs, compared with the current 4 years between change-outs;
- Manual or automated control systems to turn the lights off when not needed, trimming the hours of operation for each fixture from 4,100 per year to 300 to 400 per year; if a control fails, the light can default to the "on" mode;
- Energy reduction of up to 90 percent for facility yard lighting systems, through improved energy efficiency and reduced hours of operation; and
- An estimated energy use savings of more than 1 billion kilowatt-hours, plus carbon dioxide and carbon reductions of up to 440,000 metric tons, from the expected 67,000 converted fixtures during the 20 years of service life.

Photo: Pacific Gas and Electric

Maxwell Bridge in Napa, California, after installation of LED streetlights. The California Department of Transportation approved funding for LED conversion for streetlights on state-maintained roads and in maintenance facilities. Pacific Gas and Electric offers performance-based incentives for LED conversion.

Caltrans adopted performance specifications for lighting fixtures in fiscal year (FY) 2009–2010 and tested deployment on bridges and at selected intersections in FY 2010–2011. Vendors that met the performance specifications were identified, and Caltrans purchased more than 40,000 fixtures by May 2012. If the funding continues in FY 2012–2013, the conversion could be completed by the end of 2014.

The state's Department of General Services' Procurement Division is investigating the possibility of putting the Caltrans-specified fixtures on the state contract, which would allow city and county governments to purchase the products at volume prices, accelerating the conversion of the state's roadway, street, and outdoor lighting systems to LED technology.

Pacific Gas and Electric and other California electrical utilities are providing performance-based incentives that will reduce the total cost of the LED conversions. Many of the state's electrical utilities own and operate street lighting systems for city and county clients; the benefits of lower energy use and of an increased operational lifetime with the conversion include fewer upgrades in infrastructure and electric grid capacity, improving the utility's return on investment.

Several utilities have been working with Caltrans on this initiative since 2003, when the lighting options first came under consideration. The development process has included human vision tasking studies at the School of Visual Sciences, University of California, Berkeley, to compare nighttime visual tasking under a variety of color lighting sources.

For more information about the LED conversion project, contact Gonzalo Gomez, Senior Electrical Engineer at Caltrans: gonzalo_gomez@dot.ca.gov.

The author is Coordinator, Statewide Energy Conservation and Alternative Energy Program (retired), California Department of Transportation; Chair Emeritus of California's Energy Policy Advisory Committee; and member of the TRB Special Task Force on Climate Change and Energy.

Models indicate that without the Washington State Commute Trip Reduction program, which helps to manage transportation demand, traffic congestion in Seattle and nearby areas would be 8 percent greater.

PHOTO: ORAN VIRIYNCY

Washington State's Commute Trip Reduction Program

Reducing Emissions and Growing the Economy by Managing Transportation Demand

KEITH COTTON, KATHY JOHNSTON, KATHY LEOTTA, AND SETH STARK

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Twenty years of investment in Washington State's Commute Trip Reduction (CTR) program have built a foundation of partnerships for managing transportation demand. The program has improved transportation system performance—modeling analysis indicates that without CTR, delay in the Central Puget Sound region, which includes Seattle, would be nearly 8 percent greater.[1] CTR has benefited the economy, the environment, and communities by reducing air pollutants, greenhouse gas (GHG) emissions, and fuel consumption.

[1] The 2009 CTR survey data indicate that if CTR program participants in the Central Puget Sound region returned to driving alone to work at the same rate as they did before the program started, the freeway and arterial system would need to accommodate 22,500 additional drive-alone vehicle trips during the morning peak commute period. These additional vehicle trips would increase freeway and arterial system delays in the morning peak by approximately 12,900 hours, an increase of almost 10 percent in freeway delays and an increase of almost 6 percent in arterial delays—or a 7.6 percent increase in combined freeway and arterial delays.

Managing Demand

The CTR law was enacted in 1991 to improve air quality, reduce traffic congestion, and decrease fuel consumption through employer-based programs that encourage alternatives to driving alone to work. Today the program focuses on commuters traveling to large worksites and dense employment centers in congested urban areas.

In 2010, approximately 570,000 employees commuted to 1,100 worksites covered under the law. This CTR market represents approximately one-quarter of the state workforce, or about 25 percent of the commute-related vehicle miles traveled (VMT) in the state, and 6 percent of all VMT in the state.

Each partner in the CTR program plays a unique role:

◆ **Major employers** implement programs based on locally adopted goals for reducing vehicle trips and VMT (see locations map, Figure 1, page 29). Flexibility is allowed, so that employers can imple-

ment programs that make sense for them—however, they must make a good faith effort to achieve the program goals. Major employers participating in CTR include the Boeing Company, the Microsoft Corporation, and the Starbucks Corporation. Employers also may form transportation management associations (TMAs).

◆ **Local governments** provide technical assistance and services to help employers achieve the goals and may initiate outreach and service programs for commuters. Local governments must develop a CTR plan that is consistent with the local comprehensive plan.

◆ **Transit agencies** operate bus and vanpool services and coordinate program implementation with local governments, employers, TMAs, and others.

◆ Six **regional transportation planning organizations** provide planning support and coordination across jurisdictions, ensuring consistency in transportation and economic plans.

◆ Through the **Washington State Department of Transportation** (DOT), the state awards $3.9 million in grants to local governments every two years to support employer programs. Washington State DOT administers the funding, guides the program with policies and procedures, measures performance, and evaluates the program.

◆ The **CTR Board**, composed of representatives of the various partners, sets the policy direction, allocates the funding appropriated by the legislature, and reports to the legislature on the effectiveness of the program every two years. This innovative governance structure is one of the program's strengths.

The CTR partnership begins with the state investment—a total of $5.7 million every two years. Seventy percent of state CTR funds are distributed to local governments, which also invest their own resources to assist employers in the development and implementation of CTR programs.

Washington State DOT applies the balance for technical support and program tools and for measuring, evaluating, and reporting on the program's performance. Employers contribute far more to the program than they receive from the state and local investment; in 2006, employers invested $45 million in their CTR programs—more than $16 for each $1 invested by the state. A 2011 cost survey estimated that employers contributed an annual total of $58 million; that estimate, however, used a different method still being refined.

Climate Action

Transportation is the single largest source of GHG emissions in Washington State. Governor Christine Gregoire and the state legislature have directed the state DOT and other agencies to take action to support sustainability—such as reducing emissions, reducing VMT, increasing the use of alternative fuels, developing an electric vehicle infrastructure, conserving resources, and adapting and preparing Washington's transportation infrastructure for the impacts

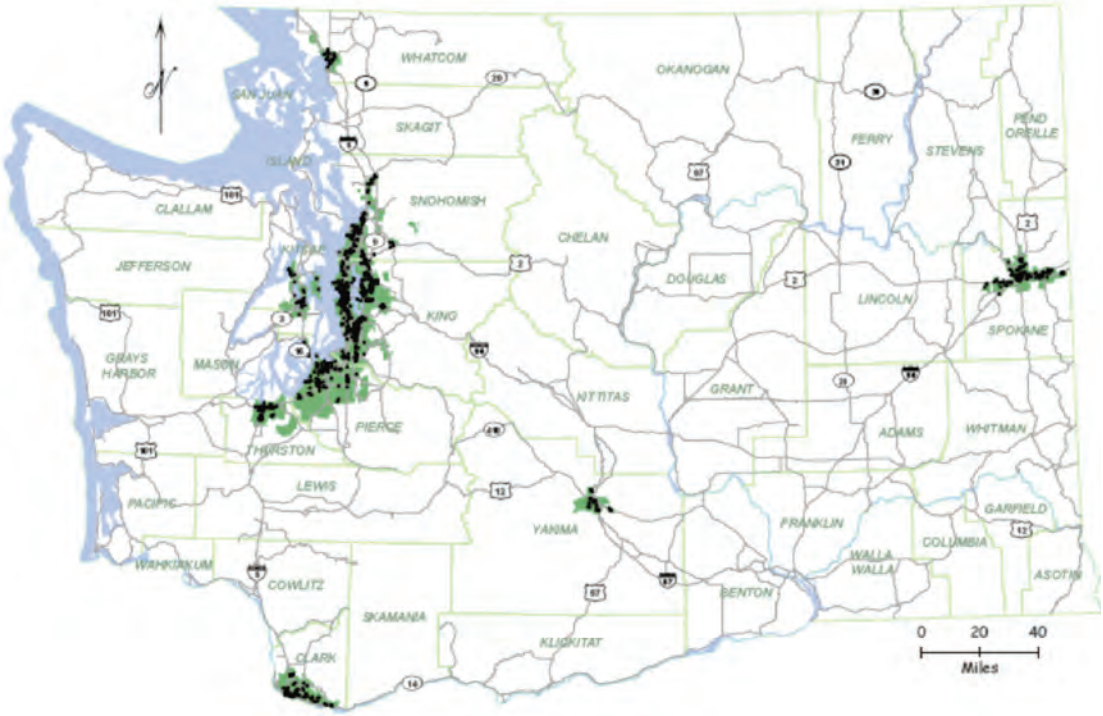

FIGURE 1 Location of CTR employers in Washington State.

Photo: Washington State DOT

CTR initiatives such as vanpool services help reduce vehicle miles traveled (VMT) in Washington State; some participants bicycle to pickup points.

of changes in the environment.[2]

In a 2009 Executive Order, Governor Gregoire directed Washington State DOT to analyze VMT in the state and to develop strategies to reduce greenhouse gas emissions from the transportation sector. The department's analysis finds no "silver bullet"—that is, no single strategy that will meet all of the state's emissions goals (*1*). The report finds that major contributions from each set of strategies, including an expanded CTR program, are necessary to reduce GHG emissions significantly. Many of the strategies would require changes in policy, funding, and authority.

The report finds that the state cannot by itself significantly reduce emissions from the transportation sector without collaborative and comprehensive actions by private citizens, businesses, and regional and local governments. The CTR program offers a working model, relying on collaborative and comprehensive action across a variety of groups.

[2] Revised Code of Washington (RCW) 70.235.020: Greenhouse gas emissions reductions; RCW 47.01.440: Adoption of statewide goals to reduce annual per capita vehicle miles traveled; RCW 43.21M.010: Statewide integrated climate change response strategy; RCW 43.19.648: Fuel usage; see http://apps.leg.wa.gov/RCW/.

Program Performance

The CTR Board's 2011 report describes the program's progress toward its goals and the program's benefits for the economy, transportation system performance, fuel savings, and emissions reduction (*2*).

The program's approach to goal setting and performance measurement has undergone changes. The CTR program's performance is measured through surveys of employees at participating worksites. In 2006, the program was reoriented with new goals, leading to refinements in the measurement methodologies. A comparison of the most recent complete survey data with the baseline survey data determines the program's performance.

The program's goals are to reduce the drive-alone rate by 10 percent and VMT per employee by 13 percent at CTR worksites between 2007 and 2012. These targets are designed so that anticipated job growth would not be constrained by the additional demand on the transportation system.

CTR worksites reduced the drive-alone rate by 4.8 percent and the VMT per employee by 5.6 percent from the 2007–2008 baseline survey to the 2009–2010 progress survey, achieving almost half of the goals for 2012. The reductions translate to nearly 16,000 fewer daily round-trip vehicle trips—that is, 32,000 one-way trips—on the roadways.[3]

[3] Compared with vehicle trips that would have occurred in 2009–2010 if the vehicle trip rate had remained the same as in 2007–2008.

Photo: Washington State DOT

With 2012 targets of reducing the drive-alone rate by 10 percent and VMT per employee by 13 percent, CTR worksite reductions have already led to 16,000 fewer daily round trips.

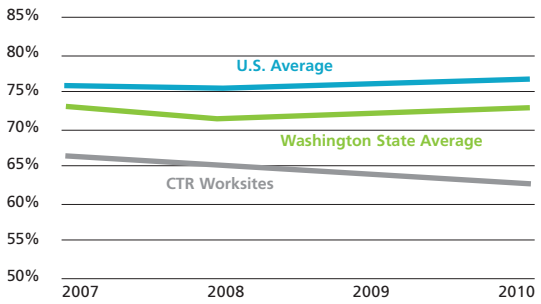

FIGURE 2 Comparison of drive-alone rates for commute trips. (Sources: American Community Survey and Washington State DOT)

In 2009, the Puget Sound Regional Council estimated that the choices made by commuters in the CTR program since its start in 1993 avoided an increase of nearly 8 percent in congestion for the central Puget Sound region—the equivalent of 12,900 hours of delay and $99 million in lost time and wasted fuel. Statewide, CTR worksites do better at reducing vehicle trips than the rest of the state and the nation (see Figure 2, above).

During the economic recession, the state lost approximately 140,500 workers, while CTR employers added 14,393 workers. Nonetheless, daily vehicle trips to CTR sites increased by only 1,225, placing far less demand on the transportation system than expected and reducing the need for additional state investments in highway capacity (see Table 1, below).

By averting an increase in vehicle trips associated with increased employment, CTR participants reduced VMT by 160 million each year between 2007 and 2010. This saved approximately 71,500 metric tons of greenhouse gas emissions annually—the equivalent of burning 389 railcars of coal—and approximately 8 million gallons of fuel each year. CTR commuters saved more than $22 million in fuel expenses in 2010.

Research and Evaluation

The CTR program began as a demonstration project requiring regular measurement, evaluation, and reporting. Although the program has moved beyond demonstration status, applied research, regular measurement, and evaluation remain essential—and required—components.

When the program was established in 1991, the legislature created the CTR Task Force, with members appointed by the governor to represent employers, local government, transit agencies, the state, and the public.

The CTR Task Force submits biennial reports to the legislature on the costs and benefits of the program. These reports present data, evaluations, and research, and have brought about changes to the program, as well as creating new programs that support transportation demand management. In 1994, for example, research by the CTR Task Force led to the creation of the Rideshare Tax Credit to spur employer investments in incentives and subsidies for employee commuting.

Focus on Urban Growth Centers

The most sweeping change to the program came in 2006 through the CTR Efficiency Act, based on extensive research by the CTR Task Force and input from partners (*3, 4*). The legislature unanimously adopted the task force's recommendations to focus on urban growth areas in the most congested parts of the state, to increase the coordination of planning, and to create the voluntary Growth and Transportation Efficiency Center (GTEC) program to assist urban growth centers in enhancing trip reduction programs. The task force sought to link economic development more closely with transportation efficiency.

Washington State provided a total of $2 million in two-year grants to launch GTEC programs in seven cities, which were required to contribute 50 percent in matching funds. These programs broadened CTR by reaching out to smaller employers, schools, and neighborhoods in the state's most congested urban areas.

The additional investment established new ways for local partners to engage the business community. Local partners were allowed the flexibility to design a GTEC program aligned with local objectives and to expand the benefits to a larger share of the travel market.

The GTEC program attracted strong interest from local partners, and the CTR worksites performed well, but state transportation revenue shortfalls led to a discontinuation of funding in 2009, after two years of implementation. Even without the funding, however, local implementation has continued at

TABLE 1 Comparison of Employment at CTR Worksites and Washington State

	Employment at CTR Worksites	Percent Change	Daily Vehicle Trips to CTR Worksites	Percent Change	Employment in Washington State	Percent Change
2007	513,720		356,861		3,154,787	
2010	528,113	+2.8	358,086	+0.3	3,014,335	– 4.7

Sources: Washington State DOT and U.S. Department of Commerce

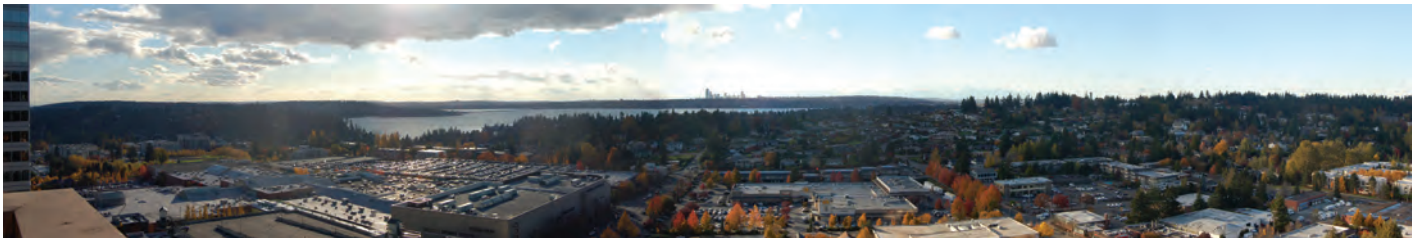

Photo: Andre Chinn

The City of Bellevue, Washington, adopted Connect Downtown—a plan under Washington State's voluntary Growth and Transportation Efficiency Center program—in 2008.

some of the designated GTECs, and some CTR implementers are asking for more flexibility in implementing programs—similar to that allowed to the GTECs.

Key Program Lessons

Partner engagement contributes to the program's success and drives its evolution.

The CTR program is a series of complex partnerships in a customer-driven structure, not a hierarchical, centralized administration. This structure is designed to integrate and align the interests and goals of the partners.

Recognizing local interest in new approaches and connecting to local objectives allows local perspectives to influence the statewide structure. Including business interests in the governance structure was critical in avoiding backlash. As a result, the feedback process has helped to drive the program from a regulation to a more transparent, bottom-up approach.

State leadership is critical.

Without state leadership, the program would not have continued for 20 years. The legislative mandate built the program up, and without the resources provided through the program—including grants for local governments, plus measurement and technical assistance from the state—partnership contributions would drop and the program's infrastructure would weaken (*5*).

Goals should knit partner interests together.

Goals align interests and provide clarity about what the partnership is trying to accomplish. Goals should be meaningful, measurable, and integrated. Employers, local governments, and legislators have supported the CTR program at crucial times—for example, when program budgets have been cut—because they see the value of what the program is trying to accomplish.

Photo: Washington State DOT

CTR conducts regular surveys and assessments of the program's effectiveness.

Measurement, evaluation, and reporting are critical.

The CTR program's regular assessment of what works is part of its success. Research by the CTR Task Force suggested that the evaluation approach was more rigorous than that of other programs (*6*).

The program provides employers with regular reports on commuting to their worksites. Local governments use the information to provide support to employers and to track progress toward their goals. Washington State DOT and the CTR Board use the data to evaluate the costs and benefits of the program and report to the legislature. The legislative reports provide a forum for sharing successes, for connecting customer and partner stories with the legislature, and for recommending program or policy changes. Evaluation plays a role in convincing the legislature to continue funding the program.

Flexible TDM networks can provide leverage points and spur innovation.

Each partner in the CTR program can build on its funding, communication networks, and relationships to implement innovative strategies to meet specific objectives. For example, the GTEC program helped to fund Downtown on the Go, a collaborative program of the City of Tacoma, Pierce County, Pierce Transit, and the Chamber of Commerce. The program extended some of the standard CTR approaches and incorporated new ideas as well—for example, partnering with employers and a local bank to offer mortgage discounts for people moving to the downtown vicinity from an outlying area.

CTR and other Washington State DOT programs are mutually supportive.

In 2011, when Washington State prepared to toll the SR-520 floating bridge, the communications strategy included reaching out to CTR employers. Washington State DOT's innovative program for construction traffic management helps keep people and goods moving

by expanding coordination and mitigation for roadway construction. When mitigation is required, the department develops a trip reduction target to keep traffic moving as in normal circumstances. The state DOT works with local partners—including cities, counties, and transit agencies—to develop trip reduction programs to meet the target, building on the demand management infrastructure in place.

Investment Framework

Washington State DOT has established a decision-making framework, Moving Washington, to create an integrated, 21st century transportation system. The principles elevate demand management to one of the state's three primary investments in transportation solutions—joining efficient operations and strategic capacity additions.

As the department organizes around this investment framework, engaging partners and aligning their investments to support corridor performance objectives will be a key. CTR offers a potential model. The approach may challenge CTR to organize by corridors and to translate its benefits for corridor needs and solutions.

Assessing New Directions

In 2010, the CTR Board initiated an assessment to chart a new direction, reaching out to employers and local and regional governments through workshops and surveys and engaging in scenario planning. Some local governments expressed interest in greater local determination and flexibility—for example, expanding the program to address other trip purposes and to involve smaller employers.

CTR has demonstrated strong performance within its target markets, but the scope encompasses only 6 percent of total VMT in the state—a relatively small part of the transportation emissions challenge. How can the program adapt to meet broader goals? Is the current success "good enough"? The CTR Board's recommended changes to the program are forthcoming.

Research Needs

Applied research can help inform program design and implementation:

◆ What are the economic benefits of public and private TDM investments for suburban and rural communities?

◆ How can demand management strategies, operational strategies, and capacity investments be considered and traded off in a common cost–benefit analysis? For example, as revenue constraints increasingly challenge state and local transportation agency plans to increase roadway capacity, can demand management strategies become a first-choice approach for cost-effective mobility improvement?

◆ How are demand management targets being used at the local, regional, and state levels? How do these targets influence strategies and investments? How is progress toward the targets measured?

◆ What is the durability of investments in changing behavior, for example, through education and incentives? How does behavior change after the intervention strategy ends?

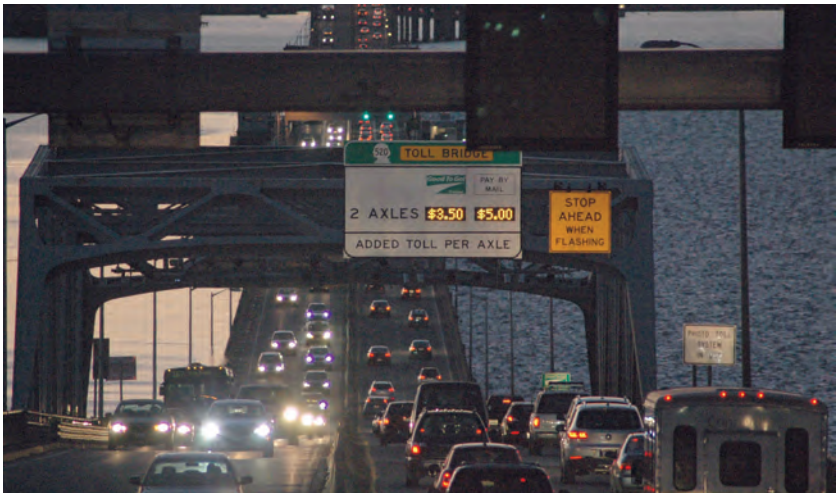

PHOTO: WASHINGTON STATE DOT

Outreach to CTR employers was an important component of the communications strategy for tolling the SR-520 floating bridge.

Leveraging Resources

With increasing financial pressures on government at all levels, strategies for managing transportation demand, such as CTR, can be part of the solution and can lead to broader actions. The CTR approach helps reduce GHG emissions by engaging employers in trip reduction and by fostering partnerships that link economic development and transportation efficiency.

Continuing to engage transportation partners will help leverage resources and align goals. Learning and adapting along the way will be critical to success.

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Photo: Ronald Killian

Ecodriving

The Science and Art of Smarter Driving

RONALD KILLIAN

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(*Photo above:*) More than 30 states and the District of Columbia have some sort of anti-idling regulation. Drivers can avoid engine idling and employ fuel-saving driving techniques to reduce the GHG output of personal vehicles.

Ken leaves home for work. He warms up his car engine in the driveway. His car roof and trunk are loaded with unnecessary equipment; the tires are underinflated. Ken drives with jack-rabbit starts-and-stops to pick up his breakfast, idling his automobile in the fast-food drive-through lane. He then heads on to the toll road, driving at up to 70 mph with the car windows open until reaching the traffic jam at the toll booths; without a transponder, he cannot zip through the EZ-Pass lane.

Arriving at work, Ken parks in a space that requires backing out when he leaves, not driving forward. After work, he drives to the drugstore, but forgets about his other errands until arriving home; then he drives back out to the grocery store and the post office.

Ken is not a smart driver—and he is contributing to energy waste and climate change.

Driving Smarter

With the U.S. and global economies struggling, with the nation dependent on foreign oil, with gasoline prices edging toward $4 per gallon, and with the effects of climate change becoming more apparent, many government agencies are searching for quick fixes and longer-term strategies to reduce fuel consumption and costs, vehicle- and roadway-related expenses, and carbon emissions. This is appropriate, because U.S. transportation consumes 28 percent of the nation's energy—approximately 13 million barrels of petroleum per day (*1*). In 2009, according to a report assessing U.S. transportation infrastructure, "Americans wasted 4.8 billion hours and 3.9 billion gallons of fuel sitting in traffic, at a cost of $115 billion—more than one-sixth the amount of oil imported annually from the Persian Gulf" (*2*).

One simple, economical way that individuals, businesses, and governments can combat inefficient

vehicle fuel consumption and its adverse effects is by adopting smarter driving techniques through ecodriving—also known as green driving, smart driving, and fuel economy–maximizing behavior. Ecodriving is an approach that incorporates techniques and technologies to reduce fuel consumption and costs, greenhouse gas (GHG) and other air pollutant emissions, vehicle miles traveled (VMT), vehicle and road degradation, and accident-related costs—such as property damage, injuries, fatalities, and insurance.

Ecodriving techniques can improve fuel economy by up to 33 percent for some drivers—for example, the distance traveled by an ecodriver on $4 of fuel would require $5.32 of fuel for an aggressive driver. Technological innovation and route selection are part of the program, through intelligent transportation systems (ITS) and adaptive driving behavior. In sum, ecodriving combines the science and art of efficient and safe driving with the American spirit of individual and collective responsibility and action (*3, 4*).

Evolving Principles

Ecodriving evolved in the United States from the "hypermiling" adopted by hybrid vehicle driving clubs.[1] Hypermilers exceed a vehicle's fuel efficiency as estimated by the U.S. Environmental Protection Agency (EPA), by modifying driving habits and adopting techniques originally applied in the Mobil Economy Run—an annual coast-to-coast road trip and demonstration that started in the late 1930s; and in the years of gasoline rationing during World War II; during the 1973 oil crisis; in the U.S. Department of Energy's short-lived Driver Energy Conservation Awareness Training Program; and later in times marked by the worldwide volatility of fuel prices (*5*).

Ecodriving is recognized internationally for its health, safety, and environmental benefits and for its contributions to national security. Ecodriving is included in the 2007 report of the United Nations' Intergovernmental Panel on Climate Change (*6*), in recommendations from the International Energy Agency (*7*), and in a report of the World Health Organization (*8*). Green Communities Canada has established an EcoDriver Program, and Canada's ecoENERGY-vehicles program applies ecodriving principles. European examples include ECOWILL[2] and programs in the Netherlands,[3] Switzerland, Germany, and Austria. Programs are in place in Japan, Australia, and other countries.

Ecodriving has yet to mature as a national energy and emissions reduction policy in the United States but is a key measure in the Global Warming Solutions acts in California and Massachusetts; in North Carolina Department of Transportation's (DOT's) "Drive Green, Save Green" campaign; in the New England Governors' Conference resolution to create an ecodriving clearinghouse[4]; and in the campaign of the I-95 Corridor Coalition.[5] In addition, the Driving School Association of the Americas passed a resolution in support of ecodriving in 2009.[6]

An integrated, robust, national ecodriving strategy is a logical next step to reap the economic, national security, environmental, and social benefits from this low-cost, high-value approach.

PHOTO: ALDEN JEWELL

The Mobil Economy Run, an annual coast-to-coast competition for fuel-efficiency that ran from the 1930s to the 1960s, was an early showcase of ecodriving techniques.

Elements of Ecodriving

A review of several ecodriving programs and studies in Europe and North America reveals four main elements of a successful program:

1. Communication and marketing with public- and private-sector support;
2. Driver and instructor training;
3. Policy support with limited legislation and regulation; and
4. Research on behavioral factors and incentives, on quantifying and measuring benefits, and on vehicle technology and ITS.

Communications and Marketing

Educating drivers and fleet managers about how to become ecodrivers is an important element in any program, but societal understanding and acceptance are needed as well. Messages delivered through a variety of media to develop positive branding for ecodriving are necessary to capture the driving public's attention.

[1] See www.CleanMPG.com.
[2] www.ecodrive.org; www.ecodrive.org/en/what is_ecodriving-/benefits_of_ecodriving/.
[3] www.hetnieuwerijden.nl.
[4] Resolution No.194, 2010.
[5] www.I95coalition.org.
[6] www.thedsaa.org.

In its *Guide to Green Driving*, the Alberta Motor Association in Canada recommends regular tire pressure checks.

PHOTO: ALBERTA MOTOR ASSOCIATION

Although ecodriving is one of the most effective strategies for reducing fuel expenses and GHG emissions,[7] an ecodriving campaign does not need to focus on cost savings and climate change, especially in areas in which skepticism about climate change remains high. At a 2011 workshop, Elliot Martin of the University of California, Berkeley, suggested that rebranding ecodriving as a national security measure might broaden its support (*4*).

The Internet provides basic and extensive sets of ecodriving tips—more than 100 pointers can be assembled from several websites—and most are ready to implement for immediate results. Top tips usually include the following:

[7] Even with the modest assumption that only 20 percent of drivers would adopt the maximum scenario for ecodriving, Cambridge Systematics projected in the 2009 report Moving Cooler (www.movingcooler.info) that ecodriving would reduce GHGs cumulatively between 2010 and 2050 more than any other strategy, except strong pricing and a national 55-mph speed limit—more than aggressive strategies for land use, transit expansion, intercity rail, and employer-based trip reduction programs.

Massachusetts DOT's digital billboard messages are seen daily by thousands of highway drivers.

PHOTO: GERARD KELLEHER, MASSACHUSETTS DOT

◆ **Drive less and chain trips** to minimize time, fuel consumption, and VMT.

◆ **Go easy on the pedals.** Rapid starts and stops can increase fuel use by up to 40 percent. Maintain a constant speed and coast when possible.

◆ **Turn the engine off**—idling wastes fuel and money for zero mph. Idling for 10 seconds consumes more fuel than starting a vehicle. EPA lists more than 30 states and the District of Columbia with some form of anti-idling regulation (*9*), and campaigns against engine idling are under way in New York City, Minneapolis, Canada, Japan, and Europe (*10*). In the United States, an estimated 3.8 million gallons of gas and $15 million (at $4 per gallon) are wasted daily through voluntary idling, which also generates 40,000 tons of carbon dioxide emissions (*11*).

◆ **Check tire pressure monthly.** In 2005, an estimated 1.2 billion gallons of fuel were lost by driving on underinflated tires. Proper inflation can provide up to a 3 percent benefit per tankful of fuel, contribute to optimizing road-holding and braking distance, and reduce tire failure. The California Air Resources Board approved a regulation in 2010 requiring automobile service providers to check and inflate each vehicle's tires to the recommended pressure when performing any maintenance or repair work.

◆ **Tighten the gas cap.** Loose, damaged, or missing fuel tank caps allow 147 million gallons of fuel to evaporate annually.

◆ **Observe speed limits.** Fuel economy decreases 5 percent or more for every 5 mph above 60 mph in highway driving; for some vehicles, the decrease can start at 50 mph or less. Observing the posted speed limit—the standard for safe drivers—can increase fuel economy by 7 percent to 23 percent. Cruise control can improve highway mileage by 7 percent if used appropriately.

◆ **Watch your weight.** An extra 100 pounds in a vehicle can reduce the mileage per gallon by up to 2 percent. Roof racks and similar exterior accessories reduce fuel efficiency by increasing the aerodynamic drag.

◆ **Instant, fuel economy feedback displays**, like those installed in many hybrid vehicles for "dynamic ecodriving," may reduce highway fuel use by 12 percent to 14 percent (*4*, *12*).

◆ **Reduce air conditioning.** Because air conditioning can decrease mileage by 5 to 25 percent, use open windows at speeds up to 40 mph, and use air conditioning at speeds above 40 mph.

◆ **Buy a vehicle wisely.** A 2011 research report found that "vehicle selection has by far the most dominant effect" for on-road fuel economy—the best-performing vehicle sold in the United States is

nine times more fuel-efficient than the worst-performing vehicle. Nevertheless, the report warns not to neglect the effects of other driver-controlled factors—such as driving techniques, route selection, and vehicle maintenance—which can contribute to "a 45 percent reduction in the on-road fuel economy per driver" (*13*).

Creative Outreach

Varying the media can help in delivering the message. Websites with tips lists, videos, and virtual games involving driving skills are becoming more common.[8] In 2011, Massachusetts DOT began displaying "Drive Smart and Save" public service announcements on seven new digital billboards along state highways. A state's motor vehicles registry can disseminate ecodriving information to citizens through licensing, driver testing, and registration processes in paper and electronic formats.

Transportation agencies can be more creative in collaborating with the private sector, including organizations already involved in promoting safe and efficient driving—such as AAA, AARP, automobile manufacturers and dealers, and insurance companies and their foundations—as well as with the media, educational institutions, businesses, celebrities, and public officials. On-road, fuel-economy competitions can generate enthusiasm and interest, like the Green Grand Prix at Watkins Glen, New York.[9]

Driver and Instructor Training

In addition to general information for the public, a successful program includes the integration of ecodriving into the traditional training curricula for driving instructors and for new and licensed drivers. Experience in the Netherlands (*14*)—which began restructuring its programs in 1988—and in Austria and other European nations indicates the effectiveness of a two-phase approach (*15*):

1. One-on-one theoretical and practical training, followed by
2. Continued mandatory training and reinforcement after initial licensing.

[8] Sample websites with ecodriving messages include Massachusetts DOT, www.mass.gov/MassDOT/DriveSmart; North Carolina DOT, www.ncdot.org/programs/drivegreen; Metropolitan Washington Council of Governments, www.mwcog.org/transportation/ecodriving/; U.S. EPA, www.fueleconomy.gov; and FuelClinic.com. The United Kingdom's ecodriver.org has posted a video, www.youtube.com/watch?v=D8_iZNnsCro), and a Dutch video delivers tips via a parody of the *Dukes of Hazzard*, www.youtube.com/watch?v=Re92es9aPB8&feature=related.

[9] www.greengrandprix.com.

Creative media can help deliver the ecodriving message—such as this Dutch parody of the *Dukes of Hazzard* on YouTube.

In 2002 and 2003, more than 6,500 Dutch driving school teachers and examiners—that is, more than 90 percent—were trained in ecodriving principles; new driving manuals, driving exams, and refresher courses were introduced. Recent studies and workshops in Europe (*7, 16*), California (*4*), and Quebec (*17*) confirm the findings from earlier studies that without positive reinforcement, drivers' incentives and motivation to maintain a high level of compliance with ecodriving principles may wane within several weeks to months after the initial training. The initial improvements in fuel economy of 5 to 15 percent or more can drop to 5 percent without continued support (*18*).

Governmental Support

Governmental support for ecodriving programs and research is crucial. The motivations may vary but should resonate with the public—economics, public health and safety, national security, or even mitigating climate change. Vehicle fuel-economy standards are a key policy measure (*19*). The adoption and enforcement of anti-idling regulations are warranted for public health, cost savings, and fuel economy.

At least 33 countries have adopted electronic speed-limiter legislation, primarily for trucks and buses; these include the nations of the European Union, as well as Australia, India, Japan, and the

Photo courtesy Robert Gillespie, Green Grand Prix

A Factory Five diesel developed by West Philadelphia High School students leads the race at the Green Grand Prix in Watkins Glen, New York. The first stage of the competition takes place on the Watkins Glen International grand prix circuit; the second stage is conducted on local roads.

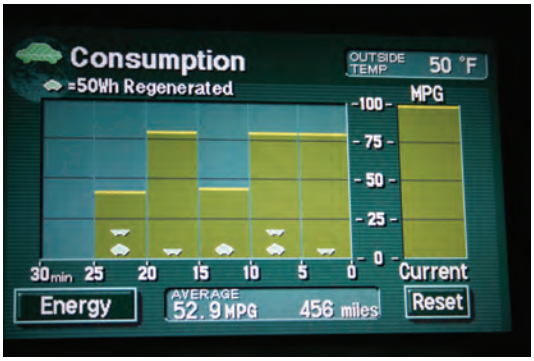

PHOTO: RONALD KILLIAN

Feedback mechanisms such as the one installed in the Toyota Prius allow drivers to monitor and adjust their driving for maximum fuel efficiency.

Canadian provinces of Ontario and Quebec[10] (*20*). In response to petitions from the American Trucking Associations, Road Safe America, and several motor carriers, the National Highway Traffic Safety Administration is expected to propose a rulemaking for a 68-mph truck limiter in summer 2012 (*21*). Nonetheless, ecodriving will advance more through education and cooperation than through government fiat—but legislation and regulations can play an essential supporting role.

Topics for Research

Longer-term and larger-scale research on the science and art of ecodriving remains critical to developing the best training programs; marketing and public education campaigns; real-time feedback mechanisms—such as the ScanGauge monitor or those installed in the Toyota Prius; and ITS and other vehicle-related technologies. Research also can improve understanding of driver behavior, motivations, and incentives and can enable more precise measurement of the many benefits of ecodriving.

Significant ecodriving research programs are under way at the University of California's Multi-Campus Research Program at Berkeley, Riverside, and Davis; and at the University of Michigan's Transportation Research Institute, Texas A&M Transportation Institute, and various U.S. DOT–sponsored and European programs.

Fleet Managers Lead the Way

Fleet managers are aggressively advancing ecodriving, primarily because of its cost savings. Managers of business, government, and military fleets are developing programs that decrease fuel consumption and increase safety and savings. Many have benefited from the EPA's SmartWay Program, a public–private collaboration with the freight transport industry.[11] Since its inception in 2004, SmartWay has assisted more than 2,900 U.S. corporations, including many of the nation's largest truck carriers, with supply-chain accounting tools and methods and has helped them save 50 million barrels of oil and $6.1 billion in fuel, while cutting more than 16 million metric tons of carbon emissions.

SmartWay emphasizes fuel-efficient technologies and ecodriving techniques, including reduced idling and speeds, improved aerodynamics and weight reduction, automatic tire inflation systems, single wide-based tires, driver training, and freight logistics. The program is producing results. At the November 2011 U.S. Freight Sustainability Summit, for example, SmartWay member Con-way reported that since 2008, it has achieved an annual reduction of approximately 6 million gallons of diesel fuel and 134 million pounds of carbon emissions from its fleets of 8,400 tractor trailers and 2,700 long-haul trucks by turning back the speed governors from 65 to 62 mph for tractor trailers, and from 70 to 65 mph for long-haul trucks.

Private-sector successes are many. United Parcel Service has minimized left-hand turns on delivery routes since 2004, saving 10 million gallons of fuel and reducing carbon dioxide emissions by 100,000 metric tons, equal to 5,300 passenger cars off the road for one year. Staples, Inc., has developed the EcoEasy program, which limits the top speed of its 1,750 delivery trucks, uses anti-idling technology and shift-point speed changes, purchases electric delivery vehicles, and provides special driver training. Fuel economy has improved by more than 25 percent since 2007, and the company has saved nearly 1 million gallons of diesel fuel annually.

Frito-Lay has applied an intensive approach to achieve more efficient driving by its 19,000 drivers for a fleet of 17,000 trucks. Three programs—Smart Miles, Smart Driver, and Road to Green—focus on vehicle technology and maintenance, driver training and follow-up support, and route management to reduce fuel consumption and maintenance costs, VMT, accident rates, and carbon dioxide emissions. Since joining SmartWay in 2005, Frito-Lay has saved more than 15 million gallons of fuel.

Changing Habits

Ken leaves home for work, warming up his car engine by driving his car immediately after turning on the ignition. His car is freed of its roof rack and of junk in the trunk, and the tires are properly inflated. He drives smoothly and carefully on his way to pick up breakfast. He parks the car, turns off the motor, and walks into the restau-

[10] Australia adopted a 62-mph limiter setting in 1990; the European Union followed suit in 1994; Japan chose a setting of 56 mph in 2003, and Ontario and Quebec went with 65 mph in 2009.

[11] www.epa.smartway.

rant. Afterward, Ken heads on to the toll road, driving as smoothly as possible through heavy traffic at 55 to 60 mph, with the windows closed. He anticipates slowdowns and avoids the traffic jam near the toll booth by zipping through the EZ-Pass lane with his transponder. He arrives at work and parks in a space that allows him to pull out going forward. Leaving work, he has planned out the shortest route home while running his errands at the drug store, grocery store, and post office. Ken is developing into an ecodriver.

Transportation and environmental agencies and regional organizations are positioned to take the lead in promoting ecodriving as an inexpensive, cost-effective, energy-efficient method that saves money; reduces fuel consumption, carbon emissions, VMT, and the costs of property damage, medical care, and insurance; and supports national security by reducing dependence on foreign oil. More effective marketing of this simple technique for saving money, energy, and reducing emissions should be pursued.

Additional research will increase understanding of more effective approaches to educating the public about ecodriving techniques and about the role of vehicle technology and ITS. More accurate metrics are needed for measuring the benefits of ecodriving, which should become a staple of daily driving habits in the United States.

Photo: CountyLemonade, Flickr

Southern Parkway in Utah posts a speed limit of 60 mph. Cars tend to be more fuel-efficient at 60 mph than at 65 mph; observing posted speed limits also can increase fuel efficiency.

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Photo courtesy Marlene Demery, City of Napa

Innovative Approaches to Reduce Greenhouse Gas Emissions from Transportation

San Francisco Bay Area Launches Variety of Pilot Projects

BRANT ARTHUR

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(*Photo above:*) The City of Napa received a grant through the Bay Area's Metropolitan Transportation Commission to conduct a cold in-place pavement recycling project.

Reducing greenhouse gases is a team sport, but on the transportation side, all too often the team is struggling to learn how to play the game. California has charged each region to develop Sustainable Communities Strategies; as part of its effort, the San Francisco Bay Area has launched a series of pilot projects to test new approaches to reduce greenhouse gases from transportation. Not only are the ideas innovative, but teamwork appears to be key—the number of partnerships forming to test the approaches hints at new methods to transform a slowly evolving sector.

The Bay Area's Metropolitan Transportation Commission (MTC) launched the Climate Initiatives Program in 2010 to spur ground-breaking transportation ideas for reducing greenhouse gas emissions. The program is designed to test strategies to reduce transportation-related emissions and vehicle miles traveled, as well as to encourage the use of cleaner fuels and to build a knowledge base through evaluation that can inform other Sustainable Communities Strategies.

MTC has awarded 17 grants totaling $33 million to projects involving clean vehicles, parking management, transportation demand management, and controlling school-related emissions. The funding for these pilot projects comes from the federal Congestion Mitigation and Air Quality Improvement Program; the goal is to reduce greenhouse gases and criteria air pollutants from transportation, including ground-level ozone, particulate matter, carbon monoxide, sulfur oxides, nitrogen oxides, and lead.

Range of Projects

Pilot projects launching this year will work to create an electric taxi fleet, a real-time ridesharing project in three Bay Area counties, and a bikeshare project spanning the region from San Francisco to San José, including Palo Alto and Redwood City. Estimated emission reductions from the projects are shown in Table 1 (below), along with the grant amounts awarded. The emission reductions are best guesses and will be revised as the projects progress in 2012 and 2013. Until data come from the evaluation, comparisons or lessons are premature.

The table of projects, however, does not tell the whole story. The following examples from each of the main project categories present the accomplishments so far.

Electric Vehicle Taxis

Clean vehicles are important in achieving long-term reductions of greenhouse gases. For the electric taxi pilot project, San Francisco and San José teamed up with the private firm Better Place to test out a battery-switching technology for a fleet of electric vehicle taxis.[1] The partnership with Better Place includes an additional $8 million in matching funds from the startup electric vehicle service provider.

The project demonstrates electric vehicles and a new approach to switchable battery technology, which can get taxis back on the road within minutes instead of waiting hours for a charge. The project requires the installation of four battery-switching stations in San Francisco and San José. The local match includes 61 electric vehicle taxis with switchable batteries. These electric vehicles primarily will be for neighborhood taxi service in San Francisco.

The project also tests the integration of battery-switching stations into the electric power grid. A new center in San Francisco will offer consumer education on electric vehicles and battery-switching stations.

Real-Time Ridesharing

Real-time ridesharing is a social network using software and smartphone applications, or apps, to allow riders and drivers to match instantly and to carpool with other commuters on the same route. The WeGo Rideshare project will be the largest demonstration yet of real-time ridesharing technology in terms of funding and of the number of partners involved.[2]

The Sonoma County Transportation Authority is leading the effort, with partners at the Contra Costa Transportation Authority and the Transportation Authority of Marin. The project is moving forward with assistance from the Climate Protection Campaign, a local nonprofit, plus matching funds from a technology partner, Avego Corporation.

Building a critical mass of riders and drivers is key to the success of real-time ridesharing. The most promising locations for user groups in each county include college campuses, large employment centers, and commuter rail stations with limited parking.

Although the program specifically addresses real-time ridesharing, WeGo Rideshare can integrate with other ride-matching services and alternative transportation programs to meet needs throughout the Bay Area. In Sonoma County, for example, WeGo

PHOTO: BETTER PLACE

A Renault Fluence Z.E. leaves a Better Place battery-switching station in Denmark. San Francisco and San José have partnered with Better Place to test the battery-switching technology on electric taxis.

TABLE 1 List of Projects with Estimated Carbon Reductions and Size of Grant Awarded

Project Name	Estimated CO_2 Reduced (tons/day)	Grant Amount (millions)
Electric Vehicle Taxis and Battery Switch Stations	10.96	$6.99
Port of Oakland Shore Power Initiative	7.67	$3.00
Bay Area School Transportation Collaborative	4.93	$0.87
WeGo Rideshare (dynamic ridesharing)	4.11	$1.50
e-Fleet: Car Sharing Electrified	4.11	$1.70
Integrated Public–Private Partnership Transportation Demand Management Program	3.29	$0.75
Bikesharing Pilot Program	3.29	$4.29
Cold In-Place Recycling (for pavement)	2.74	$2.00
Santa Rosa CityBus Automatic Vehicle Location System	2.60	$0.60
Innovative Bicycle Detection System	2.06	$1.50
City of Berkeley Transit Action Plan	1.92	$2.00
Making the Last Mile Connection	1.73	$1.49
Education and Encouragement School Route Maps	1.29	$0.25
Local Government Electric Vehicle Fleet Project	1.23	$2.81
Green Ways to School Through Social Networking	1.01	$0.38
Bike Repair and Encouragement Vehicle, or BikeMobile	0.63	$0.50
Electric Vehicle Strategy Funding Reserve	-	$2.38

[1] www.betterplace.com/global-progress-north-america-california.

[2] http://wegorideshare.com/.

Photo: WeGo Sonoma

The WeGo Rideshare project allows riders and drivers to connect using software and smartphone applications.

Rideshare is planning to collaborate with Santa Rosa CityBus to test the integration of real-time transit matching with the new automatic vehicle location (AVL) devices to be installed in fall 2012. The Climate Initiatives Program is funding the AVL project.

WeGo Rideshare is ramping up in the summer and fall of 2012 and will operate for more than one year, with the possibility that the marketplace for empty seats will build sufficient momentum to continue beyond the pilot phase. A successful project will prove that real-time ridesharing is a cost-effective, efficient use of the roadways.

Bikesharing

Bikesharing systems make bicycles easily and affordably available to people for short trips in urban areas. A partnership between the Bay Area Air Quality Management District and several cities and counties is launching a pilot project[3] with 1,000 bicycles at 100 kiosks, located between San Francisco and San José. The project will test the viability of a single regional bikesharing program serving a range of municipalities. The largest share of the bicycles—500—will be placed in 50 stations in San Francisco; San José, Palo Alto, Redwood City, and Mountain View are preparing to receive the rest.

[3] www.sfmta.com/cms/bshare/indxbishare.htm.

Photo: Dan Burden

A pilot project of the Bay Area Air Quality Management District and local jurisdictions will establish bikesharing facilities along the Embarcadero and in other Bay Area locations.

The San Francisco bicycle stations will be dispersed within a 1.78-square-mile area that is dense, mixed use, and transit-rich, as well as flat and bikeable. The density of stations is expected to be the key to success; the program's launch is scheduled for the end of summer 2012. With an influx of tourists anticipated for the America's Cup regatta in October, the project will help address first- and last-mile connections to transit. Plans call for significant expansion if the pilot project proves successful.

Berkeley Transit Action Plan

The City of Berkeley Transit Action Plan (BTAP) incorporates several strategies to reduce carbon emissions from transportation.[4] The main focus is to develop creative incentives for shifting modes of transportation. Strategies include targeted outreach and providing information about alternative transportation modes, in conjunction with financial incentives such as transit passes for participating employees and residents. The program will offer subsidized City CarShare memberships to businesses; City CarShare is working with the partnership to make carshare pods financially feasible in moderate-density neighborhoods along the Telegraph and Elmwood commercial districts.

Parking is another focus of BTAP; plans are to implement different parking rates for different times of day and on different days of the week. The rates will be coordinated with a reconfiguration of monthly parking permits in city garages, intended to reduce the incentive for daily driving. Plans also call for the coordination of off-street and on-street parking rates to encourage short-term on-street parking and longer-term parking off the street.

Other jurisdictions will be involved; for example, the parking facilities at the University of California, Berkeley, will sync their pricing with the pricing strategies of the city. Half-day and full-day parking will be implemented in on-street areas, and variable-rate pricing structures that increase rates for the second hour of paid parking will be tested. The project will use license plate recognition to enforce time limits efficiently.

The program will take advantage of grants from the Bay Area Air Quality Management District and the Federal Highway Administration. The total budget for the project in Berkeley comes to $4.5 million; planning and development have been in progress for several years.

Bikemobile

An innovative project aims to reduce emissions related to school travel. The Bike Repair and Encour-

[4] www.cityofberkeley.info/ContentDisplay.aspx?id=71002.

agement Vehicle, or Bikemobile, is a mobile truck that promotes walking and biking to school, as well as to recreation centers and community events.[5] Bikemobile provides bicycle repairs and safety education to encourage bicycle use at grade schools across Alameda County. The Bikemobile is scheduled to visit 200 to 275 sites per year, with return visits to encourage continued use of bicycles through incentives.

The Alameda County Transportation Commission manages the project, which is run by a local nonprofit, Cycles of Change. The Bikemobile outreach focuses on the large number of students who may not be riding their bicycles because of easily fixed problems, such as flat tires. By going directly to schools, Bikemobile staff connect with students who do not have access to repair services or who are unable to afford repairs.

Bikemobile, a mobile truck that promotes walking and biking for students and young people, is managed by the Alameda County Transportation Commission.

Benefits of Collaboration

Collaboration is a major theme of the grant program, and the projects display collaborations between public agencies and private partners, as well as between government agencies in multiple jurisdictions. The benefits of collaboration are evident in MTC's Climate Initiatives Program (*1*). For example, new approaches that may not have received enough support from any single jurisdiction can be tested; some approaches gain the scope necessary for adequate testing. To be effective, however, collaboration may require significant resources, as well as time for building trust.

Government may not be commonly linked with innovation and may not be well-positioned to spur innovation, but the Climate Initiatives Program has brought together several innovative companies pioneering approaches to transportation that otherwise could not be tested on the same scale and with the same exposure as the grants have provided. Collaboration unlocks additional funding and potential outreaches through the partnerships established in nearly every project in the program. Many companies and organizations are investing significant amounts of money to test out ideas in attractive markets like the San Francisco Bay Area.

Many of the pilot projects are attempting to revive some of the most tried and true methods of reducing greenhouse gases from transportation—for example, through carpooling or bicycling. Many of the pilot projects rely on mobile technology to make these solutions more practical to more people in more situations than ever before.

Such programs are easily implemented on relatively smaller budgets and shorter timelines compared with large infrastructure projects. The pilot projects address the need to achieve more efficiency from available infrastructure. The Climate Initiatives Program demonstrates the value of getting started and trying something new. The program pairs the testing of near-term projects with much longer-term policy development, such as California's Sustainable Communities Strategies.

The work in the Bay Area demonstrates regional leadership in developing new ideas to reduce greenhouse gases from transportation. Results from these diverse pilot projects will be released in the next few years, and the successful projects will be deployed throughout the region.

[5] http://bike-mobile.org/.

Photo: Gavin Newsom Flicker Photo

In 2009 the Mayor of San Francisco unveiled electric vehicle charging stations for city and county vehicles as well as City Car Share and Zip Car plug-in hybrid vehicles.

Reference

1. Taylor, B. D., and L. Schweitzer. Assessing the Experience of Mandated Collaborative Inter-Jurisdictional Transport Planning in the United States. *Transport Policy* , Vol. 12, No. 6, pp. 500–511 (2005).

Sawyer Glacier in southeast Alaska's Tracy Arm. Although ice loss from glaciers and ice caps has declined, melting land ice is increasing and contributing to sea-level rise.

Photo: Alena Jensen, National Oceanic and Atmospheric Administration

NATIONAL RESEARCH COUNCIL REPORTS

A Sea Change

Adaptations in a Warming World

NANCY F. HUDDLESTON, ANNE LINN, AND CLAUDIA MENGELT

The authors are with the Division on Earth and Life Studies, National Research Council of the National Academies, Washington, D.C. Huddleston is Director of Communications. Linn is Senior Program Officer, Board on Earth Sciences and Resources, and served as Study Director for the Committee on Sea-Level Rise in California, Oregon, and Washington. Mengelt is Senior Program Officer, Ocean Studies Board, and served as Study Director for the Panel on Adapting to the Impacts of Climate Change.

Global sea level is projected to rise an average of 1 meter, or more than 3 feet, by the end of the 21st century, according to *Sea-Level Rise for the Coasts of California, Oregon, and Washington, Past, Present and Future,* a new report from the National Research Council (NRC).[1] Along with global sea-level projections, the report provides the first comprehensive regional projections for the coasts of the three states.

Sea-level rise poses enormous risks to the valuable infrastructure, development, and wetlands that line the nation's coast. This new study was conducted in response to a California executive order issued by Governor Arnold Schwarzenegger in 2008, directing the state's agencies to plan for sea-level rise and coastal impacts; the order also required an independent assessment of sea-level rise by the National Research Council. The States of Oregon and Washington, the U.S. Army Corps of Engineers, the National Oceanic and Atmospheric Administration, and the U.S. Geological Survey joined California in sponsoring the study.

[1] www.nap.edu/catalog.php?record_id=13389.

Projecting Changes

Sea-level change is linked to changes in the Earth's climate. A warming climate causes global sea level to rise principally by (*a*) warming the oceans, which causes seawater to expand, increasing ocean volume, and (*b*) melting land ice, which transfers water to the ocean. After a few thousand years of relative

Photo courtesy of Armand Thibault

High surf during a high tide of nearly 9 feet removed the front lawn of the Pacific Sands Resort at Neskowin, Oregon, on January 9, 2008.

Contribution of Melting Land Ice to Sea-Level Rise

Since 2006, the rate of ice loss from the Greenland Ice Sheet has increased; according to most analyses, the contribution of the Antarctic Ice Sheet to sea-level change has shifted from negative—that is, lowering the sea level by accumulating ice—to positive, or raising the sea level. Ice loss rates from glaciers and ice caps have declined in the same period, but not enough to offset the increases in ice sheet melt. Melting land ice is now the largest contributor to global sea-level rise.

stability, the global sea level has been rising since the late 19th or early 20th century, when global temperatures began to increase. Tide gage measurements show that global sea level rose an average of 1.7 millimeters (mm) per year during the 20th century. More recent and precise satellite altimetry measurements and tide-gage records show that the rate increased in the past 20 years to 3.1 mm per year.

Sea level is projected to rise at an even faster rate, although the estimates vary with the method of projection (Figure 1, right). The most widely used projections come from the Intergovernmental Panel on Climate Change (IPCC), which uses computer models to simulate the physical processes contributing to global sea-level rise. An alternative empirical approach, used by Vermeer and Rahmstorf in a 2009 study (*1*), is based on the observation that sea level rises faster as the Earth gets warmer.

Neither method, however, fully accounts for the recently observed rapid changes in the behavior of ice sheets and glaciers (see box, above). The NRC's new projections use model results and extrapolations of historical trends and account for the rapid changes in ice behavior; the NRC results fall between the two estimates.

Regional Projections

Sea level is not uniform everywhere and is changing continually. On the West Coast, factors that affect relative sea-level rise include regional climate patterns such as the El Niño–Southern Oscillation, which warm and cool the Pacific Ocean; the rising and sinking of land along the coast as a result of geologic processes such as plate tectonics; and proximity to Alaska glaciers, which exert a gravitational pull on sea water.

Along the West Coast, plate tectonics affects regional land levels significantly (Figure 2, page 46). Washington, Oregon, and the northernmost parts of California lie along the Cascadia Subduction Zone, where the ocean plate descends below the North American plate, pushing the land upward. In the rest of California, the Pacific and North American plates are sliding past one another along the San Andreas

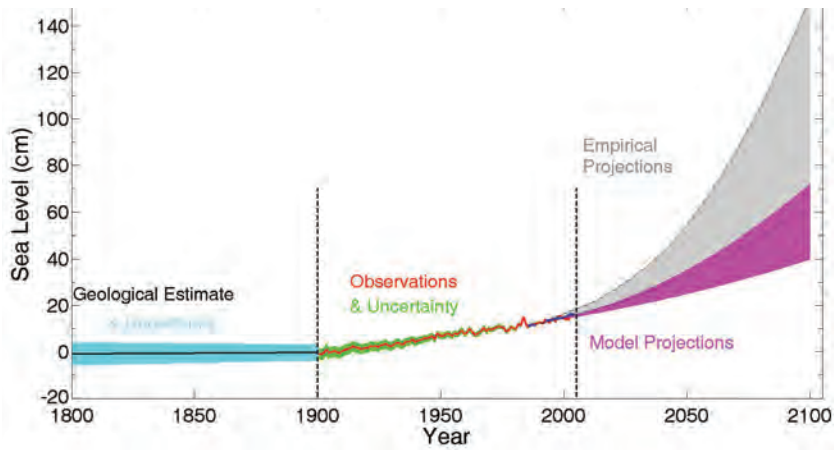
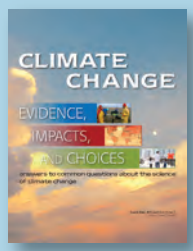


FIGURE 1 Observed and projected sea-level rise. After a few thousand years of relative stability, sea level began to rise along with global temperatures, beginning around 1900, as measured by tide gages (red line) and satellite altimetry (blue line). Projections of sea-level rise to 2100, in dark pink, are from IPCC and are based on global climate models that estimate the individual contributions to sea-level rise. Projections in gray are from Vermeer and Rahmstorf (*1*) and are based on the observation that sea level rises faster as the Earth gets warmer. The projections from the NRC report fall between the two.

Presenting the Evidence, Impacts, and Choices

A new National Research Council publication, *Climate Change: Evidence, Impacts, and Choices*, summarizes extensive research results to help the public gain a better understanding of what is known and what can be done. The 36-page, three-part booklet answers commonly asked questions about the science of climate change by outlining evidence from around the world, summarizing projections of future climate changes and impacts, and examining how science can inform choices about managing and reducing the risks posed by climate change.



Evidence for global warming caused by human activity—along with observed climate impacts and examples of natural climate variability such as the Ice Age—is outlined in Part I. In Part II, scientific projections for the changes to temperatures, precipitation, sea ice and snow, coastlines, ecosystems, and agriculture are explored. Science's role in reducing greenhouse gas emissions and preparing for the impacts of climate change is examined in Part III.

To access the booklet and view related videos, visit http://nas-sites.org/americasclimatechoices.

FIGURE 2 Plate tectonics of the U.S. West Coast.

Fault Zone, creating relatively little vertical land motion along the coast. The result is a tale of two coasts: Global Positioning System (GPS) measurements show that north of Cape Mendocino, much of the coast is rising 1.5 mm to 3.0 mm per year; south of Cape Mendocino, the coast is sinking an average of 1 mm per year.

The NRC study projected that, for the area south of Cape Mendocino, sea level will rise an average of 6 inches by 2030; 12 inches by 2050; and 36 inches by 2100. Along the northernmost part of California and the coasts of Oregon and Washington, the projected sea-level rise is somewhat less because the coastline is rising slowly. Average sea-level rise along that part of the coast is expected to be 2 inches by 2030; 6 inches by 2050; and 24 inches by 2050.

The projections for north of Cape Mendocino could change immediately, however, if the region were to experience a large offshore earthquake of Magnitude 8 or greater. Such earthquakes occur every few hundred to 1,000 years—the last one occurred in 1700—and could cause parts of the coast to drop immediately; relative sea level would rise suddenly by as much as 1 to 2 meters (3 to 7 feet).

Storm Effects

Most of the damage along the West Coast is caused by storms, particularly at the confluence of large waves, storm surges, and high tides during El Niño events. Significant development along the coast—including airports, naval air stations, freeways, sports stadiums, and housing—is situated only a few feet above the highest tides. For example, the San Francisco International Airport could flood with a 16-inch sea-level rise, which could occur in several decades. A simulation run by the committee suggested that sea-level rise could increase the incidence of extreme water heights in the San Francisco Bay Area from 9 hours per decade to hundreds of hours per decade by 2050 and to several thousand hours per decade by 2100.

Storms and sea-level rise are causing coastal cliffs, beaches, and dunes to retreat at rates of a few centimeters to several meters per year. With continued sea-level rise, cliffs could retreat more than 30 m (about 100 feet) by 2100. Nevertheless, the frequent storms and associated floods in Central and Southern California can provide enough sediment for marshes to keep pace with the sea-level rise projected through 2050. The survival of the marshes until 2100 depends on maintaining elevation through high sedimentation, room to move inland, or uplift.

Preparing for Sea-Level Rise

NRC's 2010 report, *Adapting to the Impacts of Climate Change*,[2] concluded that, although adaptation planning and response efforts are under way in many states, counties, and communities, much of the nation's experience in protecting people, resources, and infrastructure is based on the historic record of climate variability during a time of relatively stable climate. As these projections of accelerating risk from sea-level rise make clear, adaptation to climate

The San Francisco International Airport (*center*) and surrounding areas will begin to flood with as little as 40 cm (16 inches) of sea-level rise, which could occur in several decades.

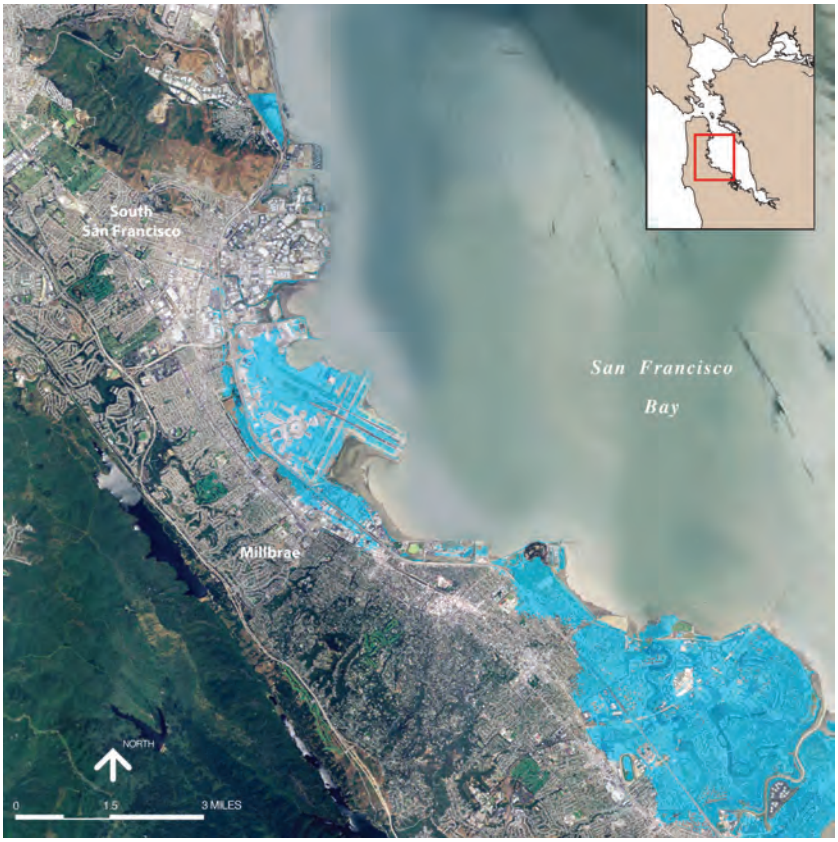


Image courtesy of Bay Conservation and Development Commission

[2] www.trb.org/main/blurbs/163484.aspx.

TABLE 1 Examples of Some Adaptation Options for One Expected Outcome of Sea-Level Rise

Impact	Possible Adaptation Action	Federal	State	Local Government	Private Sector	NGO or Individuals
Gradual inundation of low-lying land; loss of coastal habitats, especially coastal wetlands; saltwater intrusion into coastal aquifers and rivers; increased shoreline erosion and loss of barrier islands; changes in navigational conditions	Site and design all future public works projects to take sea-level rise into account	•	•	•		
	Eliminate public subsidies for development in high-hazard areas along the coast	•	•			
	Develop strong, well-planned, shoreline retreat or relocation plans and programs (public infrastructure and private properties), and poststorm redevelopment plans		•	•		
	Retrofit and protect public infrastructure (stormwater and wastewater systems, energy facilities, roads, causeways, ports, bridges, etc.)	•	•	•		
	Use natural shorelines, setbacks, and buffer zones to allow inland migration of shore habitats and barrier islands over time (e.g., dunes and forested buffers)	•	•	•		•
	Encourage alternatives to shoreline "armoring" through "living shorelines"	•	•	•	•	

Note: NGO = nongovernmental organization. Source: Adapted from Table 3.8 in the full report.

change calls for a different paradigm that considers a range of possible future climate conditions and associated impacts, some well outside the realm of past experience.

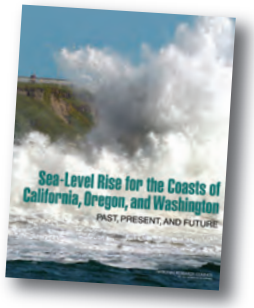
Current efforts to adapt to climate change are hampered by a lack of information about the benefits, the costs, the potential, and the limits of different responses. The impacts and vulnerabilities across the United States are diverse, and a relatively small body of research has focused on actions for climate change adaptation.

In the short term, the adaptations most easily deployed include low-cost strategies that offer near-term benefits or that reverse maladaptive policies and practices. In the longer term, more dramatic, higher-cost responses may be required. Table 1 (above) lists options that may be considered in the short term to address some of the expected impacts of sea-level rise.

The challenge is to weigh the risks and benefits and make wise choices despite uncertainties, as is done in so many other realms—for example, in buying home insurance. An iterative risk management approach offers a valuable framework for supporting climate change adaptation choices. Such a framework systematically identifies risks and prioritizes actions based on the magnitude and likelihood of the consequence; advances a portfolio of actions likely to reduce risks across a range of possible scenarios; and adjusts responses over time to take advantage of new knowledge, information, and technological capabilities.

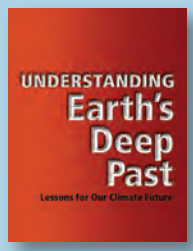
Reference

1. Vermeer, M., and S. Rahmstorf. Global Sea Level Linked to Global Temperature. *Proceedings of the National Academy of Sciences*, Vol. 106, No. 51, pp. 21527–21582, Dec. 22, 2009.



Prepublication copies of *Sea-Level Rise for the Coasts of California, Oregon, and Washington: Past, Present, and Future* are available from the National Academies Press. To order, call 202-334-3313 or 1-800-624-6242 or visit www.nap.edu.

Understanding Earth's Deep Past: Lessons for Our Climate Future



Levels of carbon dioxide (CO_2) in the Earth's atmosphere have grown so rapidly that they have already outpaced the projections of a decade ago. Without a reduction in greenhouse gas (GHG) emissions, CO_2 concentrations may increase to levels not experienced in more than 30 million years. A National Research Council study examines rocks and sediments from Earth's deep past for clues about the influence of high GHG levels on the climate of the future.

Understanding Earth's Deep Past assesses the potential of deep-time geologic records to explore the dynamics of the global climate system. Although not exact analogs for current and future climates, past climates can provide insights into the operation of physical, biogeochemical, and biological processes under warm conditions—for example, the role of GHGs in causing global warming or in affecting ice sheet stability and sea level.

The report examines past climate changes; the potential impacts of high GHG levels on regional climates, water resources, and marine and terrestrial ecosystems; and the cycling of life-sustaining elements. Authors highlight a range of high-priority research issues that could lead to major advances in the scientific understanding of climate processes. The report outlines an integrated, deep-time climate research program—and implementation strategy—on climatic response to increased atmospheric CO_2 and other GHGs; the goal would be to clarify the processes leading to abnormally warm polar and tropical regions and to gauge the impacts.

National Research Council. National Academies Press, 2011; 212 pp.; $34; 978-03-0920-915-1. For more information, visit www.nap.edu/catalog.php?record_id=13111.

Contour Plots Enhance Analysis of Pavement Data Collected with Nondestructive Survey Equipment

BOUZID CHOUBANE, CHARLES HOLZSCHUHER, PATRICK UPSHAW, HYUNG SUK LEE, AND VICKI MORRISON

The authors are with the Florida Department of Transportation. Choubane is State Pavement Materials Engineer; Holzschuher is State Pavement Evaluation Engineer; Upshaw is State Pavement Performance Engineer; and Lee is Nondestructive Testing Engineer, in the Gainesville office. Morrison is Technology Transfer Coordinator in the Tallahassee office.

(*Photo above:*) A Florida DOT survey vehicle tows a falling weight deflectometer.

Pavement engineers need accurate, complete, and reliable data to manage highway pavements optimally and to diagnose problems efficiently. Drilled core holes and cut trenches historically have yielded pavement samples for analysis. New nondestructive test (NDT) methods, however, can provide greater amounts of data more efficiently and cost-effectively, without damaging pavement or disrupting traffic.

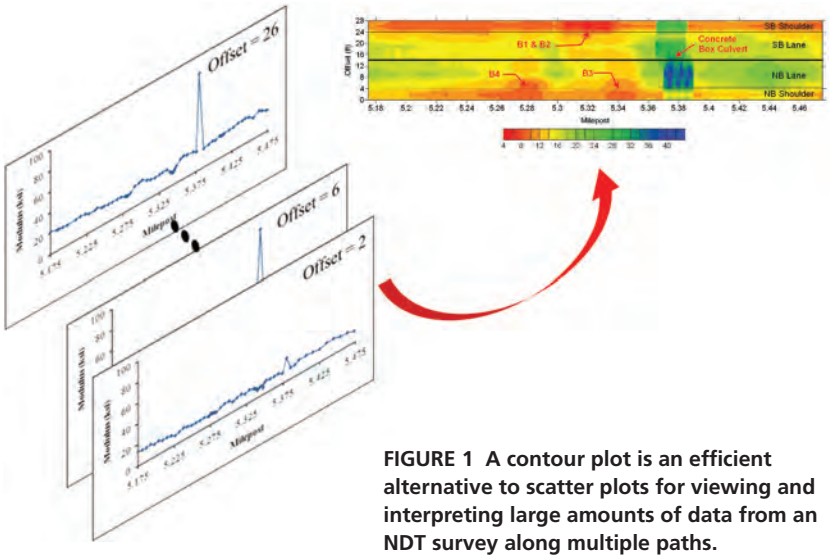


FIGURE 1 A contour plot is an efficient alternative to scatter plots for viewing and interpreting large amounts of data from an NDT survey along multiple paths.

Problem

NDT methods—such as the falling weight deflectometer (FWD) or ground-penetrating radar (GPR)—can collect pavement data at increased speeds and with great frequency. The vast amount of data obtained with NDT can enhance an engineer's understanding of the pavement's condition. An efficient and comprehensive method, however, is needed to interpret and summarize the increased quantity of data.

Two-dimensional scatter plots have served as the conventional way of presenting pavement characteristics for visual analysis. Scatter plots provide a simple and useful depiction of data points along a single survey path, but the data become more difficult to interpret when multiple survey paths are presented. Without a clear understanding of how the data interact, engineers may not be able to determine the most critical sites for follow-up destructive testing and may perform expensive, time-consuming, and damaging tests unnecessarily.

Solution

Pavement engineers at the Florida Department of Transportation (DOT) have developed a more accurate and comprehensive method to represent and interpret the voluminous data from NDT. In 2008, Florida DOT engineers applied a commercially avail-

able contour plotting tool to visualize NDT data from multiple survey paths, improving the identification of pavement areas that required follow-up destructive tests.

Figure 1 (page 48) schematically shows how the methodology enables engineers to interpret three-dimensional survey data captured with NDT equipment but presented as two-dimensional contour plots and to produce an easy-to-read map of NDT data. Contour plots allow for the efficient and reliable presentation and visualization of a large amount of NDT data and therefore eliminate the need for correlating multiple, cumbersome scatter plots. In summary, the contour plots provide pavement engineers with an improved methodology for interpreting data and accurately identifying locations for follow-up destructive testing.

Applications

Contour Plots of FWD Data

In 2010, Florida DOT pavement engineers investigated a taxiway pavement that exhibited severe cracking, heaving, and depressions near an airport hangar. With an FWD, the engineers obtained data along 14 survey paths to evaluate the structural integrity of the pavement. The contour plot generated from the FWD data (Figure 2, right) enabled the identification of critical locations for follow-up destructive tests.

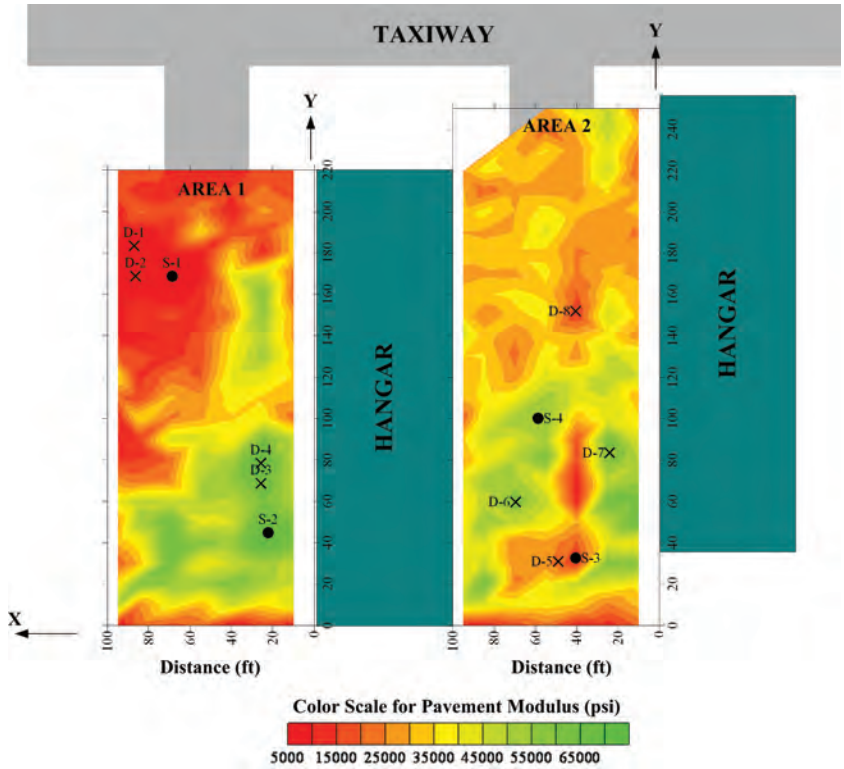


FIGURE 2 Contour plot of an airport pavement survey conducted with an FWD. Researchers combined data from 14 survey paths into a single contour plot to identify critical locations for follow-up tests.

Contour Plots of GPR Data

In a recent research project, Florida DOT pavement engineers developed a methodology to estimate asphalt pavement density with multiple survey paths from GPR. Using a contour plot like the one shown in Figure 3 (below), the engineers were able to evaluate the entire roadway density by identifying specific locations of high and low density and were able to minimize the number of destructive test cores required.

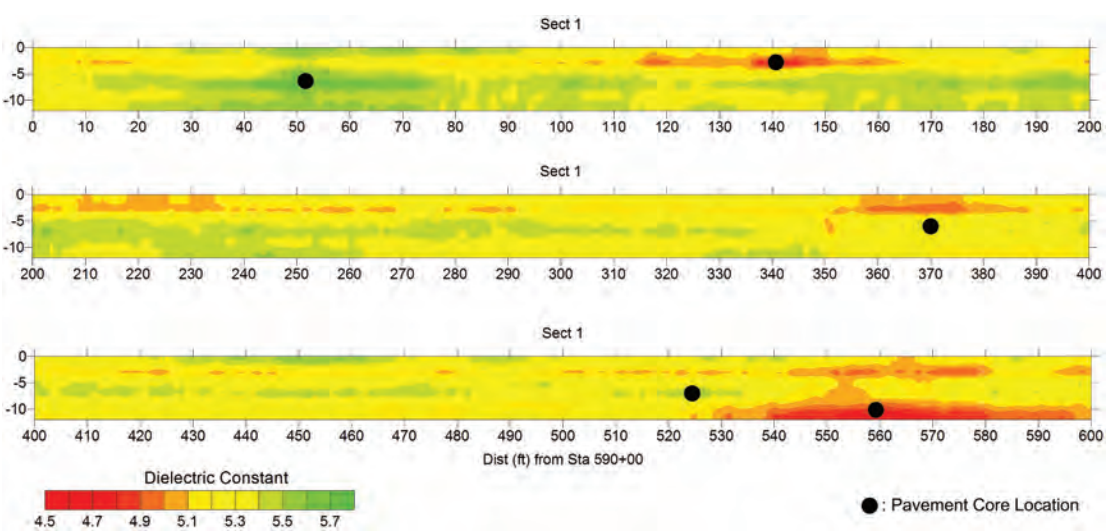


FIGURE 3 Contour plot of asphalt pavement density survey using GPR. Researchers combined data from six survey paths into a single contour map of pavement density to determine locations for destructive tests.

Survey vehicle equipped with ground-penetrating radar.

Benefits

Analyzing pavement data with contour plots offers an improved and efficient method for evaluating pavement characteristics and selecting the most critical areas for follow-up destructive testing. The contour plot analysis saves time and money by reducing the number of unnecessary destructive tests; improves safety by limiting the exposure of pavement technicians to highway traffic; and reduces disruption to the traveling public. Florida DOT estimates that integrating NDT equipment and analysis through contour plots can reduce the costs of production testing by as much as 50 percent, because of the decreased need for destructive tests and the reduced duration of lane closures.

The American Association of State Highway and Transportation Officials' Technology Implementation Group has selected this analysis technique—along with three pavement-related analysis tools developed by Florida DOT—as focus technologies to promote in the next two years. Marketed as "PaveSuite," the three analysis tools include the following:

- A method that uses FWD data to predict ground motion induced by vibratory compaction,
- An automated faulting method that uses a high-speed profiler to locate the joints in jointed concrete pavements, and
- An automated method for evaluating cross-slopes and drainage paths using a multipurpose survey vehicle to detect roadway areas prone to poor drainage and surface water entrapment.

Together or individually, these four techniques provide critical information to support informed decision making about cost-effective rehabilitation and preservation strategies for highway transportation infrastructure.

Additional information about contour plotting technology is available at www.aashtotig.org.

For more information, contact Bouzid Choubane, State Pavement Materials Engineer, Florida DOT State Materials Office, 5007 NE 39th Avenue, Gainesville, FL 32609; 352-955-6302; bouzid.choubane@dot.myflorida.com.

Resource

PaveSuite. http://tig.transportation.org/Pages/PaveSuite.aspx.

EDITOR'S NOTE: Appreciation is expressed to G. P. Jayaprakash, Transportation Research Board, for his efforts in developing this article.

Suggestions for Research Pays Off topics are welcome. Contact G. P. Jayaprakash, Transportation Research Board, Keck 488, 500 Fifth Street, NW, Washington, DC 20001 (202-334-2952; gjayaprakash@nas.edu).

CALENDAR

TRB Meetings

September

10–12 2nd International Conference on Transportation Geotechnics*
Sapporo, Hokkaido, Japan

12–13 International Transportation Research Information Access Workshop
Washington, D.C.

12–14 13th National Conference on Transportation Planning for Small and Medium-Sized Communities
Big Sky, Montana

17–21 13th International Conference on Mobility and Transport for Elderly and Disabled People (TRANSED)*
New Delhi, India

18–21 International Conference on Long-Life Concrete Pavements*
Seattle, Washington

19–21 4th International Conference on Accelerated Pavement Testing*
Davis, California

19–22 7th Symposium on Pavement Surface Characteristics*
Norfolk, Virginia

October

8–10 European Transport Conference*
Glasgow, Scotland

14–17 National Conference for Rural Public and Intercity Bus Transportation Connecting Communities: Sharing Solutions*
Salt Lake City, Utah

15–16 Marine Board Workshop: Safe Navigation in the U.S. Arctic
Seattle, Washington

26–28 International Symposium on Geotechnical Engineering for High-Speed Transportation Infrastructure*
Hangzhou, China

November

8–9 University Transportation Center Spotlight Conference on Sustainable Energy and Transportation: Strategies, Research, Data
Washington, D.C.

12–13 12th National Light Rail Conference: Sustaining the Metropolis—Light Rail Transit and Streetcars for Super Cities
Salt Lake City, Utah

December

12–16 1st International Conference on Connected Vehicles and Expo*
Beijing, China

2013

January

13–17 TRB 92nd Annual Meeting
Washington, D.C.
www.TRB.org/AnnualMeeting

April

16–18 International Highway Technology Summit—Delivering Innovative Approaches and Best Practices*
Beijing, China

May

15–17 Road Safety on Four Continents*
Beijing, China

TBD Integrating Transportation Agency Spatial and Business Data for Improved Management Reporting
Boise, Idaho

20–22 7th National Seismic Conference on Bridges and Highways
Oakland, California

June

2–3 10th International Symposium on Cold Regions Development*
Anchorage, Alaska

Additional information on TRB meetings, including calls for abstracts, meeting registration, and hotel reservations, is available at www.TRB.org/calendar. To reach the TRB staff contacts, telephone 202-334-2934, fax 202-334-2003, or e-mail TRBMeetings@nas.edu. Meetings listed without a TRB staff contact have direct links from the TRB calendar web page.

*TRB is cosponsor of the meeting.

Nathan S. Erlbaum

New York State Department of Transportation

[NOTE: *Nathan S. Erlbaum died in April 2012. The following Profile was under way before his passing, and he had approved an early draft.*]

Nathan S. Erlbaum's distinctive ability to analyze an issue in transportation planning and pinpoint its scope always proved crucial to TRB committees, on National Cooperative Highway Research Program (NCHRP) panels, and at the New York State Department of Transportation (DOT), where he worked for 39 years.

As associate transportation analyst at New York State DOT, Erlbaum headed the Data Acquisition and Integration Section of the Performance, Program, and Research Bureau. His areas of expertise included transportation, travel, energy, and freight data research and analysis; forecasting and model development; the Federal Highway Administration (FHWA) Highway Statistics and Reporting Program; data systems and information management; and the management of work programs, project budgets, bid offerings, and other administrative responsibilities.

"What problem are we trying to solve here?"

In 1973, Erlbaum received a master's degree in transportation planning from the Polytechnic Institute of Brooklyn—his undergraduate alma mater—and started as a program policy analyst at New York State DOT. In 1976, he became senior transportation analyst, assessing and solving basic transportation and program problems, collecting and synthesizing data, developing computer processing requirements and user interfaces, and managing staff.

Erlbaum often quipped that "in New York, we do it differently." While at New York State DOT, Erlbaum analyzed and disseminated data from public and private sources—the U.S. Census, the Census Transportation Planning Package, the Nationwide Personal Transportation Survey and National Household Travel Survey (NHTS) New York State add-ons, the American Travel Survey, the Truck and Vehicle Inventory and Use Surveys, and Commodity Flow Surveys. An innovator in applying the NHTS New York State add-on program to DOT research needs, Erlbaum produced a report in 2009 that compared travel behavior data in New York State with travel data nationwide and compared New York City and state travel data.

At the start of a research project, Erlbaum would ask, "What problem are we trying to solve here?" His forecasting and modeling projects included the Transportation Simulation Modeling State of Practice Review, Global Insight Development and Forecast of Population and Business Demographics and Vehicle Miles of Travel, state Transearch data acquisition and analysis, the Business Location and Analysis Tool, and the Evaluation of Transportation Simulation Modeling project. He designed, computerized, and streamlined manual computational procedures for the FHWA Highway Statistics and Reporting Program and reviewed data processes and flow for the specification of a new Traffic Monitoring System.

Among Erlbaum's accomplishments are the development of geographic information system (GIS) coverages to support data integration and analysis, TransCAD modeling, ArcView and GIS analyses of Transearch and Transborder freight flow and origin–destination data, DOT regional data profiles to assist regional offices in preparing comprehensive plans, and the use of GIS as an integrating tool for analyzing everything from potential weigh-in-motion sites to demographic growth rates. He also developed a customized ArcGIS engine application to create a multispatial, layered visualization tool for transportation data analysis and restructured the traffic count program to a 3-year cycle.

Erlbaum was noted for his ability to explain the intricacies of data to "the people upstairs." A section on the New York State DOT website detailing the American Community Survey (ACS) includes text he wrote that clarifies the results for readers. In 2001, Erlbaum played a critical role in the Data Needs in the Changing World of Logistics and Freight Transportation Conference in Saratoga Springs, New York. At the conference, he pointed out the need for transportation planners and researchers to understand freight—in particular, trucks. Later, he gained funding for the University at Albany's Regional Economic Freight Informatics Laboratory research team to develop the Traphic Tool Suite for freight analysis in New York State. The tool soon will be available on the DOT website.

Erlbaum was instrumental in obtaining support for data research through NCHRP. He served on many NCHRP project panels, including panels on Microbencost software, using ACS data in planning, and statistical and methodological standards for metropolitan travel surveys.

Erlbaum was a member of several TRB committees and task forces, such as the Urban Transportation Data and Information Systems Committee and the Planning Committee for the Conference on Using Census Data for Transportation Applications. Past service included the Microcomputer Evaluation of Highway User Benefits Committee and the National Transportation Data Requirements and Programs Committee. He also served the American Association of State Highway and Transportation Officials' Standing Committee on Planning as a member of the Census Data Work Group and of the Census Transportation Planning Products Oversight Board.

Deborah J. Goodings

George Mason University

As chair of the Department of Civil, Environmental, and Infrastructure Engineering (CEIE) at George Mason University, Fairfax, Virginia, and Dewberry Professor of Civil Engineering since 2009, Deborah J. Goodings leads a program educating 400 undergraduate and graduate students. Under her guidance, the department has initiated an undergraduate honors program, a thriving Engineers for International Development student group, and a master's program in geotechnical, construction, and structural engineering—the only such program in the country. CEIE also has redefined its graduate program, incorporated local leaders in engineering practice and research as adjunct faculty, and raised the level of involvement of the engineering industry advisory board.

Goodings' research expertise is in geotechnical engineering, with emphasis on the response of soil to extreme conditions—including cold, heat, explosives, and river scour—and slope and reinforced soil retaining wall stability. After receiving a bachelor's degree in civil engineering from the University of Toronto, Canada, in 1975 and a Ph.D. from Cambridge University in the United Kingdom in 1979, Goodings worked as a geotechnical engineer in private practice. She joined the faculty at the University of Maryland (UMd) in 1981 as a geotechnical engineering professor, and served as a National Science Foundation visiting professor at the University of Colorado at Boulder from 1986 to 1987 and as a bye-fellow at Cambridge from 1996 to 1997.

"We benefit from the efforts, successes, and planning of those who have gone before and who mentor us, and we owe the same back to our profession."

Goodings became interested in academic administration during her appointment as associate department chair at UMd. She recognized UMd's three strategic components—a distinguished engineering program, a notable School of Public Policy, and its location in the Washington, D.C., area—and worked with the School of Public Policy to establish a Master of Engineering and Public Policy program in 2004 to educate engineers for public policy practice.

She also became founding faculty adviser of the UMd chapter of Engineers Without Borders USA (EWB-USA). In 5 years, the chapter grew to a membership of 150 students and completed more than a dozen international infrastructure assignments, with Gooding acting as faculty lead on two early projects with the hill tribes of northern Thailand.

"The effect on students often was transformative," comments Goodings. "Students developed a whole new understanding of the scope of engineering as a profession, the meaning of global citizenship, and their own capacity to effect change—sometimes dramatic change—in people's lives."

With this experience founding and building successful programs, Goodings pursued new opportunities in academic administration, joining CEIE at George Mason in 2009. She was drawn to the youth of the university and its emphasis on innovation, readiness to experiment, enthusiasm for international engagement, and collegial faculty.

"Careers are understood only in retrospect—they are a blend of perseverance tempered with openness to opportunity and boldness combined with luck," she reflects. "There are no truly self-made men or women. We benefit from the efforts, successes, and planning of those who have gone before and who mentor us, and we owe the same back to our profession." Encouraging diversity in the engineering profession is a proven competitive advantage, she observes, and in a changing economic landscape, to keep the profession vibrant, new ways must be found to engage, retain, and expand the horizons of engineers—and integrate professionals with degrees in subject areas other than engineering.

Her long association with TRB has made her sensitive to the difficulties in bridging the gap between engineering practice and university research. "The comprehensive Interstate highway network, deepwater offshore drilling platforms, the use of geosynthetics in geotechnical projects, and thin-arch dams keyed into rock abutments are clear evidence that civil engineering research has made its way into broad practice," Goodings notes. "The demands placed on civil engineering research faculty by universities, however, often make fulfilling the immediate research needs of practitioners difficult."

Goodings joined the Modeling for the Design, Construction, and Management of Geosystems standing committee at TRB in 1988, serving as chair from 1993 to 1999. She was elected emerita member in 2004. She also served on the Geosynthetics Committee and on the Seasonal Climatic Effects on Infrastructure Committee. From 2005 to 2008, Goodings chaired the Soil Mechanics Section.

In 2009, UMd created the Deborah J. Goodings Professorship in Engineering for Global Sustainability in recognition of her work with EWB-USA. She has been recognized with TRB's Fred Burggraf Award, the U.S. Department of the Army Outstanding Civilian Service Medal, and the Engineering Medal of Excellence from Professional Engineers Ontario in Canada.

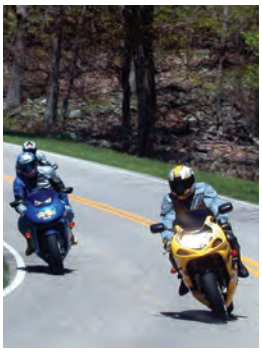


Photo: AAA Foundation for Traffic Safety

Helmets are critical in helping to prevent fatal injuries to motorcycle drivers and passengers.

Motorcycle Fatalities Rise Counter to Trends

A preliminary report from the Governors Highway Safety Association shows no decrease in motorcycle fatalities in 2011—even as the number of all other motor vehicle fatalities declined.

In the report, *Motorcyclist Traffic Fatalities by State: 2011 Preliminary Data*, 26 states and the District of Columbia reported an increase in motorcycle deaths during the first nine months of 2011, bringing the projected fatality total to about 4,500 for the year. This figure is similar to the number of motorcycle fatalities in 2010. According to the National Highway Traffic Safety Administration, in 2011, nonmotorcycle vehicle deaths fell to the lowest level since 1949.

The report offers suggestions for reducing motorcycle fatalities. For example, helmets have proved to be 37 percent effective in preventing fatal injuries to drivers and 41 percent effective for motorcycle passengers. Alcohol impairment and excessive speed also are factors in motorcycle deaths; nearly one-third of fatally injured motorcyclists in 2010 had a blood alcohol level above the legal limit, and 35 percent of motorcyclists involved in fatal crashes were speeding. Also recommended is motorcycle driver training—which is widely offered—and increasing the awareness of automobile drivers about motorcycles.

For the full report, visit bit.ly/GHSAreport.

Transit Ridership on the Increase

Research from the American Public Transportation Association (APTA) shows that in the first three months of 2012, public transit ridership in the United States increased by nearly 5 percent over ridership during the same period in 2011. A total of 2.7 billion unlinked passenger trips were taken in the first quarter of 2012—an increase of 125.7 million trips compared with data for the first quarter of 2011.

Among the modes studied, the largest increases in ridership were experienced by demand-responsive transportation, which increased 7.1 percent to 51 million, and by light rail transit, which increased 6.7 percent to 123 million, across the United States. Heavy rail trips increased by 5.5 percent, commuter rail by 3.9 percent, trolley by 3.8 percent, and bus by 4.5 percent. According to the report, bus transportation in cities of all sizes comprised more than half of the total trips taken on public transit in the first quarter of 2012.

The full report is available at bit.ly/transitnumbers.

INTERNATIONAL NEWS

Traffic Safety in Bus Corridors

EMBARQ, the World Resources Institute's center for sustainable transportation, analyzed more than 30 bus corridors worldwide to investigate traffic safety. Drawing on bus corridor data, road safety audits, and interviews with safety experts and bus agency staff, researchers identified crash types on bus corridors and examined the safety impacts of bus rapid transit (BRT) and various busway design features.

Research shows that the implementation of TransMilenio, a bus rapid transit system in Bogotá, Colombia, led to a decrease in pedestrian crash rates.

Photo: Jorge Lascar

According to the report, major urban arterials account for 15 percent of a city's road network, but more than 65 percent of severe pedestrian crashes occur on these roads. The safety impacts of bus systems vary widely, researchers found—in Bogotá, Colombia, and Guadalajara, Mexico, the implementation of BRT systems led to a reduction in crashes and fatalities in the corridors, while in New York and Porto Alegre, Brazil, streets with bus routes and bus corridors were associated with higher pedestrian crash rates.

Research findings include bus system design elements that can improve safety—for example, closed stations with high platforms or center-lane systems with left-turn interdictions. Other elements, such as counterflow lanes, may increase crash risk, according to the report. Nevertheless, a road's geometry and the size and complexity of its intersections emerged as key elements—these accurately predicted the safety in a bus corridor.

To see the full report, visit www.embarq.org/sites/default/files/EMB2012_Traffic_Safety_on_Bus_Corridors_Pilot_Version.pdf.

ANALYZING MARINE SYSTEM PERFORMANCE—The Diagnosing the Marine Transportation System: Measuring Performance and Targeting Improvement conference, held June 26–28 in Washington, D.C., offered a forum for stakeholders in government, academia, and the private sector to collaborate and to examine the use of performance metrics in maritime transportation and waterways management. Keynote speakers included (*left to right*:) Polly Trottenberg, U.S. Department of Transportation; Michael J. Walsh, U.S. Army Corps of Engineers (ACE); Margaret Spring, National Oceanic and Atmospheric Administration, and Committee on the Marine Transportation System (CMTS) Coordinating Board chair; and W. Jeff Lillycrop, U.S. ACE and CMTS Research and Development Integrated Action Team chair.

SECOND STRATEGIC HIGHWAY RESEARCH PROGRAM NEWS

PHOTO: FUGRO CONSULTANTS, INC.

SAVING MONEY THROUGH RESEARCH— Working from SHRP 2 guides that comprise research results and extensive field testing to facilitate easier selection, design, fabrication, and installation of precast concrete products, the Illinois Tollway is using precast concrete pavement panels in a large road repair project. The Tollway reports that this decision will save at least $500 per panel—in a project that involves placing more than 700 panels—compared to the typical method of full-depth replacement.

COOPERATIVE RESEARCH PROGRAMS NEWS

Revising Guidelines for Slope Traversability

Rollovers are the leading cause of fatalities in single-vehicle ran-off-road (ROR) crashes. Data indicate that 31 percent of single-vehicle ROR crashes result in a rollover, most of them initiated by vehicles digging into the ground on embankments or in ditches after encroaching into the roadside. Studies show that light trucks, with higher centers of gravity, are overrepresented in rollover crashes and are more than twice as likely as a passenger car to overturn in a single-vehicle ROR crash on a high-speed roadway.

Sales of light trucks increase each year, accounting for more than 50 percent of all new passenger vehicles sold; therefore, roadside safety guidelines and practices must be updated to accommodate the current vehicle fleet. Much of the guidance on slope ratios in the 2006 American Association of State Highway and Transportation Officials' (AASHTO) *Roadside Design Guide* is based on older research; recent studies suggest that some roadside slope conditions considered traversable for passenger cars may not be suitable for light trucks.

The Texas A&M Transportation Institute has received a $500,000, 30-month grant (NCHRP Project 17-55, FY 2012) to develop slope conditions guidelines for today's passenger vehicle fleet.

For more information, contact Mark S. Bush, TRB, 202-334-1646, mbush@nas.edu.

Crash Injury Measurement and Reporting Systems

Currently, the severity of injuries in a traffic crash is estimated by police officers at the scene, who typically use a simple injury rating scale. This scale can differ substantially from the findings of medical personnel. Although some states employ the National Highway Traffic Safety Administration's (NHTSA) Crash Outcome Data Evaluation System, which conducts a probabilistic matching of statewide health records with crash reports, it is technically complex and not used in all states.

The Governors Highway Safety Association and NHTSA recently developed safety performance measures that include the use of fatalities and serious nonfatal injuries, and AASHTO is working on similar performance measures. For serious nonfatal injuries and crashes to become major performance measures for states, an accurate and feasible method is needed for determining level-of-injury severity based on a medical assessment.

The University of Michigan has received a $450,000, 24-month contract (NCHRP Project 17-57, FY 2012) to identify an injury scoring system, to develop a roadmap for states to implement interim measuring and reporting systems and construct a state-based framework to link crash and injury records.

For more information, contact Mark S. Bush, TRB, 202-334-1646, mbush@nas.edu.

PROJECTING AHEAD—Robert L. Sack (*left*), New York State DOT, participates in discussion at the spring meeting of the AASHTO Standing Committee on Research, March 20, at the National Academies' Keck Center in Washington, D.C. The committee coordinates efforts to identify research needs for the National Cooperative Highway Research Program (NCHRP), define research emphasis areas, and apply findings, as well as solicit and screen research problem statements and provide oversight for NCHRP.

Cost–Benefit Metrics for Behavioral Highway Safety Countermeasures

States currently do not have a nationally recognized methodology for allocating safety resources among behavioral safety countermeasures. A cost–benefit methodology would assist states in making investment decisions and allow them to compare behavioral and engineering countermeasures.

HDR Engineering, Inc., has received a $450,000, 24-month contract (NCHRP Project 17-60, FY 2012) to develop a cost–benefit methodology for behavioral highway safety for use by state and local agencies, providing a quantitative analytical approach with clearly defined criteria, and to apply the methodology to countermeasures identified in NCHRP Report 622, *Effectiveness of Behavioral Highway Safety Countermeasures*.

For more information, contact Mark S. Bush, TRB, 202-334-1646, mbush@nas.edu.

An NCHRP project will produce a guide to assist local transportation agencies in the design and operation of unsignalized intersections.

Photo: Tom Saunders, Virginia DOT

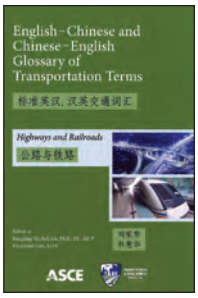
Unsignalized Intersection Guide

Approximately 90 percent of intersections in the United States are unsignalized; in 2007, more than 6,000 fatalities were estimated to have occurred at these types of intersections. State and local transportation agencies must consider how the design and operation of unsignalized intersections can better address safety performance, operations, multimodal needs, and other impacts. Many local agencies do not have professional engineers on staff but still must make decisions on treatments at unsignalized intersections. Practical guidance can assist transportation agencies in making these decisions.

Vanasse Hangen Brustlin, Inc., has received a $400,000, 21-month contract (NCHRP Project 03-104, FY 2012) to develop a practical, multimodal, and comprehensive guide to aid practitioners in selecting design, operational, maintenance, enforcement, and other treatments to improve safety, mobility, and accessibility at unsignalized intersections.

For more information, contact B. Ray Derr, TRB, 202-334-3231, rderr@nas.edu.

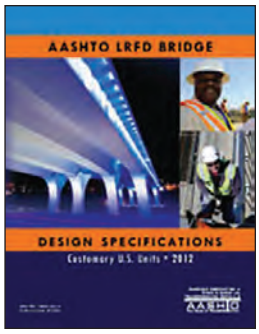
English–Chinese and Chinese–English Glossary of Transportation Terms



Edited by Rongfang Liu and Eva Lerner-Lam. American Society of Civil Engineers (ASCE), 2012; 284 pp.; ASCE members, $56.25; nonmembers, $75; 978-07-8441-205-3.

Dynamic knowledge exchange between English- and Chinese-speaking transportation researchers and professionals requires a commonly accepted glossary of transportation and development terms. This volume contains an extensive dictionary of more than 1,200 transportation expressions commonly used in American English. Each term is defined and matched with its corresponding term in simplified Chinese. Editor Rongfang Liu is chair of TRB's Major Activity Center Circulation Systems Committee and a frequent contributor to the *Transportation Research Record: Journal of the Transportation Research Board.*

Load and Resistance Factor Design (LRFD) Bridge Design Specifications, 6th Edition



American Association of State Highway and Transportation Officials (AASHTO), 2012; 1,672 pp.; AASHTO members, $280; nonmembers, $336; 15-6051-523-4.

The sixth edition of the *LRFD Bridge Design Specifications* includes significant updates on topics such as elastomeric bearing design, special shear resistance factor for lightweight concrete, designs for bridge piers and abutments to withstand vehicle collisions, clarifications for partially prestressed concrete beams, curved posttensioned box girder bridges, mechanically stabilized earth wall design, and more. A section on the design of sound barriers also has been added.

The books in this section are not TRB publications. To order, contact the publisher listed.

TRB PUBLICATIONS

Attracting, Recruiting, and Retaining Skilled Staff for Transportation System Operations and Management

NCHRP Report 693

Guidance is provided to transportation agencies for recruiting and retaining qualified professional staff in systems operation and management. Explored are career paths, skill requirements, training needs, successful programs, state-of-the-art initiatives, and best practices.

2012; 155 pp.; TRB affiliates, $50.25; nonaffiliates, $67. Subscriber categories: highways; administration and management; education and training; maintenance and preservation.

Evaluation and Performance Measurement of Congestion Pricing Projects

NCHRP Report 694

Presented in this report is information for transportation agencies that are developing measures for evaluating congestion-pricing projects, collecting data, tracking performance, and communicating results to decision makers, users, and the public. The website posting of this report includes appendix information not supplied in the print edition.

2011; 181 pp.; TRB affiliates, $51; nonaffiliates, $68. Subscriber categories: finance; highways; operations and traffic management.

Performance-Related Specification for Hot-Mixed Asphalt

NCHRP Report 704

This report provides a proposed performance-related specification for hot-mix asphalt. Quality-Related Specification Software (QRSS), a stand-alone program for Microsoft Windows, employs a database of solutions based on the *Mechanistic–Empirical Pavement Design Guide* developed by NCHRP and published by AASHTO. Information and links for downloading the QRSS are available online.

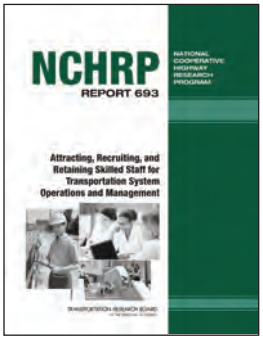
2011; 185 pp.; TRB affiliates, $51; nonaffiliates, $68. Subscriber categories: highways; materials; construction.

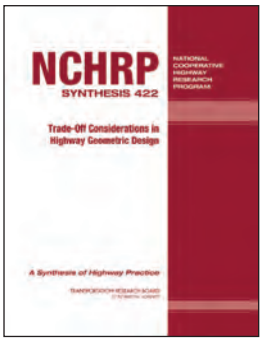
Trade-Off Considerations in Highway Geometric Design

NCHRP Synthesis 422

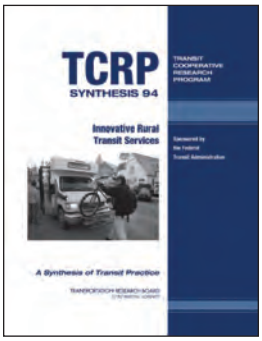
Examined in this volume are the processes transportation agencies use to evaluate geometric design trade-offs between competing interests. The report also highlights key publications on conventional approaches, context-sensitive solutions and context-sensitive design, and performance-based approaches, as well as gaps in the information or in the analysis processes that support design decisions.

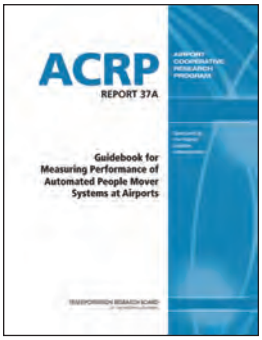
2011; 163 pp.; TRB affiliates, $47.25; nonaffiliates: $63. Subscriber categories: design; highways.





TRB PUBLICATIONS *(continued)*





Long-Term Performance of Polymer Concrete for Bridge Decks
NCHRP Synthesis 423

Research, specifications, and procedures related to thin polymer overlays (TPOs) are addressed in this volume, including the performance of TPOs in field applications, factors influencing performance, current construction guidelines and repair procedures, and successes and failures of TPOs.

2011; 63 pp.; TRB affiliates, $34.50; nonaffiliates, $46. Subscriber categories: bridges and other structures; highways; maintenance and preservation; materials.

Waterproofing Membranes for Concrete Bridge Decks
NCHRP Synthesis 425

This synthesis compiles information on materials, specification requirements, design details, application methods, system performance, and costs of waterproofing membranes on new and existing bridge decks since 1995. North American practices are the focus, with some information about European and Asian systems.

2012; 55 pp.; TRB affiliates, $34.50; nonaffiliates, $46. Subscriber categories: bridges and other structures; highways; maintenance and preservation.

Improving Safety-Related Rules Compliance in the Public Transportation Industry
TCRP Report 149

Best practices are identified for a comprehensive approach to comply with safety-related rules: screening and selecting employees; training and testing; communication, monitoring, and responding to noncompliance; and safety management. A prototype safety reporting system is presented for public transportation.

2011; 116 pp.; TRB affiliates, $42.75; nonaffiliates, $57. Subscriber category: public transportation.

Communication with Vulnerable Populations: A Transportation and Emergency Management Toolkit
TCRP Report 150

This report describes how to communicate emergency transportation options to vulnerable populations, and offers a toolkit for constructing a scalable, adaptable communication process built on a network of agencies from the public, private, and nonprofit sectors.

2011; 159 pp.; TRB affiliates, $47.25; nonaffiliates, $63. Subscriber categories: public transportation; security and emergencies; society.

Innovative Rural Transit Services
TCRP Synthesis 94

Highlighted are the responses of transit and rural intercity bus services to the changing transportation needs of rural communities, with a focus on entrepreneurship, innovation, and the conditions required for innovation.

2011; 43 pp.; TRB affiliates, $30.75; nonaffiliates, $41. Subscriber categories: administration and management; planning and forecasting; public transportation.

Practices for Wayside Rail Transit Worker Protection
TCRP Synthesis 95

This synthesis comprises the results of telephone interviews, transit agency site visits, and a literature review and assembles an overview of the knowledge, practice, lessons learned, and gaps in information related to wayside rail transit worker protection programs.

2012; 79 pp.; TRB affiliates, $40.50; nonaffiliates, $54. Subscriber categories: administration and management; education and training; public transportation; safety and human factors; society.

Off-Board Fare Payment Using Proof-of-Payment Verification
TCRP Synthesis 96

This synthesis examines the application of proof of payment on transit systems in North America and across the globe. Issues addressed include evasion and inspection rates, enforcement techniques, fare inspection personnel duties, adjudication processes, and evasion penalties.

2012; 117 pp.; TRB affiliates, $45; nonaffiliates, $60. Subscriber categories: public transportation; finance.

Guidebook for Measuring Performance of Automated People Mover Systems at Airports
ACRP Report 37A

This companion report to *ACRP Report 37* assists in the measurement of automated people mover system performance at airports. Performance measures are identified and defined—including service availability, safety, operations and maintenance expense, capacity utilization, user satisfaction, and reliability.

2012; 125 pp.; TRB affiliates, $45; nonaffiliates, $60. Subscriber category: aviation.

The Carbon Market: A Primer for Airports
ACRP Report 57

This volume explores opportunities for—and challenges to—participation in carbon and other

TRB PUBLICATIONS *(continued)*

environmental credit trading markets. Also addressed are new terms and concepts related to these markets.

2011; 72 pp.; TRB affiliates, $36.75; nonaffiliates, $49. Subscriber category: aviation.

Airport Industry Familiarization and Training for Part-Time Airport Policy Makers
ACRP Report 58

Policy issues affecting airport administrative and operational decisions are addressed, along with a common framework for policy leaders, stakeholders, and decision makers to understand airport administrative and operational requirements.

2011; 54 pp.; TRB affiliates, $32.25; nonaffiliates, $43. Subscriber category: aviation.

Information Technology Systems at Airports: A Primer
ACRP Report 59

Designed to facilitate mutual understanding between airport executives and information technology (IT) professionals, this volume offers techniques to identify and communicate critical IT issues and principles for implementing new airport IT systems.

2012; 97 pp.; TRB affiliates, $40.50; nonaffiliates, $54. Subscriber category: aviation.

Airport Insurance Coverage and Risk Management Practices
ACRP Synthesis 30

Geared to airport officials, this synthesis identifies the variables that affect insurance purchasing and the range of risk management practices among U.S. airports.

2011; 51 pp.; TRB affiliates, $32.25; nonaffiliates, $43. Subscriber categories: administration and management; aviation; finance.

Airline and Airline–Airport Consortiums to Manage Terminals and Equipment
ACRP Synthesis 31

This synthesis presents the current state of the practice in airline–airport consortiums in the United States, addressing the scope of responsibilities, consortium formation, membership, contractual agreements and insurance, organizational structures, and more. Includes appendices.

2011; 92 pp.; TRB affiliates, $73.50; nonaffiliates, $98. Subscriber categories: administration and management; aviation; finance.

Guidebook for Understanding Urban Goods Movement
NCFRP Report 14

Case studies explore how urban supply chains connect to the economy, infrastructure, and land use patterns of cities; the impact of land use codes and regulations on private-sector freight providers; and planning strategies for improving mobility and access for goods movement in urban areas. A CD-ROM with additional material is included.

2012; 107 pp.; TRB affiliates, $52.50; nonaffiliates, $70. Subscriber categories: freight transportation; planning and forecasting.

Preserving and Protecting Freight Infrastructure and Routes
NCFRP Report 16

This volume provides guidance for avoiding conflicting land uses and mitigating existing uses. Included is information about freight transportation infrastructure; the types of conflicts between freight and other land uses; and resources to help preserve facilities and corridors. A CD-ROM includes appendices.

2012; 83 pp.; TRB affiliates, $48; nonaffiliates, $64. Subscriber categories: freight transportation; planning and forecasting; terminals and facilities.

Case Studies in Collaboration
SHRP 2 Capacity Project C01

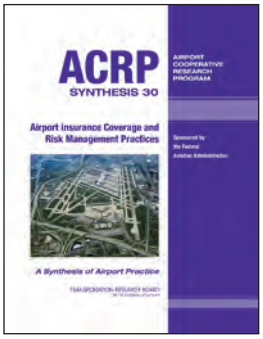
Twenty-three case studies on collaborative decision making about additions to highway capacity were developed through Capacity Project C01, exploring collaboration in a variety of transportation applications and providing real-world best practices, pitfalls, and lessons learned.

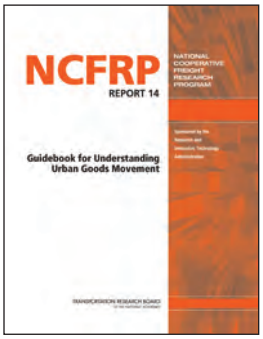
2011. Case studies available at www.trb.org/StrategicHighwayResearchProgram2SHRP2/Pages/Case_Studies_in_Collaboration_373.aspx.

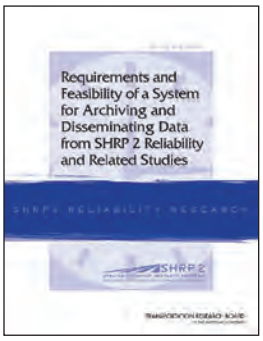
Requirements and Feasibility of a System for Archiving and Disseminating Data from SHRP 2 Reliability and Related Studies
SHRP 2 Report S2-L13-RW-1

This report assesses the technical, economic, and business aspects of developing, operating, and maintaining a long-lived archival system that preserves information from SHRP 2 projects for a period of 20 to 50 years.

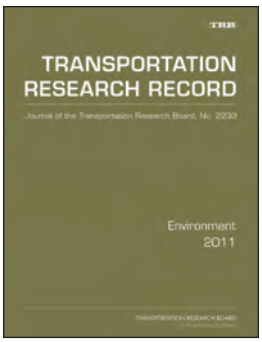
2011, 68 pp., web only. Available at http://onlinepubs.trb.org/onlinepubs/shrp2/SHRP2_S2-L13-RW-1.pdf.







TRB PUBLICATIONS *(continued)*



Encouraging Innovation in Locating and Characterizing Underground Utilities
SHRP 2 Report S2-R01-RW

This report explores underground utility locating practices, examines current and emerging technologies, and identifies areas for improvement and subsequent research.

2009, 131 pp.; web only. Available at http://onlinepubs.trb.org/onlinepubs/shrp2/shrp2_S2-R01-RW.pdf.

Development of the Selection Assistant for Utility Locating Technologies
SHRP 2 Report S2-R01-RW-2

Outlined are the software development tasks associated with SHRP 2 Renewal Project R01. The web-based application includes a decision-support system to assist users with limited expertise in understanding utility-locating equipment.

2011, 131 pp., web only. Available at http://onlinepubs.trb.org/onlinepubs/shrp2/SHRP2_S2-R01-RW-2.pdf.

Research on the Health and Wellness of Commercial Truck and Bus Drivers: Summary of an International Conference
Conference Proceedings on the Web 5

The proceedings of a 2010 conference on commercial truck and bus driver health and wellness highlight noteworthy issues and gaps in knowledge and describe suggestions for possible future directions in transportation health and safety research.

2012; 128 pp.; web only. Available at www.trb.org/Publications/PubsConferencesandWorkshopsWeb.aspx.

Transportation Systems for Livable Communities
Conference Proceedings on the Web 6

Presented in this volume is a summary of a 2010 conference that explored the challenges of incorporating livability into transportation programs and projects. Opening session presentations, panel discussions, and outlines of key research needs and possible performance measures are included.

2012; 154 pp.; web only. Available at www.trb.org/Publications/PubsConferencesandWorkshopsWeb.aspx.

Environment 2011
Transportation Research Record 2233

The papers in this volume explore topics such as integrated bus information systems, a comparison of greenhouse gas and criterion pollutant emissions, coordinated signal control, air quality–related mortality impacts of different transportation modes, and the effects of aging on tire–pavement noise generation.

2011; 186 pp.; TRB affiliates, $55.50; nonaffiliates, $74. Subscriber categories: environment; energy.

Critical Infrastructure Protection and Resilience: Emergency Evacuation 2011
Transportation Research Record 2234

Improving the resilience of critical infrastructure systems, defending transportation networks against attack, the location of medical facilities, and other topics are presented in this volume.

2011; 134 pp.; TRB affiliates, $49.50; nonaffiliates, $66. Subscriber categories: security and emergencies; transportation, general; planning and forecasting.

Maintenance and Preservation of Pavements
Transportation Research Record 2235

Authors present research on life-cycle cost-based pavement preservation treatment design, pavement preservation, preventive maintenance treatments, pavement preservation on high-traffic-volume roadways, fresh emulsified asphalt chip seals, flowable fill for rapid pavement repair, and more.

2011; 112 pp.; TRB affiliates, $45.75; nonaffiliates, $61. Subscriber categories: maintenance and preservation; pavements.

Safety Data, Analysis, and Evaluation 2011, Vol.1
Transportation Research Record 2236

Explored in this volume are the effects of mobile phone use on accident risk, a model of the relationship between Interstate crash occurrence and geometrics, an analysis of naturalistic driving event data, cyclist safety at signalized intersections, and a longitudinal analysis of traffic crashes.

2011; 119 pp.; TRB affiliates, $45.75; nonaffiliates, $61. Subscriber categories: safety and human factors; data and information technology.

Safety Data, Analysis, and Evaluation 2011, Vol. 2
Transportation Research Record 2237

Research papers address traffic conflict indicators, improved time-to-collision definition, arterial signal coordination, real-time crash risk, the effects of built-environment characteristics on pedestrian crash frequency, crash identification and reconstruction, and other topics.

2011; 159 pp.; TRB affiliates, $52.50; nonaffiliates, $70. Subscriber categories: safety and human factors; data and information technology.

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INFORMATION FOR CONTRIBUTORS TO

TR NEWS

TR News welcomes the submission of manuscripts for possible publication in the categories listed below. All manuscripts submitted are subject to review by the Editorial Board and other reviewers to determine suitability for *TR News*; authors will be advised of acceptance of articles with or without revision. All manuscripts accepted for publication are subject to editing for conciseness and appropriate language and style. Authors receive a copy of the edited manuscript for review. Original artwork is returned only on request.

FEATURES are timely articles of interest to transportation professionals, including administrators, planners, researchers, and practitioners in government, academia, and industry. Articles are encouraged on innovations and state-of-the-art practices pertaining to transportation research and development in all modes (highways and bridges, public transit, aviation, rail, marine, and others, such as pipelines, bicycles, pedestrians, etc.) and in all subject areas (planning and administration, design, materials and construction, facility maintenance, traffic control, safety, security, logistics, geology, law, environmental concerns, energy, etc.). Manuscripts should be no longer than 3,000 words (12 double-spaced, typed pages). Authors also should provide charts or tables and high-quality photographic images with corresponding captions (see Submission Requirements). Prospective authors are encouraged to submit a summary or outline of a proposed article for preliminary review.

RESEARCH PAYS OFF highlights research projects, studies, demonstrations, and improved methods or processes that provide innovative, cost-effective solutions to important transportation-related problems in all modes, whether they pertain to improved transport of people and goods or provision of better facilities and equipment that permits such transport. Articles should describe cases in which the application of project findings has resulted in benefits to transportation agencies or to the public, or in which substantial benefits are expected. Articles (approximately 750 to 1,000 words) should delineate the problem, research, and benefits, and be accompanied by one or two illustrations that may improve a reader's understanding of the article.

NEWS BRIEFS are short (100- to 750-word) items of interest and usually are not attributed to an author. They may be either text or photographs or a combination of both. Line drawings, charts, or tables may be used where appropriate. Articles may be related to construction, administration, planning, design, operations, maintenance, research, legal matters, or applications of special interest. Articles involving brand names or names of manufacturers may be determined to be inappropriate; however, no endorsement by TRB is implied when such information appears. Foreign news articles should describe projects or methods that have universal instead of local application.

POINT OF VIEW is an occasional series of authored opinions on current transportation issues. Articles (1,000 to 2,000 words) may be submitted with appropriate, high-quality illustrations, and are subject to review and editing.

BOOKSHELF announces publications in the transportation field. Abstracts (100 to 200 words) should include title, author, publisher, address at which publication may be obtained, number of pages, price, and ISBN. Publishers are invited to submit copies of new publications for announcement.

LETTERS provide readers with the opportunity to comment on the information and views expressed in published articles, TRB activities, or transportation matters in general. All letters must be signed and contain constructive comments. Letters may be edited for style and space considerations.

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◆ All manuscripts should be supplied in 12-point type, double-spaced, in Microsoft Word, on a CD or as an e-mail attachment.

◆ Submit original artwork if possible. Glossy, high-quality black-and-white photographs, color photographs, and slides are acceptable. Digital continuous-tone images must be submitted as TIFF or JPEG files and must be at least 3 in. by 5 in. with a resolution of 300 dpi. A caption should be supplied for each graphic element.

◆ Use the units of measurement from the research described and provide conversions in parentheses, as appropriate. The International System of Units (SI), the updated version of the metric system, is preferred. In the text, the SI units should be followed, when appropriate, by the U.S. customary equivalent units in parentheses. In figures and tables, the base unit conversions should be provided in a footnote.

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