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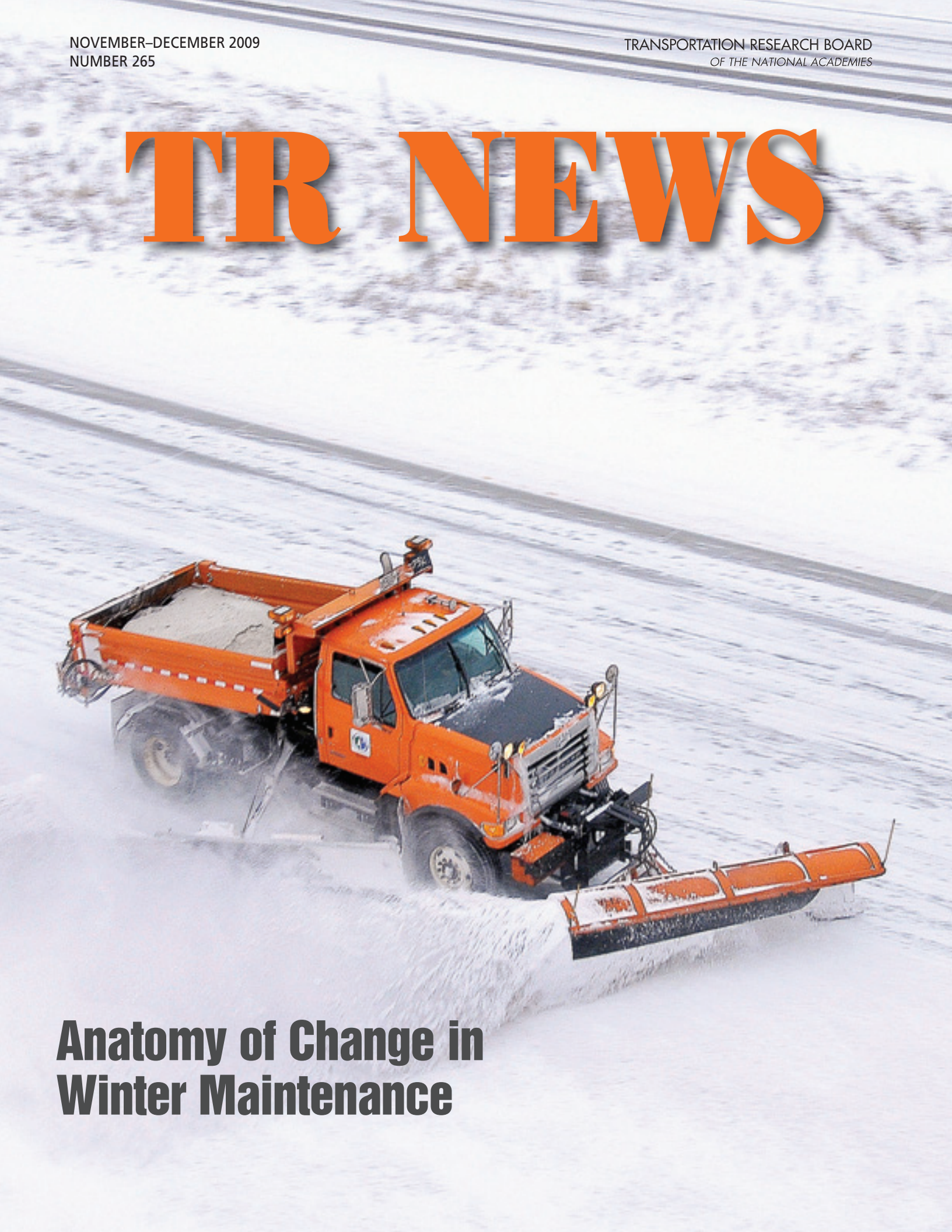
TR NEWS



Anatomy of Change in Winter Maintenance

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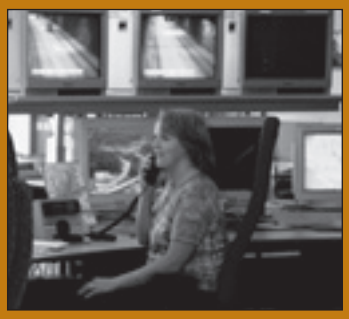

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COVER: A snowplow clears a Minnesota highway. Minnesota is one of many states that have invested in research to increase the safety, efficiency, and cost-effectiveness of winter maintenance operations. (Photo: David Gonzalez, Minnesota DOT)

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.

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COMING NEXT ISSUE

The connection between baseball and the growth of streetcar lines in the 19th century United States is the subject of a feature article by transportation historian Robert G. Cullen in the January–February 2010 issue of *TR News*. Other key features present the use of self-assessments by state departments of transportation to effect organizational change and align goals; guidelines and practical tips for communicating the value of transportation research; an overview of a National Research Council report on the potential development of hydrogen fuel cell vehicles; and a summary of findings and emerging trends from the 2009 field visits by senior program officers in the TRB Technical Activities Division.

Streetcar developers in the late 19th century invested in professional baseball as a destination to stimulate travel. The team name "Dodgers" has origins related to trolleys.

INTRODUCTION

Anatomy of Change in Winter Maintenance

Research and operations groups in the transportation and the meteorological communities around the world have collaborated for many years to develop and implement improvements in winter maintenance operations. Winter operations traditionally have relied on the experience and knowledge of field supervisors, equipment operators, and meteorologists.

The articles in this issue of *TR News* describe a variety of activities in the past two decades to develop and apply scientific principles and technologies to improve surface transportation weather measurements and forecasting, winter maintenance decision support tools and equipment, material chemistry, environment-friendly snow fences, state-of-the-practice training, and the communication of near real-time information to roadway users and maintenance personnel. The articles document how all of these elements are being orchestrated to improve the efficiency and effectiveness of winter maintenance operations. All together, these efforts have resulted in winter operations that maintain safe roadways for the traveling public, with improvements in the environmental impacts and with reductions in the costs of providing the services.

This issue presents an anatomy of continuing change as the new science of surface transportation weather evolves and as new technologies are developed, evaluated, and integrated into the operations of departments of transportation and of local and national meteorological services to preserve safe roadway networks during winter weather events.

The TRB Winter Maintenance and Surface Transportation Weather Committees have sponsored this theme issue. Committee Chairs John P. Burkhardt and Wilfrid A. Nixon, along with Leland D. Smithson, a member of both committees, were instrumental in acquiring, developing, and assembling the variety of information presented in the following pages.

—Frank N. Lisle
Engineer of Maintenance, TRB

EDITOR'S NOTE: Appreciation is expressed to TRB Senior Program Officer Frank N. Lisle for his contributions in developing this issue of *TR News*.

Winter Weather and Road Condition Forecasts

Advances in Models, Sensors, Tools, and Platforms Improve Maintenance Operations

KEVIN R. PETTY

The author is Offering Manager, Road Weather, Vaisala, Inc., Louisville, Colorado.

Photo: David Gonzalez, Minnesota DOT

The margin for error is small when it comes to ensuring safe and passable roads in hazardous weather conditions.

In contending with hazardous winter weather conditions and the adverse impacts on roadway operations, winter maintenance practitioners must make critical decisions about the best use of resources to maximize roadway efficiency and safety. Maintenance managers and crews have a small margin for error, considering the increasing cost of materials, concerns about the environment, and the traveling public's demand for safe, passable roads—a problem compounded by the growth in traffic.

The ability to garner accurate, timely information on road weather conditions is fundamental to decision making for winter maintenance. The proliferation of road weather information system (RWIS) environmental sensing stations (ESS) has enabled decision makers to obtain information about the atmosphere and the roadway network, particularly at known trouble spots—for example, bridges—and to respond promptly and effectively during hazardous weather-related situations. To plan successfully for imminent events, decision makers need information about evolving road weather conditions.

Forecasting Strategies

Winter maintenance personnel have relied on several forecasting strategies and techniques to gain insight into weather and road conditions. This information aids in determining how to allocate and position resources such as personnel, equipment, and materials, and in choosing a treatment strategy—the type, the timing, the rate, and the location.

The forecasting methods range from those based on sound scientific principles to those rooted in questionable doctrine. Some of the more recognized and noteworthy procedures include persistence forecasts, analog approaches, statistical techniques, and numerical model-based forecasting:

- **Persistence forecasts** assume that conditions will remain unchanged. This generally is not a sound assumption, because road environment conditions can change dramatically and quickly.
- **Analog approaches** correlate the current event with similar historical events. In the road environment, however, no two events—regardless of their similarity—will result in the same road weather conditions; this makes the technique problematic.
- **Statistical techniques** leverage relationships between select road weather parameters; they have produced beneficial prediction tools, particularly for

short-term forecasts—that is, for up to 3 hours of lead time. The accuracy of statistically based forecast tools, however, drops off significantly when the lead time exceeds 3 hours.

◆ **Numerical forecasting** uses computers to solve complex mathematical equations that describe the physical properties of the atmosphere and road.

Experts generally agree that numerical prediction techniques—or a combination of statistical and numerical forecast methods—offer the best approach for short- and long-term forecasting.

Numerical Models

Numerical weather models simulate the evolution of atmospheric conditions over a specified period. Numerical forecasting of the weather has been around for more than half a century, but only recently has the output developed the timeliness and quality to support effectively the tactical and strategic components of winter maintenance management. The advent of real-time, high-resolution modeling capabilities—along with advances in the basic principles of numerical weather prediction—has made this application possible. Other noteworthy elements include the introduction of mesoscale modeling, the increase of observations and observation networks, and increases in computing power.

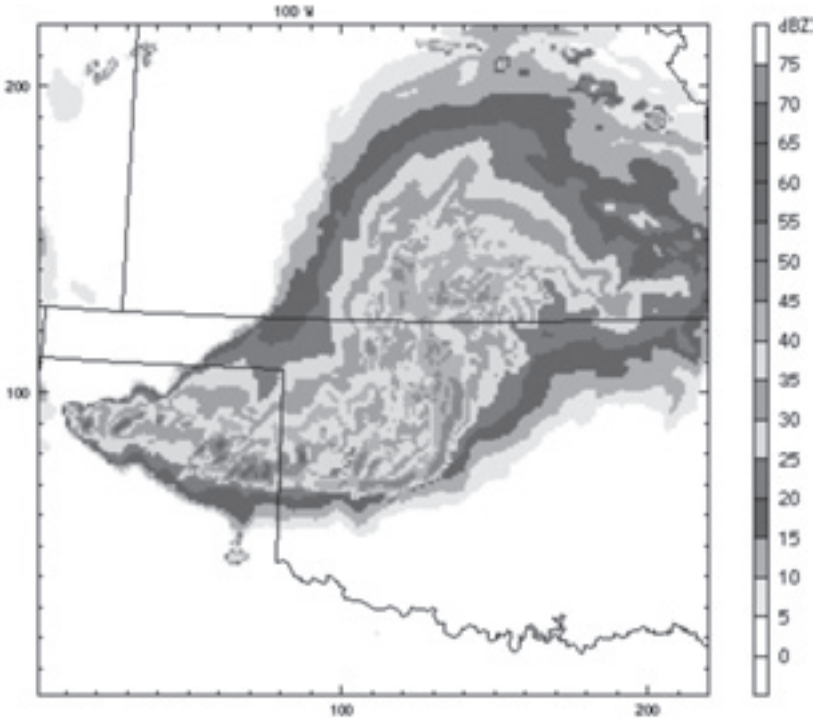
Mesoscale models can operate at spatial resolutions that allow simulation in time and space of many of the smaller-scale weather phenomena that are of interest to the road weather community. In general, this is achieved by solving equations that govern atmospheric behavior at grid points within a model. The grid points are part of horizontal grid meshes at multiple levels of the atmosphere, which represent the model's forecast domain.

The horizontal grid spacing of mesoscale models varies with the model and its application, but most range from a few kilometers to tens of kilometers. The ability to simulate the atmosphere at a higher spatial resolution—in other words, with a smaller grid spacing—is one of the many contributions that have improved winter weather forecasts (see image, this page).

An equally important advance has been the increase in the temporal resolution of the models—that is, in the frequency of the updates to the forecasts and in the intervals at which road weather information is supplied. Advances in computing permit some mesoscale models to be updated hourly.

In addition, the models have an increased capacity to output snapshots of the predicted state of the atmosphere. At hourly or smaller intervals, the snapshots can supply more detail about the expected changes in road weather conditions during the forecast period.

Source: National Center for Atmospheric Research



Numerical model–simulated reflectivity, similar to what is seen in a radar image.

Increasing Accuracy

The accuracy of model forecasts depends in part on the quality of the observations and on the process for data assimilation. To predict changes in the environment with precision, a model must "know" the state of the atmosphere at the beginning of the forecast period. Through data assimilation, numerical forecast models gather and merge observations to deliver what is called a "first guess" field.

If the initial conditions used in the model contain significant errors, however, the errors will propagate and grow throughout the forecast period, producing poor predictions. These errors can arise because of the lack of information for certain regions, faulty observations, or flaws in the assimilation technique.

To enhance forecasts for winter maintenance, weather providers have begun to leverage ESS data to obtain better initial conditions for numerical models and to support superior predictions of the road weather. But because ESS sometimes are located at roadway points that exhibit unique characteristics, the observations may not be indicative of the larger environment and may be counterproductive in predicting the road weather for the larger domain.

Nonetheless, experts agree that near-surface forecasts are likely to improve with the availability of dense, high-quality observation networks, such as those in the United Kingdom, which has more than 1,000 well-maintained ESS. In 2008, a National Research Council report recommended the establishment of a nationwide network capable of sup-

A National Research Council report recommends a nationwide network of near-surface observations; the cover shows environmental sensing stations.

PHOTO: CENTER FOR TRANSPORTATION RESEARCH AND EDUCATION

The use and maintenance of environmental sensing stations will help improve road weather forecasting.

plying near-surface observations to support a range of weather needs and requirements in the United States, including those of the winter maintenance community (*1*). The report supports the view that more high-quality regional and local observations may be the key to better forecasts.

Tools and Platforms

The ESS used by maintenance personnel can serve as a first step in gathering near-surface observations. Traditionally, highway authorities have used the information from fixed-based platforms to monitor and to respond to the changing road weather environment. In addition, semimobile and mobile units have been effective in obtaining intelligence about atmospheric and pavement conditions.

Coupled with ancillary observations, RWIS ESS will increase in importance in providing valuable information on near-surface conditions. These data will be essential in initializing and operating numerical models, as well as post-processing systems. Deploying, operating, and maintaining ESS, therefore, will support improvements in road weather forecasting.

Also important is the development of advanced computing platforms. Numerical weather prediction depends on computational resources and therefore on improvements in computers. Running today's weather forecast models on the computational resources available only a few decades ago would take so long that that the forecast would be obsolete.

Addressing Uncertainty

Despite substantial improvements, forecasts are far from perfect, particularly in terms of providing route-specific road weather information. Forecast models can predict many of the weather features and conditions that affect winter maintenance operations, but the models often fall short in supplying consistently accurate information at small scales—for example, at 1 or 2 kilometers—and in proximity to the earth's surface. A forecast always has some level of uncertainty, which increases beyond the initial forecast period.

Researchers have attempted to address the issue of uncertainty through several means; one of the more promising is ensemble forecasting, which generates multiple numerical forecasts from slightly different initial conditions, different versions of the same model, or completely different models. The variation in the simulations provides a gauge of the level of forecast uncertainty. Forecast centers worldwide are applying this technique, and end users are beginning to see measurable benefits in the accuracy of forecasts and in the communication of weather information.

Interpreting the Data

Weather forecasts, nonetheless, should be used solely as guidance in winter maintenance decision making. Mesoscale models still have difficulty with the timing and location of some weather features—such as precipitation—which are critical in road weather operations. Someone trained in meteorology and numerical weather prediction should interpret the output from the weather forecast models. Experienced forecasters can understand the strengths and weaknesses of numerical modeling and can identify when a model-generated forecast may be problematic.

Global forecast organizations—such as the United Kingdom's (UK) Met Office, the U.S. National Weather Service, Environment Canada, and the Bureau of Meteorology in Australia—employ full-time meteorologists to analyze and interpret the output from mesoscale models and then to convey the information to the public in an easily understood format. Commercial weather providers also employ meteorologists to ensure that customers receive timely notifications of significant or potentially hazardous weather events. Similarly, experienced meteorologists can clarify the data and information about current and expected adverse weather conditions for winter maintenance and can advise on treatment strategies.

Increasing computer power, new forecast methodologies, and the availability of more high-quality, near-surface observations will support road weather forecast improvements and will enhance decisions about winter road treatments. Maintenance personnel, however, must understand the links between the current and predicted weather and the resulting road

conditions. Without this understanding, the advantages of superior weather forecasts in refining winter maintenance operations are limited.

Pavement Conditions

Substantial progress also has been made in the past few decades in predicting changes in pavement conditions during winter weather events. Numerical models have been developed to simulate changes in road conditions and in the underlying subsurface at points along a road. These physically based, one-dimensional energy and mass balance models use information from RWIS ESS and weather forecasts to predict changes in pavement temperatures and conditions at a point along a roadway.

Winter maintenance crews typically are dispatched at the first sign of frozen precipitation or when atmospheric conditions appear conducive for frost formation; this practice, however, can waste resources. For example, in some parts of the world, prolonged sunny atmospheric conditions can build up a reservoir of heat beneath the pavement. Days later, this reservoir of heat can keep the pavement temperature from falling below freezing during a snowfall, negating the need to treat the surface. Without knowing how the pavement and subsurface conditions will change, agencies can deploy materials and manpower unnecessarily. One-dimensional energy and mass balance models can provide insight into the future condition of the road and can support tactical and strategic winter maintenance decision making.

Pavement Models

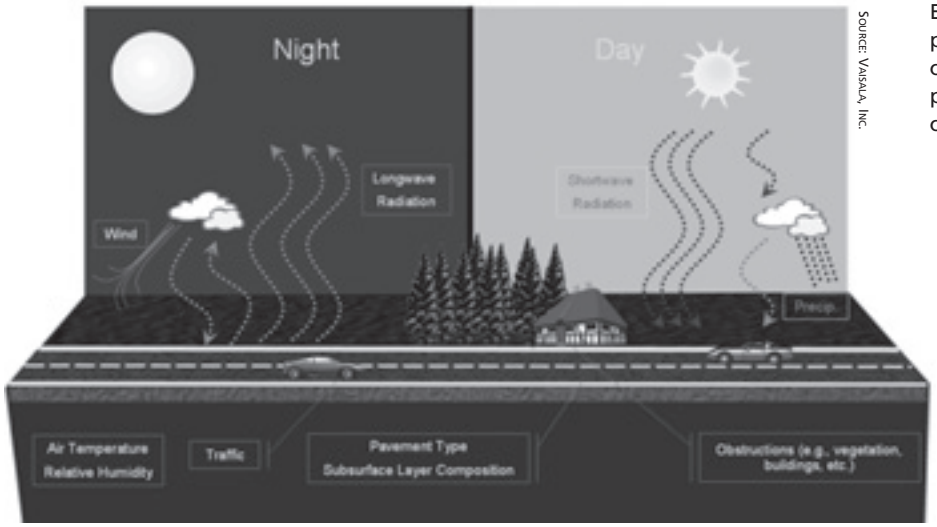
Many meteorological and nonmeteorological elements determine the state of a road. Forecast centers such as Environment Canada and the UK Met Office use single-dimensional, numerically based pavement condition models to capture these elements and develop guidance about road conditions. Commercial weather providers also are leveraging these models to supply targeted road forecasts to their customers.

Some models are better than others at simulating the surface conditions; care should be taken when using the output data and information for critical winter maintenance decisions. Multiseason experience with any model is the best way to develop an understanding of the strengths and weaknesses of the output and how best to use the output in operations.

These models calculate and consider direct energy from the sun, indirect energy from clouds and from the earth's surface, and heat exchange from atmo-

Photo: Todd Sloan, Ohio DOT

A clean, dry roadway segment after a snowfall on SR-315 in Delware County, Ohio. In some situations, higher-than-usual pavement temperatures negate the need to treat the road surface after a snowfall; it is vital to know how pavement and subsurface conditions can change before winter maintenance decisions are made.



Source: Vaisala, Inc.

Environmental parameters that can affect pavement conditions.

spheric turbulence and precipitation. The incorporation of information about the sky view factor—or the amount of sky that is visible at a particular location—will extend the performance of pavement models.

Some models include effects caused by vehicles. Higher-quality models require information about pavement properties—such as asphalt or concrete and the thickness—and about the subsurface layers, to compute the heat capacity and the ground heat flux. These models can identify and simulate the characteristics of road and bridge surfaces. Parameters such as water, snow, and ice on the surface—essential in determining a winter maintenance course of action—are computed and monitored with information about precipitation, evaporation, and runoff.

Like weather models, pavement models must start off with an accurate representation of the atmospheric and pavement conditions. A forecast site typically coincides with the location of an RWIS ESS, so that observation data from the ESS can be used in the initialization process. Some models need a 12-hour history of the site; others use only the most recent observation.

Getting the Most out of Winter Weather Forecasting Services

RICHARD M. BALGOWAN

Forecasting services have improved their ability to meet the needs of winter operations managers for accurate, timely forecasts of the weather on the mesoscale and microscale levels and for forecasts of the pavement temperature and condition. Winter operations managers need to know what will happen when precipitation hits the pavement. Will the pavement be warm enough to melt any accumulating snow? Will the pavement be so cold that rain will freeze to the surface on contact? Are conditions right for frost to form on bridge decks?

These types of forecasts formerly were not possible—the technology was not in place or did not yet exist. Today, automated weather stations across the United States collect real-time information on pavement, subsurface, and bridge deck temperatures. Forecasting services can access these systems to develop predictions that are usable by the agencies involved in snow and ice control.

Hamilton Township, New Jersey, has used a weather forecasting service for many years. Before the winter of 2004–2005, the service did not offer pavement temperature forecasts or immediate access to a forecaster for consultations on approaching storms and on weather reports. Hamilton Township rewrote its weather service specifications to require more information—pavement temperature forecasts, starting and ending times of precipitation and frozen precipitation, precipitation intensity, and other vital information. The township also sought unlimited 24-hours-a-day, 7-days-a-week access to a forecaster.

PHOTO: FORTIN CONSULTING, INC.

Deicing material blows off the road as a winter maintenance vehicle tries to remove a microscopic layer of ice—which formed when melted snow refroze—with a solid deicer. Pavement temperature and condition forecasting is essential for making the right decisions in winter operations.

The results of this enhanced weather forecasting service have been significant. Overtime hours and chemical use were cut drastically. Previously, if a weather forecast called for snow to start at 4:00 a.m., crews would be mobilized 1 to 2 hours earlier. Often the snow would melt on contact with the pavement; sometimes the melting would continue for the duration of the storm. Without forecasts of pavement temperature, the township's decision makers had no way of knowing if pavement temperatures would stay above or drop below freezing.

With the new forecasting specifications, Hamilton Township can mobilize forces on the basis of what is expected to happen when the precipitation hits the pavement. In many storms during the past few years, personnel and equipment were not mobilized or were mobilized later, because the precipitation was forecast with a reasonable degree of certainty to melt on contact with the pavement.

For Hamilton Township, a good weather forecasting service—one that provides relatively accurate pavement temperature forecasts and unlimited access to weather forecasters for consultation—has proved the single most valuable decision-making tool for snow and ice control managers.

The author is Director of Public Works, Township of Hamilton, New Jersey.

After initialization, atmospheric data such as temperature, dew point temperature, cloud cover, wind speed, and precipitation are used in the pavement models to resolve changes in pavement conditions during the forecast period. A poor weather forecast will lead to a poor forecast of road conditions, regardless of how good the pavement model is.

Route-Based Forecasting

The one-dimensional nature of pavement models is a significant limitation—the results are valid only for a single location. Obtaining information about pavement conditions at select points along a road is valuable, but the current and future conditions between these points also have implications for winter maintenance activities. An effort is under way to expand the use of pavement models to provide road condition predictions at equally spaced intervals along a route. This practice is often termed route-based forecasting.

Most route-based forecasts are generated at nonobserving sites—that is, no ESS data are available—and can be subject to significant errors, because of the lack of proper initialization. Users therefore need to understand the limitations of this approach and work closely with the forecast providers so that the forecasts meet the needs and requirements of the operating environment.

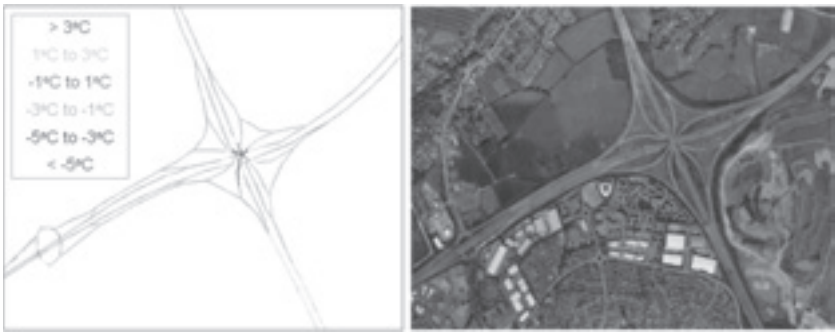
Thermal Mapping

One of the optimal ways to obtain a comprehensive assessment of pavement temperatures throughout a roadway network is through thermal mapping, which determines the spatial variation in pavement temperature with a high-resolution infrared thermometer. Thermal mapping is highly accurate and can resolve details about differing climate zones within a roadway network.

Thermal mapping surveys are conducted during winter nights under various weather conditions. With the map—a thermal signature of the roadway network—a user can identify the warm and cold sections of pavement in relation to the average temperature of the network.

Thermal mapping surveys conventionally are combined with ESS to ascertain the state of the network. The ESS establishes the pavement temperature at a particular location, and the thermal mapping information is used to extrapolate temperatures away from that point across the road network.

Thermal mapping data also can be used with pavement temperature forecast data—for example, from pavement models—to gain insight into the anticipated conditions at a point along a road. Again, the thermal mapping information is used to extrapolate between points to forecast pavement temperatures throughout the roadway network.



Sources: Vaisala, Inc., with aerial image from Google.

Thermal map of Bristol Interchange, United Kingdom. The left image displays pavement temperatures throughout the interchange, highlighting relatively warm and cold sections. Note that the coldest sections are associated with elevated roadways, and the warmest sections are insulated by the colder sections.

Although thermal mapping can provide decision makers with accurate, comprehensive information about network pavement temperatures, it has some limitations. Thermal mapping data and information, both diagnostic and prognostic, are valid only at night and during nonprecipitating situations. If the network is affected by solar radiation or if precipitation occurs for a significant time, the thermal mapping information is no longer applicable.

Nevertheless, under proper conditions, thermal mapping data can be used to pinpoint the locations most susceptible to frost or ice formation. Because pavement temperatures within a roadway network can vary by as much as 10°C, this information allows winter maintenance personnel to target winter maintenance actions more precisely.

Strategies and Tactics

The arsenal of forecasting tools available to winter maintenance practitioners continues to expand. The accuracy and the timeliness of forecasts have shown marked improvements. The combination of improved weather forecasts and pavement condition forecasts is altering the way the winter maintenance community addresses adverse winter road weather conditions. In the past, treatment actions were reactive, and decision making relied on a considerable amount of guesswork.

This new age of winter maintenance management is grounded in strategic and tactical decision making—that is, in planning and response—which can be supported only through satisfactory road weather predictions. As the quality of road weather forecasts improves, the ability to maintain safe, efficient roads during the winter will increase—and the costs associated with winter maintenance activities will decrease.

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Developing a Winter Maintenance Decision Support System

Prototype to Field Tests to Payback—and Beyond

LELAND D. SMITHSON AND WILFRID A. NIXON

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Operations decisions that affect the safety and mobility of the public during winter storms rely on information about roadway surface conditions and their expected changes as the storm progresses. Often that information has come primarily from general weather reports and forecasts and from observations by snowplow operators.

In the past two decades, collaborative research efforts have supported the development of a decision support system incorporating the science of surface transportation weather with winter maintenance treatment practices. The goal is to improve the maintenance response to changing road conditions.

All in the Timing

Winter maintenance decision making involves more than the basic—but critical—operations of applying materials and plowing snow. The key goals are safety and mobility for the traveling public. Sometimes the winter maintenance goals can be achieved in part by adjusting standard operational actions or procedures. For example, changing the timing of traffic lights in inclement weather may be beneficial in maintaining acceptable levels of mobility (see sidebar, page 11).

The timing of road treatments is particularly important in preventive or proactive winter maintenance activities. Anti-icing pretreatment techniques have been used successfully in dealing with potential frost problems; the benefits can be measured in terms of fewer accidents and reduced costs for labor and equipment. Instead of sending an operator and truck out just before—or as soon as—the frost develops, usually during the early morning hours, materials can be applied the day before, during normal working hours, and be ready to perform when needed.

Another example of the importance of timing is that snowplows are not effective in stop-and-go traffic. In areas where congestion occurs, therefore, plow activity must be timed around congestion periods. When big storms last longer than a single shift, scheduling must ensure that plow operators do not spend too many continuous hours in the truck—which could lead to fatigue and safety problems. Timing in winter maintenance is not solely an urban concern—avalanche control often requires careful timing and knowledge of particular hazards and changing conditions (see sidebar, page 13).

Photo Courtesy of Adel W. Sadek

Downtown Buffalo, New York, after a snowfall.

Photo: L. Dellovade, Ohio DOT

View from a snowplow in traffic in Ohio. Timing is important—snowplows are not effective in stop-and-go traffic.

The quality and timeliness of information about the pavement surface characteristics at a variety of points on the roadway network and about the associated characteristics of the storm are the biggest challenges to successful decision making for winter maintenance. The variety of winter storm scenarios requires a comparable variety of complementary responses.

Connecting the Maintenance and Meteorological Communities

Building on the road weather information systems (RWIS) and anti-icing research conducted under the first Strategic Highway Research Program (SHRP) in the late 1980s and early 1990s (*1–4*), the Federal Highway Administration (FHWA) supported additional field studies. Under Research Project TE28, FHWA developed a manual of practice for an effective anti-icing program for highway winter maintenance treatments (*5*).

Photo: Liz Roll/FEMA

Road closings were common during a January 2007 storm in Norton, Kansas, that left up to 30 inches of snow and ice.

The project enabled the maintenance operations and the meteorological communities to focus and coordinate efforts to improve the basic understanding of the microclimate at the road surface and of the appropriate treatment responses. The manual of practice distilled the results of field tests into a description of the winter maintenance operations decision-making process for eight winter storm scenarios.

FHWA and the Office of the Federal Coordinator

Adjusting Traffic Signal Timing in Inclement Weather

ADEL W. SADEK

Winter weather often causes gridlock along arterial systems in cold climates. Snow and ice typically alter driver behavior and patterns of travel demand. This renders the normal traffic signal coordination plans inappropriate, because the plans typically are developed for normal weather conditions and typical driver behavior.

With funding from the New England Transportation Consortium, researchers recently evaluated the impact of inclement weather, at varying degrees of severity, on driver behavior at signalized intersections. The researchers specifically looked at startup lost time and discharge headway—that is, the distance between vehicles moving through an intersection. They evaluated the likely benefits of implementing signal timing plans specially tailored for inclement weather.

The findings indicated that inclement weather has a statistically significant impact on discharge headway, especially when slushy conditions develop or snow begins sticking to the pavement. For example, at one intersection, when snow began to stick to the pavement, the saturation flow rates were reduced by as much as 16 percent.

Using several well-calibrated simulation models, the researchers assessed the likely benefits of special timing plans during inclement weather. They concluded that significant operational benefits could be achieved, especially when arterials are operating close to capacity and the duration of the inclement weather event increases (*1, 2*).

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Photo Dennis Nee, The Post-Standard

Special timing plans for intersection signals in inclement weather can improve safety and traffic flow.

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PHOTO: IDAHO DOT

Roadway weather information system environmental sensor station in Idaho.

for Meteorology of the U.S. Department of Commerce extended the TE28 work by involving stakeholders from the winter maintenance and the meteorological communities in two collaborative efforts:

- The Surface Transportation Weather Decision Support Requirements (STWDSR) activity,[1] started in 1999; and
- The Weather Information for Surface Transportation (WIST) project, started in 2000 to define needs in the field of surface transportation weather (*6*).

Among the outcomes of these efforts was a consensus to develop a maintenance decision support system (MDSS) to integrate computerized winter maintenance practices—developed from the TE28 manual of practice treatment recommendations—and the user requirements identified in the STWDSR and WIST efforts with state-of-the-art weather forecasting models and techniques (*7*).

Solving Data Issues

Two important data issues arose in stakeholder meetings. First, little was known or recorded as metadata about the characteristics of the locations of RWIS stations operated by state departments of transportation (DOTs). RWIS metadata include site information, such as location on a hill or in a valley; orientation to or away from the sun; relationship to the area—typical of or unique; and the availability of power and communications links. Second, the accuracy of the RWIS-generated data was uncertain.

To resolve the first issue, FHWA initiated a project in 2003 to establish guidelines for siting RWIS environmental sensor stations (ESSs). The recommendations include criteria for siting tower locations in relation to a roadway and guidelines for mounting sensors for the wind, the camera, radiation, the dew point, the temperature, precipitation, visibility, and snow depth (*8*).

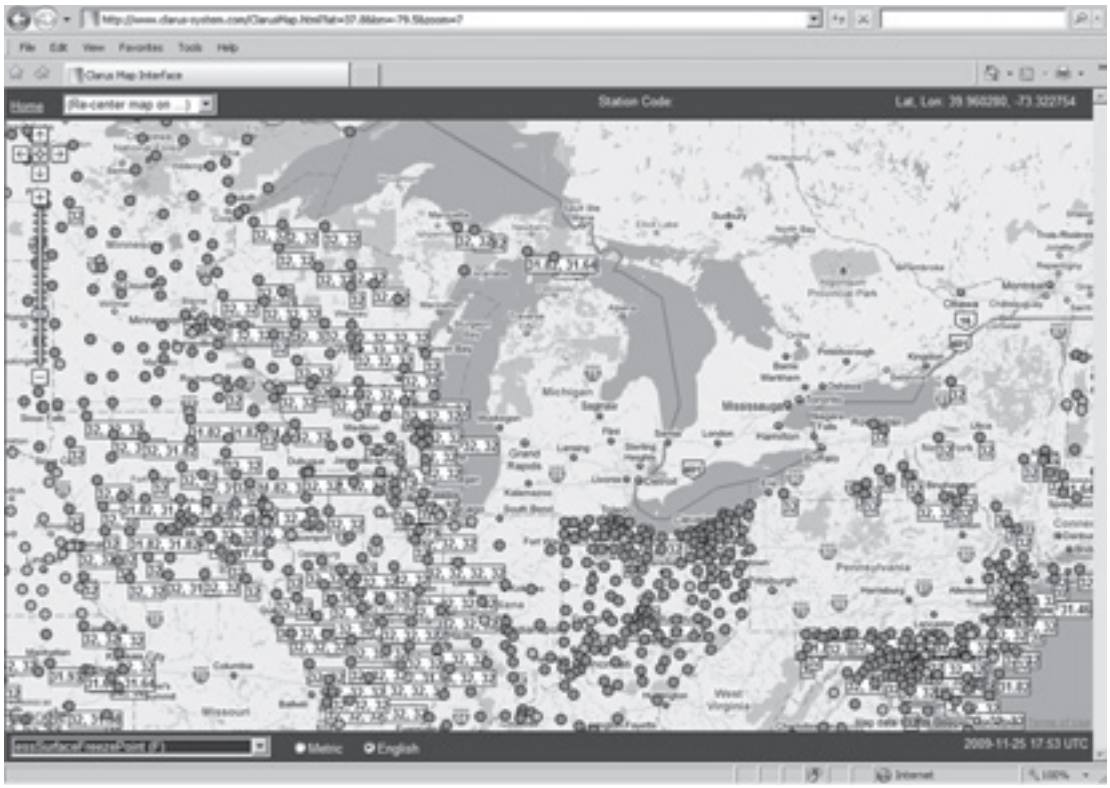
To resolve the second issue, U.S. DOT and the National Oceanic and Atmospheric Administration (NOAA) joined forces in a project called Clarus—Latin for "clear"—to prepare roadway users, transportation managers, and weather services providers for adverse weather conditions year-round—rain, sleet, snow, ice, fog, wind, floods, or dust.

Clarus is collecting weather observations from weather and transportation sources, analyzing the data for accuracy, and then packaging the data into a common format that meets the needs of public and commercial end users.

Federal MDSS Prototype

The federal MDSS prototype project began in 2000 in response to the user-defined needs for surface trans-

[1] Federal Highway Administration Road Weather Management Program, http://ops.fhwa.dot.gov/weather/.



Map interface developed by the Clarus project to provide information about adverse weather conditions year-round.

Avalanche in the Teton Mountains

Chronology of an Event on Wyoming State Highway 22

JAMIE YOUNT

During the 2008 holiday season, the Teton Mountains near Jackson, Wyoming, experienced a deep slab avalanche cycle—one of the most intense in 20 years—that had a severe effect on State Highway 22 over Teton Pass. A heavy rainfall at an elevation of 11,000 ft on November 29, 2008, produced a formidable rain crust on all the high elevation zones, the starting points for avalanches, around Teton Pass. Weather conditions remained cold and dry into December, and a weak, sugary, faceted snow developed above and below the rain crust.

On December 20, a series of sizable winter storms hit the Teton Area, culminating in a 30-in. snowfall that pushed mountain slopes to a critical condition on December 25. The following timeline recounts the avalanche control measures and highway operations to deal with this event and to keep Teton Pass open to traffic.

◆ *Monday, December 12.* A Gazex® exploder is ignited to produce a controlled avalanche from the northeast face of Glory Bowl onto Highway 22.

◆ *Thursday, December 25.* Teton Pass is closed at 1615 hours, because of increasing avalanche danger.[1] A major storm deposits 30 in. of new snow—a water equivalent of 3 in.

◆ *Friday, December 26.* At 0200 hours, a natural slide at Glory Bowl deposits 10 ft of debris on the highway. The first shot from an avalanche control device brings another 20 ft of debris down onto the road. A loader and rotary plow require several hours to remove the debris from the highway. At the summit of Teton Pass, two 10-lb avalanche control shots are detonated, with no results in the Twin Slides area; the first Gazex ignition, however, brings 15 ft of debris down onto the road. During the cleanup, several small banks avalanche onto the highway. Teton Pass reopens to traffic at 1500 hours.

◆ *Sunday, December 28.* At 2200 hours, an avalanche at Milepost 13 (Beaver Slides) near Coal Creek puts 12 to 15 ft of debris on the road, including the remains of a moose, whose movements may have triggered the slide. The pass is closed to traffic for the rest of the night.

◆ *Monday, December 29.* At 0300 hours, Gazex ignitions in the Twin Slides and the Glory Bowl Slide bring no further movements. The detonation of hand charges at Milepost 13 brings three more slides onto the road, each with 2- to 3-ft crowns and 10 to 12 ft of debris. Teton Pass reopens to traffic at 0700 hours.

◆ *Tuesday, December 30.* Teton Pass closes at 0800 hours. At 1030 hours, a helicopter drops 25-lb ANFO (ammonium nitrate–fuel oil) bombs to reduce the avalanche hazard. The first bomb in the Glory Bowl Slide produces a 5- to 6-ft crown and deposits 50 feet of debris on the highway. A shot in Shovel Slide produces an avalanche with a 4-ft crown that stops 30 ft short of the highway. The bombs produce no results in Rocky Gulch, Surprise Slide, and Second Turn. A howitzer fires 16 rounds at targets in Glory Bowl, Rocky Gulch, and Surprise Slide with no additional results. A bulldozer mounts the avalanche debris at Glory Bowl and reduces the pile to a workable height for the rotary plow. Teton Pass reopens to the public at 1900 hours, ending the 5-day avalanche event.

Helicopter bombing produced an avalanche at Glory Bowl that deposited 50 ft of debris onto the highway.

The author is Avalanche Technician, Wyoming Department of Transportation, Jackson.

View of avalanche debris at the Glory Bowl Slide.

[1] Military time is used in this article; hours are numbered from 00 to 23, followed by two digits for minutes; midnight is 0000 hours, 1 a.m. is 0100 hours, 1 p.m. is 1300 hours, and so on.

portation weather information that were developed in the TE28, STWDSR, and WIST efforts. The federal MDSS prototype integrates road surface condition, road weather forecast information, winter maintenance rules of practice, and maintenance resource information to generate recommended winter road treatment strategies for maintenance managers. With good information, the managers can allocate resources proactively to meet the operational and safety needs of road users in real time.

FHWA funded the development of the prototype, with the National Science Foundation's National Center for Atmospheric Research providing the lead. The U.S. Army Cold Regions Research and Engineering Laboratory, the Massachusetts Institute of Technology–Lincoln Laboratory, and the NOAA National Severe Storms Laboratory and Forecast Systems Laboratory made project contributions (*8*).

Field Testing

Three Iowa DOT maintenance garages field-tested and evaluated the federal MDSS prototype during two winters, starting in 2002. Start-up problems during the first winter were traced to the road weather forecasting models, which were being field-tested for the first time in the new science of surface transportation meteorology. In the second winter, implementation went well—several of the recommended treatments were applied without modification, and other recommended treatments required only minor modifications.

The third year of field demonstrations took place in the winter of 2004–2005 in central Colorado. The move provided new challenges for the MDSS prototype—addressing the more complex terrain around Denver instead of the relatively flat terrain of central Iowa. The Colorado demonstration showed that weather forecasting was much more difficult on the leeward side of the Rocky Mountains.

Since the demonstration in Denver, significant improvements have been made to the forecasting components of the federal MDSS prototype, with corresponding improvements in the treatment recommendations. When Colorado experienced the blizzard of 2006, Phillip Andrle, deputy transportation maintenance supervisor at Colorado DOT, indicated that the MDSS weather forecasting tool "has been very, very close to predicting the start and stop times of precipitation….We're being more efficient, putting out the right product at the right time in the right amounts" (*9*).

FHWA is promoting the deployment of the MDSS for winter road maintenance and is expanding the scope to include a Maintenance and Operations Decision Support System to assist in weather-related decision making for summer maintenance and for construction.

Building on the Prototype

Two winter MDSS efforts are building on the technologies developed with the federal MDSS prototype: the Pooled Fund MDSS and the DTN–Meteorlogix WeatherSentry® MDSS.

The pooled fund study, started in 2002 with FHWA assistance and support, involves five state DOTs—South Dakota as the lead, North Dakota, Minnesota, Indiana, and Iowa. The study contracted with Meridian Environmental Technology[2] of Grand Forks, North Dakota, to develop, integrate, and deploy a winter MDSS. Study participants include 10 other state DOTs—California, Colorado, Idaho, Kansas, Kentucky, New Hampshire, Nebraska, New York, Virginia, and Wyoming—and FHWA.

After using the Pooled Fund MDSS in field trials, Indiana DOT moved to statewide implementation in the 2008–2009 winter season. With revenues declining, Indiana DOT expected to realize savings achieved by the maintenance units with the Pooled Fund MDSS (see article, page 35).

DTN–Meteorlogix—now part of Telvent—leveraged the capabilities of the federal MDSS prototype to create a web-based MDSS tool complementing the company's WeatherSentry forecast product. Ten states—Idaho, Iowa, Maine, Michigan, Missouri, Nebraska, Nevada, New York, Ohio, and Wisconsin—and the New York State Thruway Authority evaluated DTN–Meteorlogix's new service during the winter of 2005–2006. In the second season, the winter of 2006–2007, 11 states and 75 local agencies used the WeatherSentry MDSS.

The following winter, more than 30 states used Telvent–DTN weather services, 21 in conjunction with the WeatherSentry MDSS, and more than half applied the system statewide. Telvent–DTN now has more than 1,000 city and county subscribers to its

[2] http://meridian-enviro.com/pages.pl?pg=mdss.

Construction on I-71 in Ohio; the scope of the MDSS is being expanded to address summer maintenance and construction.

Photo: Joyce Dunford, Ohio DOT

weather services, with approximately one-quarter subscribing to the MDSS.[3]

Progress and Achievements

During the test trials of the federal MDSS prototype, field and management personnel indicated that the concept made good operational sense, supplied a check on their decisions, and optimized treatment strategies. Field personnel initially expressed concern that treatment recommendations tended to underestimate—if only slightly—the amount of chemicals needed; most therefore increased the application amount to ensure a margin of safety.

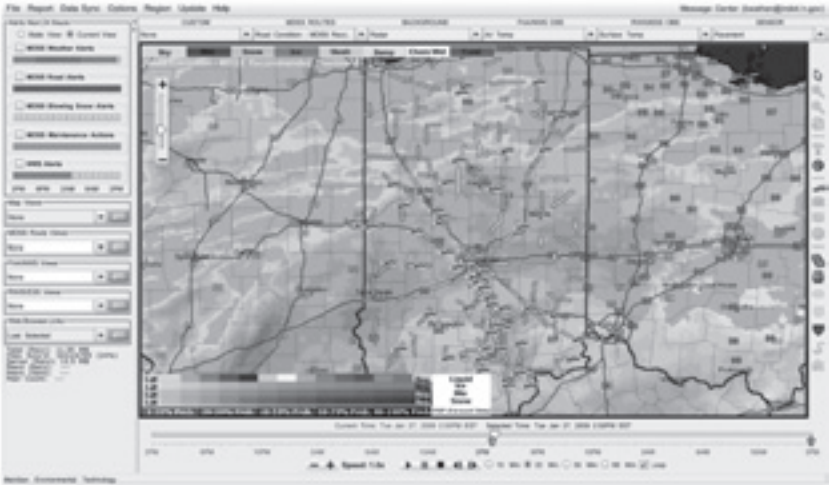
Further research was conducted in response to the field concerns, to advance the science of anti-icing, and to expand and refine the chemical requirements to allow for dilution factors that adjust to field conditions, such as traffic volume and speed, precipitation type and rate, treatment cycle-time, and the presence or absence of an ice–pavement bond (*10*).

In interviews, Iowa supervisors who evaluated the field tests of the federal MDSS prototype doubted that the DOT had received a favorable return on its investment, because the recommended treatments usually were consistent with what they would have done without the MDSS. This observation confirms at least that the MDSS was providing accurate and practical guidance; each of the supervisors had considerable field experience and, along with their operators, had completed the American Association of State Highway and Transportation Officials' anti-icing–RWIS computer-based training program (*11*). They shared a base of knowledge in winter maintenance decision making (see article, page 30).

In cooperation with Meridian Environmental Technology and DTN–Meteorlogix, Iowa DOT conducted quality checks on its winter road weather forecasts in 2007 and 2008. Hourly road temperature, bridge temperature, and precipitation forecasts were compared against bridge and road temperature observations from RWIS and the Automated Surface Observing Systems at nearby airports. The data were shown to be acceptable for decision making, and improvements in the second year earned the confidence of field operations personnel.

Performance Measures

Performance measures for snow and ice control operations are undergoing development. Performance measures assist agencies in monitoring winter maintenance operations, making adjustments, and managing resources. Agencies measure performance in terms of inputs, outputs, and outcomes:



Screenshot from the MDSS prototype.

- Input measures represent the resources used to perform winter maintenance operations and include fuel, labor, equipment, and materials.
- Outputs quantify the work performed and include lane miles plowed, tons of anti-icing or deicing materials used, pounds of material applied per lane mile, amount of equipment deployed, and cost per lane mile.
- Outcomes generally assess the effectiveness of winter maintenance operations, often from the user or customer perspective. Desired outcomes may include improvements in safety, mobility, and user satisfaction; the measures of outcomes typically are related indicators, such as pavement friction, number of crashes, travel speeds, and traffic volume during storms (*12*).

Payback

At the conclusion of the first SHRP in 1993, several state DOTs took the lead in implementing the RWIS and anti-icing research results. Their success encouraged other states to follow a new proactive approach to snow and ice control operations. Before field testing the Pooled Fund MDSS, state DOTs reported a benefit–cost ratio between 2:1 and 13:1 on investments in RWIS and anti-icing technologies, with increased travel safety and level of service and improved environmental quality (*13*).

New Hampshire Case Study

The Pooled Fund MDSS study selected New Hampshire as a case study for the benefits and costs associated with the implementation of MDSS. New Hampshire DOT began implementing the MDSS in the 2006–2007 winter season. The baseline data module included statewide road data, crash data, traffic data, and weather data.

A simulation was performed on a 9-mile highway segment of I-93 for seven consecutive winter seasons.

[3] www.meteorlogix.com/products/mxvision/weathersentry/weathersentry.cfm.

Photo: David Gonzalez, Minnesota DOT

The simulation inputs included weather data from a nearby weather station, rules of practice for winter maintenance operations, and daily records of maintenance use of salt. Tangible costs associated with implementing the MDSS included software and operations costs, communication costs, in-vehicle computer hardware, training, additional weather forecast provider costs, and administrative costs.

Measuring from the baseline condition, the state's standard rules of practice were applied without the MDSS at a projected annual cost of $2.9 million (in 2008 dollar values). Providing the same level of service with the MDSS and at the same level of resources would cost approximately $2.4 million. The case study results showed that the MDSS could reduce materials use, reduce delay, and improve safety (*14*).

Indiana Implementation

The savings reported by the states in the Pooled Fund MDSS study provided the impetus for Indiana DOT to implement the MDSS statewide during the winter of 2008–2009. Indiana DOT participated in the MDSS field trials for three winters, adding more routes each year and improving its communication processes before statewide implementation of the MDSS. During the field trials, Indiana subdistricts reported savings of 10 to 30 percent in salt use; increased use of MDSS therefore seemed appropriate when the state sought to reduce costs to offset declining revenues.

With the MDSS in the 2008–2009 winter season, Indiana DOT realized a savings of $12.1 million in salt use and $1.4 million in compensation for overtime. When the savings were normalized for varying winter conditions, Indiana DOT realized a savings of almost $10 million in salt use and $1 million in overtime compensation (*15*).

Pushing the Boundaries

The experiences of many agencies suggest that the MDSS is an excellent aid to decision making in winter maintenance operations. The MDSS, however, is far from the complete solution. Opportunities are being pursued to link the MDSS with traffic operations, maintenance management systems, and other enterprise systems.

The days of "wait until there are a couple of inches of snow on the road before taking any action" are long gone. Winter maintenance personnel now avidly scan radar readouts and weather forecasts, and they are integrating technological advances into decision making and pushing the boundaries of this science forward into other areas of transportation operations.

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Evolution of the Highway Maintenance Concept Vehicle

Assembling the Ideal Platform for Mobile Winter Operations

LELAND D. SMITHSON AND JOHN P. BURKHARDT

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In fall 1995, with support from the Federal Highway Administration (FHWA), the Iowa, Michigan, and Minnesota Departments of Transportation (DOTs) formed a research consortium to design and develop a highway maintenance concept vehicle (HMCV) deploying the latest technologies to improve snow and ice control operations. The consortium project was divided into three phases: prototype functions and feasibility; prototype evaluation; and field tests and evaluation.

The three-phase project was followed by a second project, or Phase IV, for operations and field demonstrations. Two additional partner states, Wisconsin and Pennsylvania, joined the project at Phase IV. The Center for Transportation Research and Education (CTRE) at Iowa State University provided assistance and support at all phases.

Functions and Feasibility

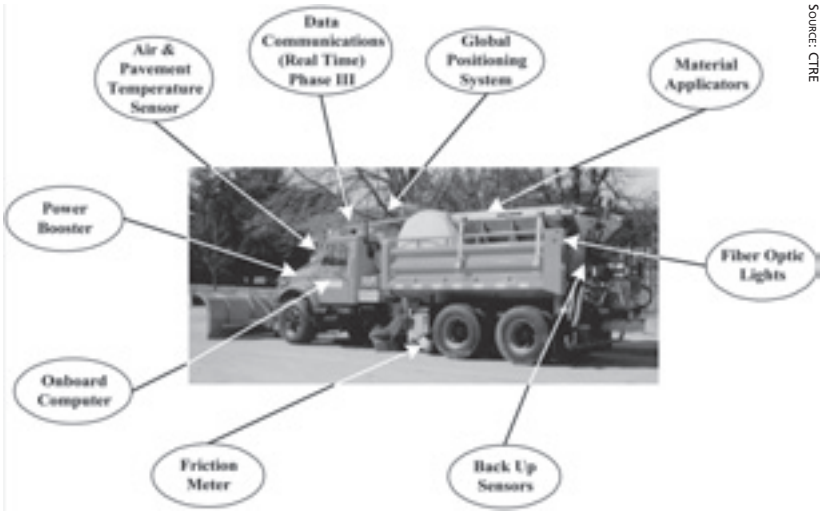
During Phase I, which ran from 1995 to 1997, the objective was to identify the HMCV functions, evaluate their feasibility, and enlist private-sector partners to supply the functionalities, technologies, and equipment. The consortium discovered early on that defining the scope and breadth of the research beyond the first phase would be difficult—while innovative technologies and new equipment options were being explored, new ideas would arise for consideration. A multiphase research plan therefore was adopted, with the earlier phases described in detail and the later phases broadly defined to provide flexibility for accommodating discoveries (*1*).

During the first phase, concepts were identified and the desired capabilities and functions of the HMCV were defined from the perspectives of the customers. The project pursued the development of public–private partnerships for building the vehicle and explored funding opportunities for subsequent phases.

A literature search in 1995 located relevant state-of-the-art snow and ice control materials and identified equipment technology and research activities to improve operations. The process of identifying the capabilities of a concept vehicle was similar to that used in the manufacturing community for developing a new product; therefore the consortium approached Rockwell International for assistance in selecting and conducting focus groups for input.

Rockwell recommended the quality function deployment process, which encourages direct customer input—that is, expressed in the customers' words, not in the terminology of a design engineer or marketing specialist (*2*). The focus groups also followed the procedures of total quality transformation, which encourages participants to concentrate on the causes of a problem, not on the symptoms.

Phase II prototype concept vehicle design.



SOURCE: CTRE

Focus Group Findings

All three consortium states conducted focus groups to capture customer input and to quantify the ideal capabilities of the concept vehicle. Focus group participants consisted of DOT equipment operators, mechanics, equipment specification writers, maintenance managers, maintenance supervisors, and representatives from other professions with an interest in the concept vehicle, such as law enforcement personnel and emergency responders.

To help cast off old paradigms and to encourage innovative thinking, the opening presentation to

TABLE 1 Equipment and Technologies Installed in Phase II

Equipment and Technologies	Vendor or Provider
Engine power booster	Fosseen Manufacturing
Global positioning system	Rockwell International
High-intensity discharge warning lights	Innovative Warning Systems
Norsemeter ROAD Friction Meter	Roadware Corporation
Material applicators and spreaders	Bristol Company, Monroe Truck Equipment, and Tyler Ice
Pavement and air temperature sensors	Sprague Controls
PlowMaster computer	Rockwell International
Reverse obstacle sensor	Global Sensor Systems
Trucks and plows	Iowa, Michigan, and Minnesota DOTs
Vehicle weight sensors	Rockwell International

each focus group showed new technologies identified on an International Winter Maintenance Technology Scanning Tour to Japan and Europe in March 1994 (*3*). The tour participants discovered differences in snow removal equipment, anti-icing and deicing materials and methods, weather monitoring, winter hazard mitigation, and road user information services.

The focus groups provided a list of ideal features for the HMCV, including the ability to

- Measure roadway friction and surface temperature;
- Record vehicle activities, such as plow-up or plow-down, and spreading chemicals or not;
- Improve fuel economy and provide adequate horsepower for the snowplow;
- Carry and distribute several types of materials with removable salt and salt brine dispensing systems; and
- Provide sensors for obstacle detection when backing up.

Public–Private Partnerships

Private companies were invited to judge the feasibility and practicality of the prototype and to enter into a partnership with the state DOTs. The consortium hosted two workshops in 1996—one in Detroit, Michigan, in April, and the second in St. Paul, Minnesota, in July. At the workshops, DOT maintenance engineers, industry designers, and manufacturers discussed the application of new technologies for highway maintenance vehicles and formed a consensus on the scope and direction of the research.

The workshops revealed that off-the-shelf technologies were available, with minor modifications, to satisfy most of the operational needs identified in the focus groups. The private-sector participants were asked to indicate interest in contributing time, equipment, technology, and financial support.

The initial budget for three prototype vehicles—one for each of the consortium states—was just under $650,000 and included the equipment and technologies shown in Table 1.

Prototype Evaluation

Phase II, 1997 to 1998, focused on evaluations of the prototype; details of the Iowa prototype vehicle are shown in the photograph on page 17. Iowa's regular equipment purchase program paid for each base truck adapted from the prototype. Iowa's and Minnesota's trucks have dump boxes; the Michigan truck has a chassis-mounted material spreader and brine tank. Each truck had a front, wing, and underbody plow (*4*).

Each truck was equipped with a Global Positioning System (GPS) receiver, with an antenna mounted above the cab. The truck's location was determined every 5 seconds and recorded by the PlowMaster™ system developed for the concept vehicles. Data from the pavement surface and air temperature sensors, friction meter, material applicator, plow operations, and the truck's engine were integrated into PlowMaster, displayed on monitors at the maintenance garage and traffic operations centers, and communicated to intelligent transportation system (ITS) programs.

All three prototype vehicles were equipped to

SOURCE: CTRE

Final placement of displays and technology gauges in the Iowa prototype vehicle.

TABLE 2 Equipment and Suppliers Involved in HMCV Phase III

Equipment	Vendors
Air and pavement temperature sensor	Sprague Company
Engine power booster	Fosseen Manufacturing
Global positioning system	Rockwell International
High-intensity discharge warning lights	Tri-State Signing
Material applicator	Bristol Company
Pavement friction measuring devices	Roadware Corporation and Norsmeter Company
Plows and spreader	Monroe Truck Equipment
Reverse obstacle sensor	Global Sensor Systems
Truck vendor	O'Halloran International, Inc.

spread dry, prewetted, or liquid materials for deicing or anti-icing operations. Different private-sector partners provided the material application system for each vehicle.

Each prototype vehicle had a hydrous-ethanol injection system that automatically injects ethanol into the engine whenever a power boost is needed. Transit buses had used this technology to provide a power boost for quicker entry into the traffic stream. Truck dynamometer tests on the concept vehicle showed that the injection system provided a 20 percent power boost when maximum power was needed.

A device on the prototypes measured and recorded the road surface friction and would send a signal to activate the spreader if an application of granular material was needed to increase friction or to inform the operator that the friction was sufficient. Infrared sensors monitored air and pavement surface temperatures and conveyed the data to a digital gauge in the truck cab or to a recorder in the PlowMaster system.

Other sensors could detect obstructions behind

The Role of Chemicals in Winter Maintenance

RICHARD L. HANNEMAN

Snow and ice control chemicals play a significant role in assuring the safety of winter driving. Before salt and other chemicals became common in winter maintenance, roadway agencies often relied on abrasives like sand. Abrasives do not melt snow or ice, however, and contribute to air and water pollution; their use therefore must be confined principally to unpaved rural roads or as a stopgap measure when it is too cold for available chemicals to melt frozen precipitation on the roadway surface and restore safe levels of surface friction.

Chemicals can be applied in solid or liquid form; solid chemicals do not begin their vital service until turning to liquid. The public generally understands that winter maintenance agencies use chemicals to depress the freezing point of winter precipitation. The chemicals, however, do not have the effect of plowing the icy roads. Ideally, the chemicals prevent the snow and ice from bonding to the roadway surface. This anti-icing effect minimizes the amount of chemicals required and increases the safety of the road. The chemicals can be applied by vehicles; by fixed, automated spray systems; or by the pretreatment of special pavement overlays that retain chemicals and release them when needed to prevent surface freezing.

If the anti-icing goal is not achieved, the options are to surrender to winter or to apply traditional deicing techniques. Deicing is reactive and starts when the snow and ice already have bonded to the pavement. The chemicals are applied not to melt the snow and ice off the road, but to bore through the snow and ice to the pavement, where the liquid chemical works to destroy the bond between the snow and ice and the roadway surface. When the bond is broken, the action of traffic and of the snowplows breaks up and removes the snow and ice. Chemicals may be a necessity, but most of the work of clearing away the snow and ice is accomplished mechanically with the plows.

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the vehicle, automatically applying the brakes when the truck was in reverse. The arrangement of instruments, levers, digital and graphical displays, and dials in the snowplow operator's cockpit of the Iowa prototype vehicle is shown in the photo on page 18.

CTRE researchers documented equipment performance during the 1997–1998 winter operations. Coupled with operator interviews, the documentation led to guidelines for the desired equipment capabilities for the Phase III prototype vehicle. CTRE researchers also solicited information from vendors about new and developing technologies and evaluated the appropriateness for the Phase III vehicle.

Field Test and Evaluation

The general objectives of the Phase III effort, 1998–1999, were to establish the functionalities and technologies to implement; conduct field tests and evaluations; and produce data flow and decision process maps to integrate the functionalities into management systems. Table 2 (page 19) lists the equipment evaluated and the suppliers involved in this phase (*5*).

The National Aeronautics and Space Administration facilities at Wallops Island, Virginia, and North Bay, Ontario, conducted field evaluations of the technologies, particularly of the friction meter. The device demonstrated that the principle of continuously measuring friction and transferring the data to the vehicle management system was sound. The friction meter design, however, needed further work—a failure analysis of one of the units showed that the gearbox had been damaged by corrosion. Other equipment and technologies evaluated in Phase III were successful.

Photo: Don Halliday, Halliday Technologies, Inc.

Friction wheel for measuring road grip under an Ohio DOT truck.

Operations and Field Demonstration

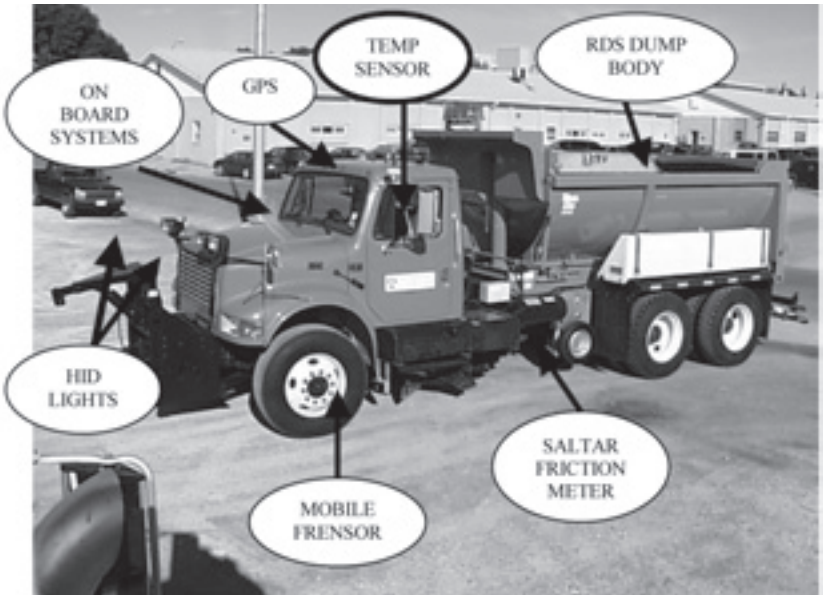
Phase IV examined and tested emerging technologies for improving the winter maintenance level of service at the least cost to taxpayers. The HMCV underwent two winters of operations, starting in 2000–2001. Data were collected on the bench testing and field testing of a friction meter; the freeze-point detection sensors; an automated vehicle location (AVL) system; a radius dump body, which has rounded corners to facilitate the flow of material to the spreader; the dual, side-mounted, 120-gallon prewetting tanks; a 900-gallon stainless steel anti-icing tank; the high-intensity discharge (HID) plow lights; and the integration of these technologies and systems, along with communications links (*6*).

Supervisors offered the following comments and recommendations:

- Ensure that operators can change application rates when needed;
- Keep the systems simple;
- Provide a means for supervisors to compare temperatures reported from snowplows against readings from fixed-location road weather information systems (RWIS);
- Improve the accuracy of predictive weather information to support storm response planning;
- Install a friction wheel on all supervisor trucks, to obtain information on different road surfaces; and
- Make the friction wheel more robust.

Operators commented most frequently on the infrared pavement temperature sensors, the AVL, the friction wheel, the radius dump body, and the HID lights. They were satisfied with the performance of the HMCV, but wanted improvements in visibility, particularly at night and in whiteout conditions—

Phase IV highway maintenance concept vehicle.



Source: CTRE

that is, they wanted to see in front of the plow at all times and know what hazards were ahead. They wanted to be able to determine the road conditions quickly and to treat the roadway properly with the right amount of material and effort.

The CTRE researchers recommended continued use of pavement friction as a performance measure in winter maintenance operations; further investigation of chemical freezing-point devices; expanded use of AVL by providing snowplow information to the traveling public; and development of a business case for deploying the technologies on a fleet of vehicles. The concept vehicle is equipped with emerging technologies to apply the correct amount of material precisely, tailored to current and predicted pavement conditions.

Additional HMCV Activities

By 2004, according to the Midwest equipment assembler, Monroe Snow & Ice Control, most state DOTs were ordering trucks equipped with all the functionalities listed and tested in Phase IV, with the exception of the friction measuring and mobile freeze-point detection devices. Both of these are under study to refine their output and design.

During the winter of 2006–2007, Ohio DOT sponsored research on friction-measuring equipment developed by Halliday Technologies, Inc., for use on racetracks. The researchers found that the equipment is capable of distinguishing changes in roadway traction conditions with high resolution and good repeatability. The device indicates segments with pavement conditions that require greater maintenance treatment and those that have acceptable traction (7).

Evolving Platform

The HMCV technologies are expected to provide traffic management centers with an expanded set of data for monitoring the status and operation of the transportation system. IntelliDrive[SM] on-board equipment, integrated with vehicle electronic systems, can relay information on vehicle conditions such as traction control or antilock braking activation, which are proxy indicators of road surface conditions.

Photo: Don Halliday, Halliday Technologies, Inc.

Ohio DOT sponsored research for the HCMV on friction-measuring equipment developed for use on racetracks.

Photo: Monroe Snow and Ice Control

New truck equipped with radial dump spreader and salt slurry generator; state DOTs are ordering trucks with the features developed and tested for the HCMV.

The HMCV continues its evolution into the ideal mobile winter maintenance operations platform, capable of matching maintenance anti-icing and deicing treatments with current and forecast pavement conditions by collecting what is called ground-truth data on pavement conditions throughout the roadway network. This mobile source of roadway network data can improve the accuracy of meteorological near-surface mesoscale models and of the corresponding maintenance treatments, enhancing traveler safety, reducing winter maintenance material use, minimizing adverse impacts on the environment, and lowering the costs of winter maintenance.

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Going Green with Snow Fences

Technology Reinvents a Settler Practice

LELAND D. SMITHSON

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Snowy, windy winter weather can create major problems for the public and for the maintenance personnel tasked with keeping the roads open to traffic. Deep snow and reduced visibility increase safety risks and sometimes bring traffic to a standstill. Understanding the interactions between the atmosphere, terrain, roadway design, and snow can help reduce the adverse effects and the uncertainties associated with blowing and drifting snow.

Early Mitigation Efforts

The early settlers of the United States recognized the hazards of blowing and drifting snow. After building shelters for people and livestock, they planted trees and bushes to slow cold winter winds and to deposit snow away from homes and pasturage. Common sense and experience guided these early mitigation efforts—which we would call living snow fences.

Common sense for the early settlers dictated the planting of one to three rows of spruce, cedar, or juniper trees approximately 100 yards upwind from the protected areas, with perhaps two or three rows of scrubs planted in between to help during the years before the trees became fully effective. Evidence of those early snow mitigation efforts can be seen in the countryside anywhere in the snow-belt states.

Modern snow fences are a continuation of early settlers' efforts to mitigate large snow drifts by strategically planting banks of bushes and trees.

Photo: Jeff Vanuga, NRCS

Windbreak and snow fence catch snow and impede drifting in Dubois, Wyoming.

Blowing and drifting snow has major impacts on transportation safety and mobility and can add significantly to the cost of snow and ice control operations. Early construction recognized these impacts, especially in windy locations, where the quantity of snow blown onto a highway or railroad can be hundreds of times greater than what falls directly onto the right-of-way (*1*).

Tabler documented examples of rock snow fences built in the late 1860s to protect the railroad cuts in southeast Wyoming; a wooden snow fence, 4 meters in height built in 1900 near Skagway, Alaska, to protect the White Pass and Yukon Railroad; and a wooden snow fence constructed in 1901 to protect sections of the Union Pacific Railroad near Laramie, Wyoming (*1*). After the 1930s, design improvements for trucks, snowplows, and locomotives made brute-force snow removal possible, minimizing the importance of drift control research for the next three decades.

Maintaining Mobility and Safety

The design and construction of the Interstate Highway System increased highway users' expectations

for mobility and safety. The new open cross-section Interstate design worked well in most of the country, but problems arose in the windy and snowy regions of the western part of the United States.

The power of winter was dramatically demonstrated on the newly constructed Interstate 80 in Wyoming. Three months after the ribbon cutting in October 1970, snowdrifts as deep as 16 feet encroached into the traffic lanes at 27 different locations (*1*). Despite the around-the-clock efforts of six bulldozers battling winds of more than 30 miles per hour, the road remained closed for 10 days because of poor visibility and accidents. Something more than cross-section design and brute force was required.

Reverting to previous technology, Wyoming constructed snow fences ranging from 6 to 12 feet in height; the fences' effectiveness in preventing drifts and improving visibility and road surface conditions was demonstrated in the first year. The success led to installation along many more miles. Tabler documented benefit-to-cost ratios of 50:1 to 100:1 for permanent snow fences, based on the reduced costs for snow removal (*1*).

The first Strategic Highway Research Program (SHRP), during 1988 to 1993, accomplished further advances in the materials, design, and understanding of the basic physics involved in controlling blowing and drifting snow. Tabler's 2003 report documented the logic and the algorithms for the design of measures to mitigate blowing snow (*2*).

From Research to Implementation

Two major efforts have occurred since the completion of the updated guidelines in 2003:

- Tabler developed a formal training program and has provided onsite training for maintenance and design employees at many state departments of transportation (DOTs). This comprehensive training has led to the installation of newer and better-designed snow fences and living snow fences in the snow-belt states.
- In cooperation with the Clear Roads Consortium, the Snow and Ice Cooperative Program of the American Association of State Highway and Transportation Officials developed a computer-based

Snow on Wyoming's I-80, at Milepost 278 (*a*) before and (*b*) after the installation of a snow fence; and at Milepost 279, (c) before and (*d*) after the snow fence installation.

(*a*) (*b*) (*c*) (*d*)

Photos: Ron Tabler, Tabler & Associates

Photo: Lynn Betts, NRCS

Living snow fence of trees and shrubs in north central Iowa protects the highway from snow drifts in winter.

training (CBT) program, Blowing Snow Mitigation. The CBT includes lessons on the problems caused by blowing snow; how snow fences work; identifying and analyzing problem areas; structural snow fence design; living snow fences; road design to mitigate blowing snow; and working with landowners.[1]

International Connections

In March 1994, an International Winter Maintenance Scanning Tour viewed winter snow and ice control operations in Japan, Austria, and Germany (*3*). The purpose of the tour was to discover differences in winter maintenance operations and to evaluate the operations for potential implementation in the United States. The scan observed differences in snow removal equipment, weather monitoring, winter hazard mitigation, road user information services, public perception, methods used for financing, and the cooperation between public agencies and private enterprise in research and development.

One unique discovery was an alternative snow fence called a blower fence, used in areas of Japan with a limited right-of-way unable to accommodate conventional snow fences. The blower fence is designed to accelerate the air flow in the immediate vicinity of the roadway; the vigorous wind action reduces accumulations of snow on the lee side of the fences.

The Hokkaido Development Bureau's Construction Machinery Engineering Center developed a unique wind tunnel for modeling and analyzing the effects of blowing and drifting snow on highway cuts, fills, and structures. The tunnel simulates a blizzard, using clay particles that behave like blowing and drifting snow. Terrain models are placed in the wind tunnel and subjected to blizzard-level conditions.

After studying the resulting drift patterns, researchers recommended altering the highway's cross-section design or installing a snow fence. The model was rerun to evaluate results and determine the best design solution.

Computer Tools

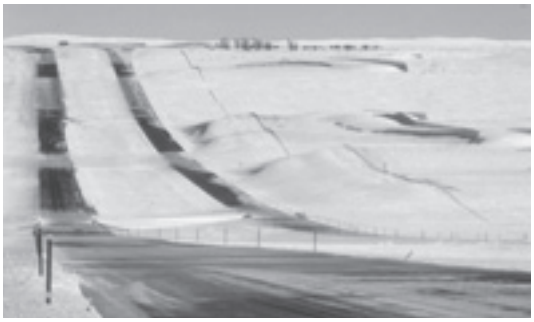
Several efforts have aimed at developing computer-based tools to assist in the computations needed for designing passive controls for blowing and drifting snow. These include PASCON, an expert system for passive snow control on highways (*4*); the Wyoming DOT Drift Profiler, which predicts drift profiles

[1] www.transportation.org/sites/sicop/docs/CBT_Handout.pdf.

An interactive website developed by the University of Minnesota and Minnesota DOT allows users to design snow fences to match a location's profile (http://climate.umn.edu/snow_fence/Components/Design/introduction.htm).

Photos: Ron Tabler, Tabler & Associates

(a)



(b)

Snow fences reduce the need for snow removal operations, which leads to the environmental benefits of saved fuel and reduced use of chemicals; (*a*) closeup view of highway protected by snow fence and (*b*) wide view.

(5–6); and an interactive website developed by the University of Minnesota and Minnesota DOT that allows the user to determine the height, setback, and overlap of snow fence systems for locations in Minnesota.[2]

A recent development in engineering the mitigation of blowing and drifting snow is the software tool, SnowMan—short for snow management—which combines road design and snow fence design (7). Developed through New York State DOT's Transportation Infrastructure Research Consortium at the University of Buffalo, The State University of New York, SnowMan generates terrain cross sections parallel to the prevailing winds, drawing on digital model files and a New York State climatological database that quantifies snow transport for specific locations.

The first SnowMan-designed mitigation was constructed on a road serving the Erie County Correctional Facility near Buffalo and was evaluated during the winter of 2008–2009, which was notable for heavy snows and high winds. Results exceeded expectations—visibility was improved and drifting was reduced, with no drift removal required.

Iowa DOT is now evaluating SnowMan, to determine if the program can run on its computer-assisted design microstations and if it can be adapted to the Iowa climate. Iowa DOT will explore several problem areas in 2009–2010 for the application and construction of engineered mitigation techniques.

Realizing the Benefits

Blowing and drifting snow add significantly to the cost of snow and ice control operations. Reduced snow removal equates to fuel savings and reduced use of chemicals—benefits for the environment. In addition, capturing drifting snow and storing it between the snow fence and the roadway ditch provides valuable meltwater to recharge underground water supplies.

Progress has been made in the research, modeling, technology transfer, and implementation of engineered mitigation techniques for blowing and drifting snow in the United States and other parts of the world. Although underutilized, these mitigation techniques are becoming easier to understand and apply, and implementation is increasing. Agencies are realizing the environmental benefits of permanent snow fences, as well as the economic benefits of favorable benefit-to-cost ratios.

New York State DOT's SnowMan software, which brought the science of the engineered mitigation of blowing and drifting snow to a computer-assisted design Microsoft application, is expanding to incorporate the use of the living snow fence. If this is successful, other state DOTs may adopt the software to design fences for their blowing and drifting snow areas.

[2] http://climate.umn.edu/snow_fence/.

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Real-Time Traffic Management Communications in Sweden

An Effective Smorgasbord of Technologies

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Easily accessible and accurate traffic information is a key to efficient use of the road transport system. For many years, the Swedish Road Administration (SRA) has gathered and provided traffic information about road conditions, road work, limited bearing capacity or weight limit restrictions, and accidents and other traffic disruptions on the nation's road network. The traffic information traditionally has been transmitted via radio, and traffic broadcasts are much in demand and appreciated.

SRA has supplemented these sources of information. Road users now can obtain real-time traffic information through other channels, such as the Internet, traffic management communications (TMC), and automated telephone services. These services rely on SRA's basic traffic information and are provided through the cooperation of other parties, such as SOS Alarm,[1] service providers, and public transport authorities.

The commercial vendors adapt and process the SRA traffic information for delivery to a variety of road user groups. Only a few commercial services are in operation as yet, but the number is expected to increase in the next few years. Sweden is implementing and evaluating a variety of projects and programs that use a range of technologies, to improve the efficiency and effectiveness of the transportation network during adverse winter conditions.

Extending Traditional Media

Television, radio, text TV, and telephones have been the traditional sources of information about winter

[1] SOS Alarm handles emergency calls and coordinates rescue work in Sweden; see www.sosalarm.se/sv/Om-SOS-Alarm/About-SOS-Alarm/.

Photo: Ulrika Lindström

A Swedish Road Administration (SRA) traffic control center gathers information on road conditions, disruptions, and problem areas to transmit to the traveling public by a variety of media.

road conditions, but these too are receiving enhancements.

For example, the **Radio Data System–Traffic Message Channel** (RDS-TMC), a system for traffic information, has proved successful and is being extended into other countries of Europe. To receive an RDS-TMC message, a car must have an RDS-TMC-capable radio or navigation system. The messages are presented as an icon and text; in Sweden, the RDS-TMC service is free of charge and available around the clock.

Travelers also can connect to an **automatic voice response for road inquiries** by telephone and by wireless application protocol (WAP). Users call a specific telephone number to receive information about winter road conditions via an automated voice response. The information is accessible by mobile telephones with WAP service.

Road Conditions Website

Läget på vägarna (Conditions on the Road) is an SRA website that shows what is happening on roadways in Sweden.[2] Users can search the text menus for a county and road number or they can click to an area of interest on the displayed maps. Different symbols assist map users in locating information.

SRA updates the information about the major roads and highways around the clock. The information comes from in-house sources, as well as from maintenance contractors, the police, the Swedish Meteorological and Hydrological Institute, closed-circuit TV systems, and the automatic incident detection systems in Stockholm and Gothenburg.

Starting with the map, a user can obtain the following information:

- Road conditions—colors are used to portray different conditions;
- Air and road surface temperature;
- Precipitation; and
- Average wind velocity in meters per second.

Also via the Internet, travelers can access the **slippery road forecast map**, which shows the risks of slippery roads for the next few hours.[3] SRA provides this service free of charge.

Controlling Vehicle Speeds

Variable speed limit (VSL) is an automated system that runs with a weather model. In poor weather or pavement conditions, the system can lower the speed limit through adjustable, luminous road signs. Researchers are evaluating additional applications of VSL and their cost-effectiveness.

VSL has been in operation since 2003 and has been implemented at 20 locations in the country. Four locations selected for winter road conditions are controlled automatically. These four road segments have environmental stations with road weather information systems (RWIS) that record temperature, precipitation, wind, surface status, and related information. Two of the stations are equipped with optical sensors that measure the accumulation of

Road users can access information from SRA about road conditions or disruptions via *Läget på vägarna*, an interactive website (http://trafikinfo.vv.se/triniMenu/).

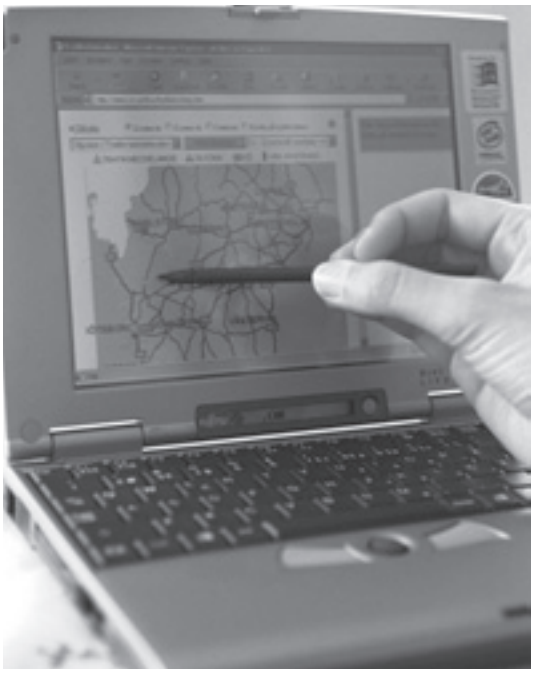


Photo: Ulrika Lindström

On the website *Läget på vägarna*, users can search text menus or click to an area of interest on displayed maps.

[2] For more information on *Läget på vägarna* in English and Swedish, see www.vv.se/vagarna/laget-pa-vagarna.

[3] For additional information on the Slippery Road Forecast Map, see http://trafikinfo.vv.se/triniMenu/trinimenu.html?startmenu=6.

Pushing Road and Weather Information to the Public

Japan's Use of Cell Phones and E-Mails

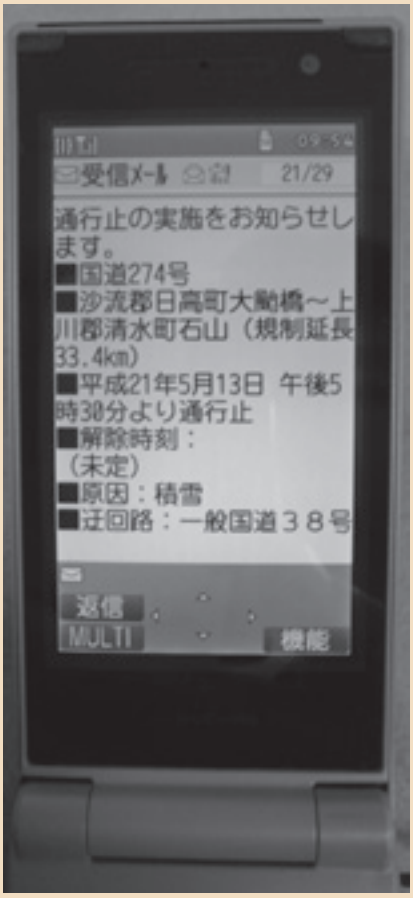
MASARU MATSUZAWA

Sapporo, the capital city of Hokkaido—the northernmost island of Japan—receives more than 6 meters (19.7 feet) of cumulative snowfall annually, and snow covers the ground for approximately 4 to 5 months. This annual snowfall makes the delivery of safe, efficient, and effective highway travel for a population of approximately 5.7 million an enormous challenge.

The Hokkaido Regional Development Bureau maintains the island's national highways. This past April, to help citizens and businesses meet travel challenges, the Bureau started to send notices of national highway closures by e-mail. The e-mails are sent to users when a route closes because of severe conditions—such as heavy rain, snowstorms, avalanches, and so on—and again when the route reopens for normal service. The user receives notification only about selected routes and can opt to stop delivery of the notifications during nighttime hours (from 10 p.m. to 7 a.m.).

Other anticipated services include the following:

◆ **46 Navi:** The Akita National Road Office provides road weather information on National Highway Route 46 via the Internet.[a] Akita is in the northern part of Japan's main island. The system also provides snowfall forecasts and road closure notifications by e-mail. At six sites along Route 46 during the winter of 2008–2009, the forecast included the snowfall from the evening of that day through 9 a.m. of the following day and from 9 a.m. of the following day to the evening. The forecasts are provided by e-mail. An e-mail is delivered when a road closure starts or ends because of severe weather, avalanches, or other events.



The Hokkaido Regional Development Bureau sends e-mail alerts to update users about route closures or changes.

◆ **Hida Michi Guide:** "Michi" means "road" in Japanese. The Hida region is located in central Japan; Takayama is the biggest city. The Takayama National Road Office provides road weather information for National Highway Route 41 via the Internet and e-mail.[b] E-mails report the air temperature and the snow depth at a point along the route selected by the user, who also can select the delivery time for the e-mail. A general weather forecast is also available via e-mail.

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[a] http://akita-road.thr.mlit.go.jp/r-46navi/.
[b] http://takayama-41nh.jp/index.html and http://www. cbr.mlit.go.jp/takayama/index.html.

Sapporo, Japan, receives more than 6 meters (19.7 feet) of snow annually.

snow and water, as well as the surface friction in terms of road grip by percent. With this information, a weather model calculates the conditions for the relevant road segment; this determines the appropriate speed limit.

Most motorists have a positive perception of the weather-controlled variable speed limits. Many recognize that the displayed speed is appropriate for the prevailing weather and road conditions. Weather-controlled VSL may be suitable for motorways, expressways, and dual carriageways if

- The stretch of road is prone to accidents, and a high proportion of these are related to road conditions.
- Speed adaptation is poor under difficult road conditions.
- The roadway segment is subject to weather conditions that can produce treacherous effects such as black ice—difficult for motorists to detect before skidding.
- The roadway segment has local road condition variations—for example, on bridges, dips, or shadowed sections—that complicate driving in poor weather.

Slippery Road Information System

Traffic safety researchers developed the **Slippery Road Information System** (SRIS) by combining in-vehicle technology with data from the infrastructure. The SRIS collects information from sensors in vehicles—such as antilock brake systems and electronic stability control systems—and information about the road conditions and other applicable information—such as temperature, windshield wiper use, and the like. The data are transmitted to a central database and combined with RWIS data to generate more detailed information about the road conditions.

SRIS users include motorists inquiring about road conditions; road maintenance personnel seeking feedback on the effectiveness of their winter maintenance activities; and the road administration validating the results of winter maintenance operations. The SRIS maps display vehicle reports of slipperiness and the ambient temperatures during a winter weather event. Stars are used to designate slippery locations, and colors on the roads indicate the local ambient temperatures. The maps help visualize the actual road conditions over wide geographic areas.[4]

The purpose of the SRIS is to deliver higher-quality information about the actual conditions to drivers and road maintenance personnel—and thereby to prevent accidents. Approximately 90 percent of all new cars in Sweden are equipped with electronic stability control, providing the capability of wide geographic coverage for the SRIS. Many new cars also have telecommunication equipment, which enables the transmission of data to the SRIS without the installation of additional devices in the vehicles.

The SRIS was field-tested successfully with 100 cars in the winter of 2007–2008. In most cases, the information from the vehicles corresponded with the information from the road weather stations. In some instances, however, the SRIS detected slippery conditions without warnings or indications from the road weather stations. The challenges of implementing the SRIS, however, may be more political than technical.

[4] For more information on SRIS, see www.sris.nu/index_en.aspx.

Photo: Ulrika Lindström

A motorway control system in Sweden; variable speed limits have been implemented at 20 locations in the country.

Partnering for Safety

Sweden is implementing these projects and programs to provide quality information on roadway conditions to motorists in near real-time. Working with various technologies and through public–private partnerships, SRA is improving the safety and efficiency of roadway network operations during adverse weather conditions.

Photo: Kerstin Ericsson, SRA

The Slippery Road Information System serves the needs of motorists, road maintenance workers, and road administration personnel.

Training for Winter Maintenance Operations

Reaching the Public, Building on Know-How

WILFRID A. NIXON

The author is Professor, College of Engineering, University of Iowa, Iowa City, and Chair of the TRB Surface Transportation Weather Committee.

Training is a key to the efficient and effective operation of a modern transportation system. During adverse winter weather events, for example, each participant's knowledge and understanding of operations and of the necessary cautions can contribute to—or detract from—the system's travel times, average traveling speeds, numbers of accidents, costs, environmental impacts, and other measures of system performance.

Training for winter maintenance operations has a who, what, when, how, and why. The who of training may appear to be anyone in a transportation agency who is involved in a winter maintenance activity, but this interpretation is too narrow. Training efforts need to be tailored for—and delivered to—all users and maintainers of the transportation system.

Training the Public

Training the public requires effort and may not always yield the desired results. At least three different training approaches have been used successfully to increase public knowledge of winter operations.

Winter maintenance operations depend on successful training efforts—not just of maintenance personnel but also of transportation system users.

Photo: David Gonzalez, Minnesota DOT

Some agencies work with local schools and invite students to paint snowplows with various themes (see the sidebar, Creativity Takes to the Streets, page 31). This approach provides an opportunity for winter maintenance representatives to visit schools and provide students with useful information and tips about winter maintenance activities. "Don't follow a plow too closely" and "Don't drive into a large cloud of snow on the highway—it could hide a plow truck" are the kinds of tips that can be shared, in the hope that the students will pass the messages on to their parents and to other drivers in the family and later remember the lessons when applying for a driver's license. The plow painting activity also creates a strong link between the students on the project and the transportation personnel; many students identify strongly with the plow they have decorated.

A second training exercise is to invite the media for ride-alongs in the plows during a winter storm. Legal and other barriers may arise, however, and should be addressed; care also must be taken in selecting the operators. Nonetheless, the benefits of building a rapport with the local media can be significant. For example, sometime during the ride-along, a member of the public probably will do something dangerous in the vicinity of the plow, enabling the reporter to witness the danger firsthand and to communicate the warning message more effectively.

A third training activity is to survey the public about their expectations for winter operations. The Minnesota Department of Transportation (DOT) has been a leader in this technique. Although the role of a survey in training may not be obvious, the survey questions inevitably bring about a greater awareness of what winter operations involve; moreover, the questions can help adjust the public's expectations of what the DOT realistically can deliver.

Assessing the Workforce

Clearly the personnel involved in winter maintenance operations need training—the question is

what training they need and when it may best be delivered. Agency personnel involved in winter maintenance should undergo a regular assessment of their knowledge of winter operations—perhaps every year. Ideally the assessment should be a "low stakes or no stakes" test that can be developed easily with a measurable result. Washington State DOT, for example, uses a web-based multiple choice test.

Operations managers can use the results of the workforce assessments in several ways. First, the results can indicate areas in which the majority of the workforce requires training. This allows an effective

PHOTO: WASHINGTON STATE DOT

Plow driver Arie VanderZouwen checks in with other Washington State DOT plow drivers in the area; in 2008, as part of a public information outreach, Washington State DOT shared "ride along" photos of snowplow crews, like this one, via its Flickr page.

Creativity Takes to the Streets

KATHY AHLENIUS

State and municipal transportation agencies often develop outreach programs for children. Most programs aim at safety issues, such as those related to bicycle riding and to seatbelt use, but once in a while children are given the opportunity to participate in a hands-on project. The Minnesota and Wyoming Departments of Transportation (DOTs) and the cities of Coeur d'Alene, Idaho, and Indianapolis, Indiana, for example, have taken a hands-on approach to educate school-age children in the basics of winter operations.

◆ Minnesota DOT offers a web page designed for children between the ages of 5 and 10, presenting fun facts, games, and a video clip titled "A Snowplow—Cool" that teaches about safety around plows and explains why sledding and making snow forts near roadways are dangerous.

◆ "Snowplowpalooza" is the annual kick-off of the snow season in Indianapolis. The program started 10 years ago and involves schoolchildren from the elementary grades through high school in the painting of snowplows. The mayor awards prizes, and the feedback from parents and children is enthusiastic, especially when they see the plow they decorated out on the streets during a storm.

The City of Indianapolis displays student artwork in Monument Circle.

Young artists paint their designs on a snowplow canvas.

◆ Through the Wyoming Transportation Department Employee Association (WTDEA), Wyoming DOT arranges for schoolchildren to paint snowplows in the City of Cheyenne and in Laramie County. Wyoming DOT employees vote on the entries, and WTDEA provides tee-shirts and cash prizes for first, second, and third places.

◆ Coeur d'Alene's Street Maintenance Department has an inventive program for outreach to schools, holding a contest for students in the elementary grades to devise names for 15 snowstorms, similar to the way that hurricanes are named. The department selects three winning themes, which are then used for the next three winter seasons. Themes have varied from characters in the Harry Potter novels to historic Idaho symbols.

These creative programs represent some of the many successful and promising approaches developed by state and municipal transportation agencies to teach school-age children about the importance of winter operations.

The author is Winter Research Project Analyst, Wyoming Department of Transportation, Cheyenne.

Photo: Minnesota DOT

Workforce assessments can point out areas in which the majority of the workforce requires training and can show whether employees at different job levels have knowledge appropriate to their job functions.

targeting of training funds. Second, the results can show whether employees at different job levels have the levels of knowledge appropriate to their job functions. For example, a winter maintenance supervisor should have a more extensive understanding of the processes of anti-icing than a truck operator does.

Bloom's *Taxonomy of the Cognitive Domain* offers a useful way to consider levels of learning (*1*). The taxonomy identifies six levels of understanding a concept or idea, ranging from the simple, such as recalling the safety rules; to application—for example, using a manual to determine how much chemical to apply under a specific condition; to evaluation—for example, developing an anti-icing process for the agency as a whole.[1]

With a suitable selection of questions in the assessment, the level of employees' knowledge and understanding can be determined. An appropriate level of training then can be applied. For example, supervisors may know how much chemical to apply in specific conditions but may not understand why; the agency must decide if the supervisors need to know the reasons, and if they do, to provide the training.

Ideally, training is a year-round activity. Winter training conducted at the end of the fall, however, proves helpful. Although training in winter may seem to be a good idea, the classroom training of truck drivers while snow is falling outside does not achieve the agency's mission. Regular training reinforces key concepts and does not require cramming the full range of information into a single training opportunity—small portions are more easily assimilated.

[1] Bloom's Taxonomy is described and discussed in several documents—for example, www.skagitwatershed.org/~donclark/hrd/bloom.html.

Training Delivery

People learn in different ways—some are visual learners; others are verbal learners.[2] A well-designed training program should accommodate a range of learning styles.

In addition, the delivery of training offers many options. Providing a training manual is one form of training, although not always effective. Workshops are often the mode of delivery, either with an in-house presenter or a trainer from outside.

The trainer can be a major contributor to the effectiveness of the session. A trainer who is an agency employee may prove the biblical observation that "a prophet is never honored in his own house." An outside expert, however, may be unaware of the dynamics and history within the agency. Certain topics may need to be approached carefully, if at all. Some trainers are experts at training but not experts in the subject matter; others are subject matter experts but are clueless about how to train or teach effectively. Resources may limit an agency's training options, but changing the approach from time to time can be valuable.

Winter maintenance workshops are effective ways to deliver training.

Photo: Fortin Consulting, Inc.

Computer-Based Training

A novel training approach arose in the late 1990s. Transportation organizations sought a way to provide initial and refresher training to impart an operational understanding and to maintain skill levels in two complex topics: anti-icing (AI) and road weather information systems (RWIS). To address these needs, the Snow and Ice Cooperative Program (SICOP) of the American Association of State Highway and Transportation Officials (AASHTO), working with the Aurora Consortium—an RWIS pooled-fund research program—initiated a joint effort to develop a national AI-RWIS training program. The American

[2] Several websites deal with this topic—for example, www.ldpride.net/learningstyles.MI.htm#What%20are.

Public Works Association, the National Association of County Engineers, and almost all of the snow-belt state DOTs provided support.

The collaborative effort produced a computer-based training (CBT) program in AI-RWIS that uses illustrations, videos, tutorials, storm scenarios, and assessments to train users to a high level of understanding.[3] After logging in to the program, the student can work through the stand-alone training from beginning to end—as with a book—and can return to the main menu at intervals, as desired, to select another path. Opportunities are given at various points to assess the user's educational progress, through such means as quizzes, scenario-based problem cases, and exercises. The training can be administered individually or in a group setting and can be the foundation for a certification program.

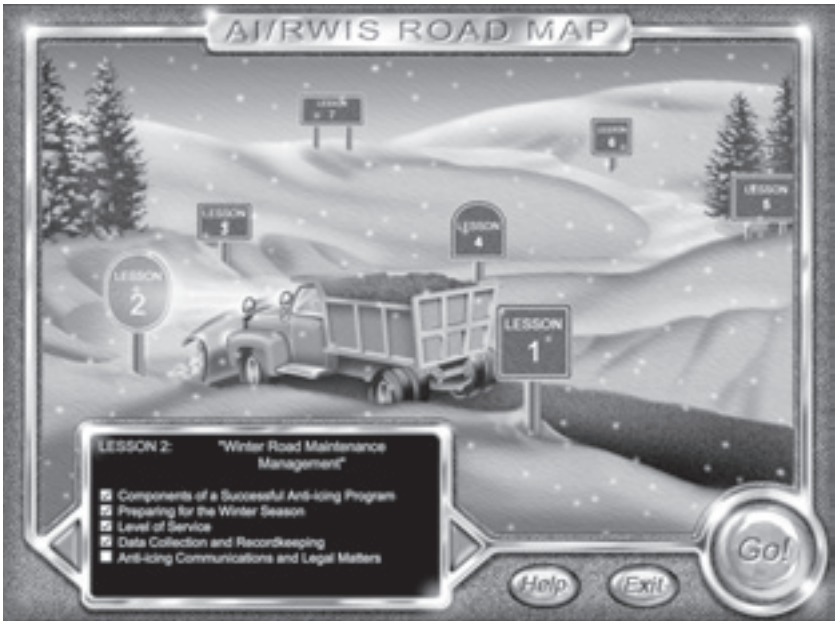
The CBT course in AI-RWIS consists of seven lessons: introduction to AI and winter maintenance; winter road maintenance management; winter roadway hazards and principles for overcoming them; weather basics; weather and roadway monitoring for AI decisions; computer access to road weather information; and AI practices in winter maintenance operations. The course also includes an electronic performance support system that allows students to use the software as a reference tool.

Updating and Introducing CBT

To keep current, any training program must incorporate additional research and field experience that yield new techniques and knowledge. For example, the findings in National Cooperative Highway Research Program (NCHRP) Report 526, *Snow and Ice Control: Guidelines for Materials and Methods* (2) were integrated into the CBT lessons, and a new lesson was developed to highlight the findings in NCHRP Report 577, *Selecting Snow and Ice Control Materials to Mitigate Environmental Impacts* (3). (See sidebar, page 34.)

In 2006, at the request of the Clear Roads Consortium, AASHTO initiated efforts to develop CBT lessons on winter maintenance training needs

[3] www.transportation.org/?siteid=88&pageid=2179.



SOURCE: AASHTO

Lesson 2 opening screen from AASHTO's Winter Roadway Maintenance Computer-Based Training.

A Missouri DOT TowPlow, or trailer plow, developed by now-retired engineer and active consultant Bob Lannert, can clear a path that can be adjusted from 10 to 26 ft wide with one operator, doubling or tripling production, and can allow a gang plowing operation to release two trucks to clear other routes, saving labor and fuel. New techniques and technologies require continual training of the workforce.

Selecting Snow and Ice Control Chemicals to Mitigate Environmental Impacts

RICHARD L. HANNEMAN

Every winter, millions of tons of snow and ice control chemicals are applied to highways and bridges in the United States. Despite concerns about the environmental impact of these chemicals, standard test matrices were not available until recently to compare the effects.

In May 2007, the National Cooperative Highway Research Program (NCHRP) released Report 577, *Guidelines for the Selection of Snow and Ice Control Materials to Mitigate Environmental Impacts,* evaluating the environmental and corrosion impacts of 42 frequently used deicers—including sodium chloride, magnesium chloride, calcium chloride, calcium magnesium acetate, and potassium acetate (*1*). With findings based on a technical review and investigative laboratory testing, the report presents three valuable tools for road agencies: a decision tool to select the most suitable snow and ice control chemical, a purchase specification, and a monitoring program for quality assurance, including procedures and standard test methods.

PHOTO: LEVELTON CONSULTANTS LTD.

Specimen setup for NCHRP project that compared the corrosion effects of various snow and ice control materials on concrete.

The material selection tool is designed to be customized—an agency can apply its local priority weightings into the analysis and can develop different scenarios for comparison. Every community has an ecological uniqueness, a unique infrastructure, and a unique combination of values to balance the demands of ecology and infrastructure. The material selection tool enables rational, informed, and objective decision making about the choices of chemicals, considering the locally determined balance of costs, performance, and handling methods, as well as the probable impacts on the environment and infrastructure.

The author is President of the Salt Institute, Alexandria, Virginia.

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1. *NCHRP Report 577: Guidelines for the Selection of Snow and Ice Control Materials to Mitigate Environmental Impacts*. Transportation Research Board of the National Academies, Washington, D.C., 2007. http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_577.pdf.

beyond AI-RWIS, including equipment maintenance; proper plowing techniques; deicing; mitigation of blowing snow; and winter maintenance management. The new material was completed in 2008.[4]

State DOTs have used a variety of techniques to introduce winter maintenance CBT programs into their curricula. Iowa DOT presents the first lesson in a workshop or classroom setting, and students who have demonstrated progress without requiring help may proceed to complete the entire set of lessons on their own—back in the office or garage. All of Iowa DOT's operators, supervisors, and management personnel have received the training. At Kansas DOT, the CBT programs are part of the core curriculum, and employees are eligible for an educational salary bonus after completing the courses.

Goals of Training

The goal of training is to operate the transportation system better, more efficiently, more effectively, and with greater respect for the environment. Training is not a hoop to jump through or a tedious way to spend a day that already has a long agenda. Well-designed, focused training can boost operational effectiveness, but training that is routine and uninspired will not be likely to improve performance and assist in achieving key goals—notably, to provide a safe and efficient transportation network for the traveling public during adverse winter weather events.

[4] www.transportation.org/sites/sicop/docs/CBT_Handout.pdf.

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Implementing a Winter Maintenance Decision Support System

Indiana Department of Transportation's Process, Success, and Savings

TONY McCLELLAN, MELODY COLEMAN, PAUL BOONE, AND KIRK CARPENTER

Three of the authors are with Indiana Department of Transportation's (DOT) Seymour District: McClellan is District Highway Operations Director, Coleman is Operational Performance Manager, and Boone is District Special Projects Engineer. Carpenter is Snow and Ice Program Director, Highway Operations, Indiana DOT, Indianapolis.

Collectively, state and local departments of transportation (DOTs) in the snow-belt states spend approximately 25 percent of their maintenance budgets—or more than $2.3 billion—annually on winter maintenance operations.[1] Even slight improvements in the efficiencies of snow and ice control operations, therefore, can save millions of dollars.

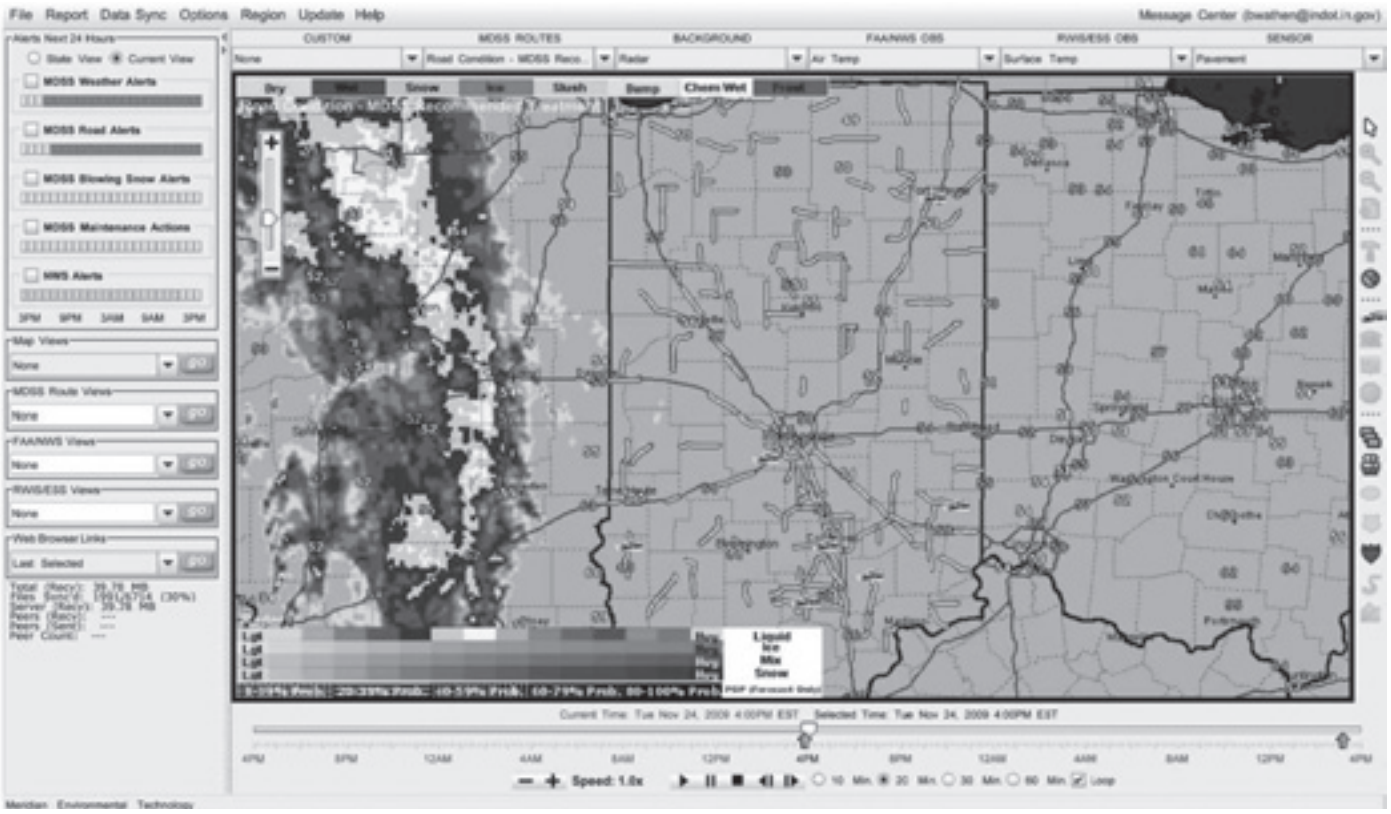
Problem

Charged with providing safe and efficient transportation for motorists, agencies apply maintenance treatments to minimize the adverse impacts of winter storms. For decades, winter maintenance decisions have depended on the experience and judgment of maintenance supervisors and personnel, who decided what treatments to apply and when to apply them. The decision makers had to rely on their knowledge of pavement conditions; the effects of previous treatments; the prevailing and forecast weather conditions; and the availability of the agency's winter maintenance techniques and resources.

Recent developments in computers and numerical modeling, however, have made possible the processing of large volumes of weather and maintenance operations data in near real-time to support and improve winter maintenance operations.

[1] Road Weather Management Program, Federal Highway Administration, http://ops.fhwa.dot.gov/weather/index.asp.

(*Below:*) MDSS map view displays weather radar and roadway conditions on a background of states and counties.



SOURCE: INDIANA DEPARTMENT OF TRANSPORTATION

Solution

In 2002, Indiana DOT joined the South Dakota, North Dakota, Minnesota, and Iowa DOTs in a pooled fund study to develop a maintenance decision support system (MDSS). The system started with a federal prototype that integrated relevant weather forecasts, winter maintenance rules of practice, and maintenance resource data to recommend appropriate road treatment strategies to maintenance managers.[2] The study now has 15 state DOTs participating, with support provided by Meridian Environmental Technology, Inc.[3]

The primary objectives of the pooled fund MDSS research project are to

- Assess the need, potential benefit, and receptivity for state and regional MDSS among participating state DOTs;
- Define functional and user requirements for an MDSS that can assess road and weather conditions, forecast weather that will affect routes, predict changes in road conditions after application of the recommended maintenance treatments, suggest optimal maintenance strategies, and evaluate the effectiveness of the maintenance treatments that are applied;
- Build and evaluate an operational MDSS that will meet the requirements of the participating state DOTs; and
- Improve the ability to forecast road conditions in response to changing weather and applied maintenance treatments (*1*).

Going Statewide

As part of the pooled fund MDSS effort, Indiana DOT conducted field trials for three winters, starting in 2005–2006, adding routes and improving communications processes each year. A significant finding from field trials was that participating subdistricts reduced salt use from 10 to 30 percent compared with the use in neighboring areas. Indiana DOT's Fiscal Year (FY) 2008 budget for salt exceeded $20 million—even a 10 percent savings in salt use would have a positive impact on the DOT's budget. The Indiana DOT administration therefore decided to implement the MDSS statewide during the winter of 2008–2009 (*2*).

Indiana DOT developed and provided training on the use of the MDSS to winter maintenance personnel throughout the state. The statewide implementation of the new system required a significant change in the department's winter maintenance procedures and a change in the mindset of the employees. The reasons for the change in the approach were communicated throughout the organization, to gain early acceptance at all levels.

Feedback mechanisms were created to assure that input from employees at all levels received appropriate consideration. The MDSS was introduced at the Indiana DOT Snow and Ice Conference in September 2008 to ensure that all employees received the same message.

Training Modules

Indiana DOT's implementation team developed training modules to provide the working knowledge to support successful implementation of the MDSS. The training modules included the following:

- Graphical User Interface Module—presenting the screen views of the MDSS for maintenance employees;
- Quality Assurance–Quality Control Module—presenting a checklist to assure that the system is functioning properly and to foster a sense of trust in, and ownership of, the MDSS by employees;
- Snowplow Drivers' Classroom and Hands-On Module—reviewing the operation of equipment for automatic vehicle location (AVL) and mobile data collection (MDC), installed in the snowplow trucks; and
- Mechanics Module—detailing the installation of AVL and MDC equipment in the snowplow trucks.

Starting Up

The MDSS used by maintenance employees in winter maintenance operations connects to a central server that continually transfers current and forecast weather data, conditions for all routes in the state, advisory messages, and available maintenance actions. The MDSS functions as a window to past, present, and future weather and highway conditions, as shown in the map view on page 35.

Indiana DOT equipped 10 percent of the state fleet with AVL and MDC units, and a vendor provided training at a total cost of $529,000. The newly equipped trucks and their routes were used as rep-

[2] FHWA Road Weather Management Program Publications, http://ops.fhwa.dot.gov/weather/resources/publications.htm.
[3] Development of Maintenance Decision Support System, www.pooledfund.org/projectdetails.asp?id=240&status=6.

TABLE 1 Comparison of Indiana DOT Salt Use for FY 2008 and FY 2009

Statewide	FY 2008 Tons	FY 2009 Tons	Difference in Tons	Savings @ $53/ton
Salt Usage	558,274	329,804	228,470	$12,108,910
Normalized Salt Usage	518,078	329,804	188,274	$9,978,536

TABLE 2 Comparison of Indiana DOT Overtime for FY 2008 and FY 2009

Statewide	FY 2008 Hours	FY 2009 Hours	Difference in Hours	Savings @ $23.33/hour
Overtime Compensation	226,484	168,210	58,274	$1,359,591
Normalized Overtime Compensation	210,177	168,210	41,967	$979,136

resentative samples for the state. A few problems arose during implementation—equipment failure and errors in predicting storm start times and the types and amounts of precipitation—but all were resolved quickly.

Because winters vary from year to year, the observed data were normalized by determining three-year averages of salt use and of the hours of snow and freezing rain during each July 1 to June 30 fiscal year. The information about salt use came from management systems, and the hours of snow and freezing rain were obtained from measurements at five different National Weather Service sites in the region. The goal was to generate reports of salt used per hour of snow and freezing rain for each of the six DOT districts and for the state. In addition, researchers tracked worker overtime compensation during the winter operations.

Benefits

Indiana DOT realized that the MDSS is a tool that forecasts weather conditions; recommends chemical and mechanical treatments; assists management in providing a consistent level of service throughout the state; and provides proactive planning for forecast storms. The AVL and MDC units provided timely input on each truck's activity, such as its spread rate, speed, and plowing, and cameras installed in the trucks provided managers and others with a view of the field conditions—known as ground-truth readings. This information assisted in coordinating efforts among all involved in winter operations.

A comparison of FY 2008 and FY 2009 revealed that implementation of the MDSS saved Indiana DOT $12,108,910 by reducing salt use by 228,470 tons (40.9 percent) and another $1,359,951 by reducing overtime compensation by 58,274 hours (25.7 percent). When normalized for varying winter conditions, Indiana DOT's savings came to $9,978,536 through reduced salt use and $979,136 through reductions in the need for overtime (see Tables 1 and 2, above). The efficiencies gained by optimizing the maintenance strategies for snowplow routes produced a total savings in material and labor of $10,957,672 during the 2008–2009 winter season.

Implementation of the MDSS statewide has generated a significant net savings in the first year, and Indiana DOT anticipates a continued accrual of benefits annually, as the MDSS continues to be integrated into standard operational procedures.

For more information, contact Tony McClellan, Seymour District Highway Operations Director, Indiana DOT, 185 Agrico Lane, Seymour, IN 47274; 812-524-3708; TMCCLELLAN@indot.IN.gov; or Kirk Carpenter, Snow and Ice Program Director, Highway Operations, Indiana DOT, 100 North Senate Avenue, Room N901, Indianapolis, IN 46204, 317-234-5048, KCarpenter@indot.IN.gov.

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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).

Reaping the Benefits of Attending the TRB Annual Meeting

Utah Department of Transportation's Practical, Systematic Model

RUKHSANA LINDSEY

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Networking with other transportation professionals, contributing to the work of technical standing committees, and gaining insights from an array of program sessions at the Transportation Research Board (TRB) Annual Meetings have greatly benefited representatives of the Utah Department of Transportation (DOT). But beyond that, those who attend have been instrumental in implementing within Utah DOT cost-saving ideas brought back from the TRB Annual Meetings. Utah DOT has developed a formal process to document the benefits of sending its personnel to the TRB Annual Meeting, by tracking the implementation of innovative ideas within the department.

Utah DOT's Process

1. Selecting Attendees

The Utah DOT process begins with the Research Division and the director of project development, who submits a list of recommended attendees to executive leaders. The recommendations are based on the employees' leadership roles in administration, operations, program development, project development, and the department's four regions; approved status as a presenter of a paper in a lectern or poster session; membership on a TRB committee; and past performance in implementing initiatives and availability to participate.

The executives review the recommendations and budget, prepare a final list of approved attendees, and return the list to the Research Division. The Research Division then notifies attendees of the executive approval and shares information to assist in registering and preparing for the TRB Annual Meeting.

2. Preparing for the Meeting

As part of the preparation, the approved attendees meet with the director of research and the director of project development to discuss the Annual Meeting and to receive instructions on Utah DOT's expectations—that each attendee return with at least two ideas to implement in their areas of practice. Each attendee receives copies of a form, TRB Project Implementation and Note Taking, to use during and after the Annual Meeting.

3. Focusing Onsite

After arriving in Washington, D.C., the Utah DOT attendees gather for an informal meeting to share ideas and coordinate efforts to make the most of sessions that have the potential for a high return value to Utah DOT. They take notes at sessions and committee meetings and select ideas to implement.

4. Presenting Ideas

Soon after returning from the Annual Meeting, each attendee compiles a list of ideas and projects to implement, using the TRB Projects Tracking–Status Sheet, and submits a copy to the Research Division for tracking. Attendees then meet with the Utah DOT executive leadership and present at least two initiatives that they plan to implement from the Annual Meeting; the leaders provide helpful feedback and perspectives. The presentations must include a clear outline of the logistics for the implementation of their ideas, the relationship to ongoing projects in Utah DOT, and the benefits and cost savings expected.

5. Implementing Ideas

The implementation of the ideas gathered by Annual Meeting attendees may take 1 year or several years.

During the implementation period, the attendees must provide quarterly reports of progress, including actual cost savings and other accrued benefits. Attendees who move to other positions in Utah DOT during the implementation must help to continue the process by coordinating with their successors and reporting on the status of the implementation. The Research Division tracks the implementation of ideas, the cost savings, and other benefits in a master spreadsheet and reports periodically to the director of project development.

Cable median barrier on I-15 in Utah, prevents a tractor semitrailer from crossing over into the oncoming traffic.

Not all ideas brought back from the TRB Annual Meeting have gained implementation at Utah DOT. Nevertheless, the formal implementation-tracking process has focused the department on collecting new ideas and realizing the benefits of the TRB Annual Meeting.

Benefits of Implementation

Between 2003 and 2009, Utah DOT has sent 49 individuals—5 to 20 each year—to the TRB Annual Meeting. These attendees have introduced a total of 269 initiatives stemming from ideas gained at the Annual Meeting, and Utah DOT has implemented 136 of these as of October 2009.

The benefits of implementing cost-saving ideas from the TRB Annual Meeting have far surpassed the cost to Utah DOT of sending a relatively small group of people to the event. Since the tracking process began in 2003, Utah DOT has realized a cost savings of more than $189 million by implementing initiatives in contracting methods, safety improvements, accelerated bridge construction, and other areas.

Some attendees have reported difficult-to-quantify, intangible benefits from the Annual Meeting, such as information transfer, networking, and the ability to develop and maintain technical competency by attending lectern and poster presentations at technical sessions. Two key examples of beneficial projects based on Annual Meeting initiatives are cable median barriers and accelerated bridge construction with self-propelled modular transporters (SPMTs).

Reduced Crossover Crashes

Applying the information gathered at a 2003 TRB Annual Meeting session on road safety features, Tracy Conti, Director of Operations for Utah DOT, promoted the installation of cable median barriers along Utah highway corridors that had a significant history of crossover crashes. Utah DOT has installed cable median barriers at several locations along I-15 and I-215 to decrease the number of injuries and fatalities from crossover crashes. Moreover, by using cable barriers instead of concrete barriers, Utah DOT was able to stretch its safety funds as far as possible—the cable barriers can be installed for approximately one-third the cost of concrete barriers.

In 2004, Utah DOT installed its first cable median barrier system on two sections of I-15 in Utah County, totaling approximately 18 miles and $3.08 million in project costs. Between 2002 and 2004, before installation of the barriers, a total of 35 crossover crashes with fatal or serious injuries occurred in these freeway sections; the total dropped to 4 between 2005 and 2007 after barrier installation.

The estimated benefit–cost ratios for these projects range from 23:1 to 35:1. Cable median barriers have been successful in Utah in preventing crossover crashes and serious injuries and even deaths.

Accelerated Bridge Construction

Utah DOT has used several contracting methods and construction technologies to accelerate project delivery and to minimize the impacts of construction. In a collaborative effort, Jim McMinimee, Director of Project Development, and Rukhsana Lindsey, Director of Research and Bridge Operations, introduced

A bridge span built off-site is moved into place using SPMTs in Salt Lake City, Utah.

accelerated bridge construction methods to Utah DOT, applying information collected at the 2007 and 2008 TRB Annual Meetings. In particular, the Annual Meeting sessions on the accelerated construction of bridges made Utah DOT aware of the benefits of a key technology, the self-propelled modular transporter (SPMT).

Utah DOT has used SPMTs on bridge replacement projects, to remove bridges without the need for in-place demolition, and then to move entire prefabricated spans from the staging area to the bridge site. This process limits the interruption of service during a bridge replacement to days or hours, by eliminating the need for onsite, months-long construction. Replacing bridges with SPMTs also has increased worker and traffic safety and has improved construction and durability. Drawing from the successes and lessons learned from the projects, Utah DOT has developed an SPMT manual with guidelines for designers and contractors involved in moving bridge spans.

Since 2007, Utah DOT has used SPMTs on six projects to replace a total of 21 bridges. With off-site fabrication and SPMTs, bridge spans often can be replaced in a weekend. For example, construction time on the 4500 South crossing of I-215 in Salt Lake City was reduced by 120 days, saving drivers approximately $4 million in user costs.

The total value added from the deployment of SPMTs on the six Utah DOT projects was approximately $55.16 million, including user cost savings. The total cost of the SPMT moves and the associated staging was approximately $10.59 million. This technology, combined with other accelerated bridge construction methods—such as sliding and deck panels—has benefited Utah DOT and the traveling public.

Looking Ahead

Utah DOT may be one of the first agencies to develop and use a formal process for tracking the implementation of innovative ideas brought back from the TRB Annual Meeting, as well as the associated benefits. Utah DOT looks forward to improving the process and to achieving greater efficiency and cost savings through continued Annual Meeting attendance and implementation of initiatives gathered there. Reader comments are welcome.

For more information, please e-mail Rukhsana Lindsey, rlindsey@utah.gov.

TRB Meetings

January

9 Pavement Performance Data Analysis Forum
Washington, D.C.
A. Robert Raab

10–14 TRB 89th Annual Meeting
Washington, D.C.
www.TRB.org/AnnualMeeting

February

16–17 Climate Change and Ships: Increasing Energy Efficiency*
Linthicum Heights, Maryland
www.sname.org/SNAME/climatechange/Home/Default.aspx

March

28–30 Road Safety on Four Continents Conference*
Abu Dhabi, United Arab Emirates

April

12–16 1st International Conference on Pavement Preservation*
Newport Beach, California

27–29 High-Speed and Intercity Passenger Rail Systems and Strategies Joint Rail Conference*
Urbana, Illinois
Elaine King

May

5–7 1st International Conference in North America on Nanotechnology in Cement and Concrete
Irvine, California

9–12 Innovations in Travel Demand Forecasting 2010
Tempe, Arizona

13–14 Innovations in Pricing of Transportation Systems: Workshop and Conference*
Orlando, Florida

19–21 Transportation Finance: Forging a Sustainable Future—Now
New Orleans, Louisiana

30–June 2 Safety and Mobility of Vulnerable Road Users: Pedestrians, Motorcyclists, and Bicyclists*
Jerusalem, Israel
Richard Pain

June

2–4 TRANSED 2010: 12th International Conference on Mobility and Transport for Elderly and Disabled People*
Hong Kong, China

2–5 4th International Symposium on Highway Geometric Design*
Valencia, Spain

3–5 GeoShanghai 2010 International Conference*
Shanghai, China

6–10 Environment and Energy in Transportation Summit*
Raleigh, North Carolina

21–24 North American Travel Monitoring Exposition and Conference (NATMEC): Improving Traffic Data Collection, Analysis, and Use
Seattle, Washington
Thomas Palmerlee

29–July 1 Marine Transportation System Research and Technology Coordination Conference*
Irvine, California
Joedy Cambridge

July

11–14 TRB Joint Summer Meeting
Minneapolis, Minnesota

11–14 49th Annual Workshop on Transportation Law
Newport, Rhode Island

11–15 5th International Conference on Bridge Maintenance, Safety, and Management*
Philadelphia, Pennsylvania

August

4 Pavement Performance Data Analysis Forum
Sao Paulo, Brazil
A. Robert Raab

September

Mid-month International Conference on Sustainable Concrete Pavement Technologies: Practice, Challenges, and Directions*
California

October

10–13 9th National Conference on Access Management*
Natchez, Mississippi

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 lkarson@nas.edu. Meetings listed without a TRB staff contact have direct links from the TRB calendar web page.

*TRB is cosponsor of the meeting.

Wallace T. McKeel

Virginia Transportation Research Council

Wallace (Wally) McKeel's career as a research scientist has focused on the maintenance, design, and evaluation of highway bridges. Until his retirement in 2001, McKeel was associate director in charge of the structural, pavement, geotechnical, and maintenance areas of the Virginia Transportation Research Council (VTRC), a partnership of the Virginia Department of Transportation (DOT) and the University of Virginia.

The first study in McKeel's career involved the application of epoxy membranes to protect bridge decks. His research work also included many early efforts to address an emerging problem—the protection, repair, and rehabilitation of deteriorated bridge decks; studies of the potential for wind turbines to generate electricity for highway buildings; and the implementation of computer-aided drafting and design in Virginia DOT operations—which he calls the most rewarding of his projects.

"Developing a research program—either as an individual or as the manager of a team of scientists—is a challenge requiring a balance of timeliness, flexibility, and opportunism."

McKeel is impressed with the increasing application of sophisticated technology in bridge maintenance. "Instead of the reactive patching of decks based on hammer soundings, we now have several testing procedures to map deteriorated areas in the deck, an understanding of the corrosion mechanism, and a selection of more effective materials to combat and prevent recurrence of the problem," he comments. "Health monitoring instrumentation may eventually allow safety inspectors to approach a bridge with more complete information about its condition. The development of today's more impermeable concrete, corrosion-resistant reinforcement, and better tools for the evaluation of bridge condition and performance will take us a long way toward our goal of long-lasting structures that require minimal maintenance."

McKeel received a bachelor's degree in civil engineering from the Virginia Military Institute in 1957 and a master's degree in civil engineering from the University of Virginia in 1968. He joined the Bridge Division of what was then called the Virginia Department of Highways in 1959 as a bridge design engineer. After 4 years, he transferred to VTRC—then the Virginia Council for Highway Investigation and Research—as one of two permanent staff members assigned to initiate a bridge research program.

McKeel attended his first TRB annual meeting in 1964, and he credits TRB with maintaining a strong influence in his efforts to network and keep abreast of the latest developments in transportation research. His TRB activities have included service as member and chair of the Adhesive Bonding Agents and Their Uses Committee; and as a member of the Dynamics and Field Testing of Bridges Committee and of the Bridge Management Committee. In 2001, he was selected as an emeritus member of the Structures Maintenance Committee, which he has served since 1982, including a term as chair. McKeel has contributed to several National Cooperative Highway Research Program (NCHRP) project and topic panels. He was the principal author of NCHRP Reports 222 and 243, which explored the rehabilitation and replacement of bridges on secondary highways and local roads.

"Developing a research program—either as an individual or as the manager of a team of scientists—is a challenge requiring a balance of timeliness, flexibility, and opportunism," notes McKeel. "Timeliness is essential if the study is to satisfy the needs of the customer, but the research program must be flexible enough to meet unanticipated needs or requests. A sense of opportunism is useful to the researcher in the selection and timing of projects for maximum impact."

McKeel considers it absolutely essential for managers to mentor young colleagues. "Mentorship yields great benefits not only for the new researcher, but also for the organization—the spread of knowledge and experience in project selection, opportunities for networking, or introductions to others in various research areas greatly accelerate the progress of new researchers and enhance their value to the team," he observes.

Since his retirement, McKeel has continued his involvement in VTRC's historic research program, working with Virginia DOT's Knowledge Management and Public Affairs Divisions to produce a recorded history of transportation in Virginia, as well as a video, "Virginia's Covered Bridges," which aired on public television stations and won a 2009 Telly Award in the TV Documentary category. A recent report, "Best Practices for the Rehabilitation and Moving of Historic Metal Truss Bridges," has been well received and was published in a 2007 volume of the *Transportation Research Record: Journal of the Transportation Research Board*. McKeel assisted VTRC in the Long-Term Bridge Performance Project, sponsored by the Federal Highway Administration. He also received the Virginia DOT Commissioner's Award of Excellence and a service award from the Virginia Section of the American Society of Civil Engineers.

Thomas F. Zimmie

Rensselaer Polytechnic Institute

Thomas Zimmie attended his first Transportation Research Board Annual Meeting in 1974—the same year he began his career at Rensselaer Polytechnic Institute (RPI) in Troy, New York, where he is now Professor of Civil and Environmental Engineering. Since then he has been active in TRB. "Transportation research requires a wide range of skills," he notes. "There is plenty of activity at TRB for all engineering specialties."

Zimmie served the Physicochemical and Biological Processes in Soil Committee as chair and longtime member; in 2004, he was named an emeritus member. From 1974 to 1992, Zimmie was a member of the Subsurface Drainage Committee. He has been a member of the Modeling Techniques in Geomechanics Committee since 1999 and is the TRB University Representative for RPI.

"One must not only communicate with researchers in other fields, but also communicate clearly and simply with the general public."

Group collaboration and research are necessary to present well-rounded solutions to complex problems, maintains Zimmie. "One of the negative aspects of too much specialization is the difficulty of seeing the big picture, and this can stifle innovation. Funding agencies' increased emphasis on multidisciplinary research and group research is good."

Zimmie's professional interests have found a wide range of application—from soil mechanics to recycled waste materials to centrifuge testing. In recent years, Zimmie has researched the use of materials such as waste paper sludge and fly ash in low-volume roads, and as part of the geotechnical centrifuge team at RPI, he has conducted tests to help solve problems in such areas as natural disasters, erosion, and security. He has used centrifuge testing expertise to study explosive effects on dams, levees, tunnels, and other critical infrastructure. In 2007, Zimmie received the U.S. Army Corps of Engineers' Patriotic Civilian Service Award for his work on the team that investigated the New Orleans levee failures during Hurricane Katrina. He also testified before a U.S. Senate committee about the investigation.

Zimmie received a bachelor's degree in civil engineering from Worcester Polytechnic Institute in 1960. After earning a master's degree in civil engineering from the University of Connecticut two years later, he worked with the Navy Oceanographic Office and served as a combat engineer officer in the U.S. Army Corps of Engineers. Zimmie designed and constructed industrial plants for Union Carbide and then returned to the University of Connecticut to pursue a doctorate in civil engineering. At the same time, he worked as a consultant and as engineer for the Town of Mansfield, Connecticut. In 1972, Zimmie spent a year at the Norwegian Geotechnical Institute in Oslo, Norway, as a National Science Foundation (NSF) fellow. Returning to the United States, he accepted a teaching position at RPI, where he has worked for more than 35 years.

In addition to his professorship at RPI, Zimmie has worked as a part-time town engineer; worked with NSF in Washington, D.C., as program manager; and has taken sabbaticals with the New York State Department of Environmental Conservation. Throughout his career, he has maintained an active consulting practice; he is the president and CEO of Civrotech Engineering, P.C., a geotechnical engineering firm in the Troy–Albany area.

Communication is vital to the successful dissemination of research findings, notes Zimmie: "One must not only communicate with researchers in other fields, but also communicate clearly and simply with the general public. This is especially important in the transportation sector, for it is a rare transportation project that does not involve public hearings and approval."

Zimmie estimates that, in the course of his career at RPI, he has conducted 25 different courses at all levels, taught 2,000 civil engineering students, and produced 150 master's thesis and doctoral dissertation students. He is the longest-serving faculty adviser of a student chapter of the American Society of Civil Engineers (ASCE), and continues to recruit and engage young transportation researchers in group research. He recalls the advice he received at his first TRB meeting, which he now passes on to new TRB participants: "Get on a committee, for that is where the action is."

Zimmie has authored more than 250 publications. In 2005, he coauthored several papers on centrifuge models and experiments for ASCE's Pipeline Division Specialty Conference; for the International Conference on Energy, Environment, and Disasters; and for the Association of State Dam Safety Officials' annual conference. Other coauthored papers include "Seismic Retrofit of Coastal Dikes," "U.S. National Report: Geotechnical Education in the U.S.A.," and "Technical Possibilities for Paper Sludge Utilization." In 2000, he was the editor of *Environmental Geotechnics*, published by ASCE.

Zimmie's contributions to the field of geotechnical research have been recognized with more than a dozen honors and awards, among them RPI's Jerome Fishbach Faculty Award, the NSF Merit Award, and several honors from ASCE, including the Meritorious Service Award.

A major rockslide buries U.S. Highway 64 in Polk County, Tennessee.

Photo: George Hornal, Tennessee DOT

Cleanup Under Way for Massive Rockslide

By Julie Oaks, Tennessee Department of Transportation

A rockslide on Little Frog Mountain in Polk County, Tennessee, covered a section of US-64 with approximately 30,000 yd^3 of rock and debris, causing a wide detour and major cleanup effort. Around 6 a.m., November 10, a motorist traveling along US-64 encountered several large boulders lying in the roadway that had tumbled from the side of Little Frog Mountain during the night. The driver called 911 to report the rockfall, and the Tennessee Department of Transportation (DOT) Polk County maintenance team quickly went to work clearing the debris. After assessing the size of the boulders that fell onto the roadway, however, the Polk County crew realized the debris was too large to remove with their equipment, and a contractor was called to help break up and remove the rocks from the roadway. When Tennessee DOT Geotechnical Engineer Vanessa Bateman arrived at the site, she began assessing the slide area.

"As I looked at the site, I kept hearing pops that sounded like a car door slamming, and I noticed raveling on the slope," Bateman recalled. "I knew another slide may be imminent and I ordered the workers out of the roadway and away from the slope."

Around 1 p.m., the section of Little Frog Mountain crumbled, burying the roadway under a massive pile of rock, dirt, and trees within seconds. Federal assistance would be needed to clear the massive rockslide. Tennessee DOT immediately drew up a contract and contacted road builders about the emergency rockslide removal project.

On November 13, Tennessee DOT awarded a $2.1 million emergency contract to Charles Blalock & Sons, Inc., Sevierville, Tennessee, to stabilize the slope and clean up the blocked portion of US-64. Workers will scale and trim the rock along the mountain face, then remove any unstable material and drive 40-ft. rock anchors to secure other material along the slope.

After the rock along the face of Little Frog Mountain has been stabilized, crews will remove the large boulders and other slide material from the roadway. The contractor will then repair the damaged roadbed on US-64, and Tennessee DOT crews will repave the roadway and reopen it to traffic. The entire project was expected to take at least 8 weeks.

"We estimate that the removal of the rock and other debris will require 3,000 dump truck loads," notes Tennessee DOT Chief Engineer Paul Degges. "This is dangerous work that requires a highly skilled contractor. Our geotechnical engineers will be working closely with Blalock throughout the project to ensure the slide removal is completed safely and as quickly as possible."

Tennessee DOT has created a web page for the US-64 rockslide (http://bit.ly/1Tlc8m) that includes a live time-lapse camera of the work site, news releases, photos, and a map of the slide detour. Tennessee DOT will add daily progress updates, plus photos and periodic videos. Updates will be provided on Tennessee DOT's Chattanooga area Twitter page (www.twitter.com/Chattanooga511) and on Tennessee DOT's statewide Twitter site (www.twitter.com/TN511). Travelers also may dial 511 from any land line or cell phone to receive information on the rock slide.

Most Dangerous Cities for Pedestrians

Dangerous by Design, a recent report by Transport for America and the Surface Transportation Policy Partnership, has named the 10 most dangerous cities for pedestrians. According to the report, more than 76,000 pedestrians have been killed in the United States in the past 15 years, and most of these deaths occurred along roadways that were not suitable or safe for walking, bicycling, or using wheelchairs.

Less than 1.5 percent of funds authorized under the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users have gone to pedestrian safety projects, the report states. Pedestrian deaths account for almost 12 percent of all traffic fatalities.

In the 1990s, researchers at the Surface Transportation Policy Partnership developed the pedestrian danger index (PDI) to measure the safety of the nation's roads for pedestrians. The PDI analyzes the rate of pedestrian deaths against the rate of pedestrian activity in various areas.

In 2007–2008, the most dangerous metropolitan areas for foot travel were, in order: Orlando, Tampa, Miami, and Jacksonville, Florida; Memphis, Tennessee; Raleigh, North Carolina; Louisville, Kentucky; Houston, Texas; Birmingham, Alabama; and Atlanta, Georgia. According to the report, no state uses more than 5 percent of its federal transportation funds on safety improvements for pedestrian or bicycle facilities such as sidewalks, crosswalks, speed humps, or safety programs; the average metropolitan area spends 2.2 percent of federal funds for this purpose.

Many pedestrian deaths occur on roads that have been designed for automobile traffic. Programs and policies such as Complete Streets, Safe Routes to School, and pedestrian-friendly street design have helped to combat pedestrian fatalities; design retrofitting may also aid in this task, according to the report.

PHOTO: DAVID HALL, NOAA

NEW TECHNOLOGY ON THE WAVES—The officers and crew of Pisces, the National Oceanic and Atmospheric Administration's (NOAA) newest and most advanced fisheries survey vessel, line the deck during a commissioning ceremony, November 6, in Pascagoula, Mississippi. Also dedicated was the new Southeast Fisheries Science Center's Pascagoula laboratory, a 55,000-ft^2 fishing services facility that replaces the laboratory destroyed by Hurricane Katrina in 2005. The new ship and laboratory facility will support NOAA's fisheries research in the Gulf of Mexico, the southeastern United States, and the Caribbean. Built by VT Halter Marine, Inc., the 208-ft Pisces is the third of four new NOAA fisheries vessels of the same class. Its quiet-hull technology will allow scientists to study fish populations and collect oceanographic data with minimal impact on fish and marine mammal behavior.

POLICY REVIEW— The TRB Executive Committee's Subcommittee on Planning and Policy Review (SPPR) conducted its fall meeting, November 12 at the Keck Center. The SPPR reviews proposed projects and studies, monitors critical issues in transportation, and recommends opportunities for new Executive Committee initiatives.

IN MEMORIAM

John R. Meyer, 1927–2009

Called "the father of transportation economics" by the *New York Times* and a longtime influential figure in U.S. public policy, John R. Meyer, 81, died October 20, in Cambridge, Massachusetts. He was the 2002 recipient of the Transportation Research Board's Roy E. Crum Distinguished Service Award.

John R. Meyer

After earning a doctorate in economics from Harvard University, Meyer received the prestigious Harvard Junior Fellowship, soon followed by an appointment as assistant professor. Meyer's academic career included tenures in the Department of Economics at Harvard (1955–1968); the Department of Economics at Yale University in New Haven, Connecticut (1968–1973); Harvard Business School (1973–1983); and at Harvard's Kennedy School of Government (1983–1996), as James C. Harpel Professor of Capital Formation and Economic Growth.

Meyer also served as Vice Chairman of the Union Pacific Corporation; on the boards of directors for several corporations; and as a consultant to Rand Corporation, the World Bank, the European Bank for Reconstruction and Development, and the President's Council of Economic Advisers.

His pioneering vision helped introduce microeconomic analysis and statistical methods to the study of transportation policy, while still respecting a traditional perspective informed by institutions and history. Meyer's studies had a profound effect on U.S. transportation policy, into which many of his conclusions became incorporated.

President of the National Bureau for Economic Research from 1967 to 1977, Meyer also served on two Presidential task forces on transportation policy and a government commission on railroad productivity. He was a member of the Presidential Commission on Population Growth and the American Future, a fellow of the American Academy of Arts and Sciences and the Econometrics Society, a National Associate of the National Academies, and a member of the Council on Foreign Relations.

Meyer characteristically involved fellow researchers in his work—all 21 of his books are coauthored. As a young academic, Meyer ensured his place in the field of transportation economics with *The Economics of Competition in the Transportation Industries* (1959) and *The Urban Transportation Problem* (1965), and over the course of his career his mentorship of young colleagues set the standard for integrity and group effort. He directed and contributed to a study of airline deregulation in the 1980s; and in 1996, after providing guidance to the European Bank for Reconstruction and Development and to the World Bank on restructuring transportation systems in the former Soviet Union and in China, he wrote *Moving to Market: Restructuring Transport in the Former Soviet Union*. At the end of his life, Meyer was working on an economic history of American railroads in the 20th century—a subject close to his heart.

At TRB, Meyer chaired the National Research Council (NRC)–appointed TRB Committee for a Study of Competition in the Airline Industry from 1998 to 1999, after serving on the committee for the earlier TRB Study on Air Passenger Service and Safety Since Deregulation. He also was a member of the standing committees on Passenger Transportation Economics and on Taxation, Finance, and Pricing; of the NRC-appointed Committee on Education and Training for Civilian Aviation Careers; and of the Committee on Transportation Options for Megacities in Developing Nations.

A NEW DAY—U.S. Secretary of Transportation Ray LaHood (*right*) and Peter H. Appel, Administrator, Research and Innovative Technology Administration, spoke at a TRB conference on Developing a Research Agenda for Transportation Infrastructure Preservation and Renewal, November 12, at the National Academies' Keck Center in Washington, D.C. LaHood characterized the new administration's approach to transportation policy as "a new day at the U.S. Department of Transportation." LaHood described a holistic approach to transportation policy—especially with respect to university-based research—that reaches across all modes and levels. Appel emphasized the commitment of LaHood and the new administration to improving transportation safety and infrastructure.

MARINE BOARD WELCOMES NEW MEMBERS—New Marine Board members Steven Barnum, Hydrographic Consultation Services (*second from left*) and George Newton, Arctic Research Commission (*second from right*), are welcomed by Marine Board Vice Chair Michael Bruno, Stevens Institute of Technology (*left*) and Chair Malcolm MacKinnon III, MacKinnon-Searle Consortium, LLC (*right*). At their fall meeting, November 16–17 at the Keck Center, Marine Board members heard presentations on issues such as expanded commercial shipping activity in the Arctic, port resiliency, offshore energy installations, the economic significance of navigation, ship propulsion loss, hazardous cargoes, maritime incident reporting systems, the role of visual aids to navigation in an e-navigation environment, and the marine highway.

COOPERATIVE RESEARCH PROGRAMS NEWS

Handbook for Pavement Design, Construction, and Management

The design, construction, and management of highway pavements are complex tasks that involve the consideration of many topics—structural design and analysis, drainage provisions, traffic load spectra, construction practices, pavement evaluation, life-cycle cost analysis, and more. Documents from the American Association of State Highway and Transportation Officials (AASHTO) have addressed some of these topics—for example, the *Pavement Management Guide*; the *Guide for Pavement Friction*; and the *Mechanistic–Empirical Pavement Design Guide, Interim Edition* (MEPDG)—and information on the other topics is available in other literature.

This practical information, however, needs to be synthesized and assembled into a format that will facilitate accessibility and use by highway agency professionals. It is necessary, therefore, to identify current practices, review relevant information, and develop a handbook that incorporates relevant AASHTO documents into a discussion of topics pertaining to the design, construction, and management of pavements.

Applied Pavement Technology, Inc., of Urbana, Illinois, has been awarded a $400,000, 27-month contract [National Cooperative Highway Research Program (NCHRP) Project 1-46, FY 2008] to develop a handbook that addresses the design, construction, and management aspects of pavements. The handbook, to be recommended for adoption by AASHTO, will be prepared in an interactive, electronic format with a printer-friendly option.

For further information, contact Amir N. Hanna, TRB, 202-334-1432, ahanna@nas.edu.

Sensitivity Evaluation of Performance Prediction

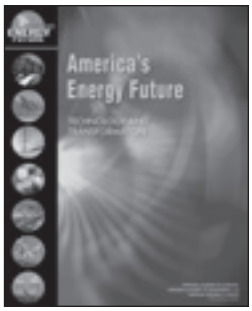
AASHTO's interim edition of the MEPDG *Manual of Practice* and related software developed under NCHRP provides methodologies for the analysis and performance prediction of different types of flexible and rigid pavements. The pavement performance predicted by these methodologies for anticipated climatic and traffic conditions—in terms of distresses such as cracking, rutting, faulting, and smoothness—depends on the values of input parameters that characterize pavement condition and its materials, layers, and design features.

Differences in these values, however, may cause variations in predicted pavement performance. Although studies have related predicted pavement performance to differences in input parameter values, the relationship has not been addressed systematically to identify the values' relative influence. In addition, these studies have not comprehensively considered the combined effects of variations in two or more values on predicted pavement performance.

The University of Maryland, College Park, has been awarded a $249,952, 20-month contract (NCHRP Project 1-47, FY 2009) to determine the sensitivity of pavement performance predicted by the MEPDG to the variability of input parameter values. This information will help identify—for specific climatic regions and traffic conditions—the input parameters that appear to influence predicted pavement performance. This will allow users to focus their efforts on the input parameters that have greater influence on pavement design.

For further information, contact Amir N. Hanna, TRB, 202-334-1432, ahanna@nas.edu.

America's Energy Future: Technology and Transformation



Committee on America's Energy Future, National Academy of Sciences, National Academy of Engineering, National Research Council. National Academies Press, 2009. 650 pp.; $69.95; 978-0-309-11602-2.

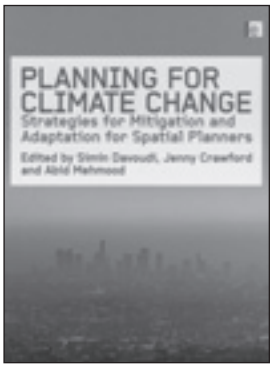
A report of the America's Energy Future project at The National Academies—which is examining the role of energy in long-term U.S. economic vitality, national security, and climate change—this book explores six key technology areas: efficiency, alternative transportation fuels, renewable energy, fossil energy, nuclear energy, and the power grid. The costs of energy use have an impact at all levels, from the personal to international—the challenge is for the United States to develop an energy portfolio that addresses the costs yet still provides sufficient and affordable energy reserves.

America's Energy Future analyzes the potential of a range of technologies for the generation, distribution, and conservation of energy. Offering a detailed assessment of the associated impacts and projected costs of implementing each technology, the report also projects the three time frames required for implementation.

Planning for Climate Change: Strategies for Mitigation and Adaptation for Spatial Planners

Edited by Jenny Crawford, Simin Davoudi, and Abid Mehmood. Earthscan, 2009. 319 pp.; $79.95; 978-1-844-07662-8.

Human activity–induced global climate change is a premise that is widely accepted; however, uncertainties and disagreements remain about the right course of action—mitigation or adaptation. These ambiguities raise problems for spatial planners and decision makers. Divided into three sections—The Challenge of Climate Change: Adaptation, Mitigation, and Vulnerability; Strategic Planning Responses; and Implementation, Governance, and Engagement—this volume provides spatial planners with the tools to make sustainable and effective decisions in transportation policy and urban planning. Transportation-related chapters include "Transport Policies and Climate Change" and "Transitioning Away from Oil: A Transport Planning Case Study with Emphasis on U.S. and Australian Cities."



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

TRB PUBLICATIONS

Performance Measurement Framework for Highway Capacity Decision Making

Second Strategic Highway Research Program (SHRP 2) Report S2-C02-RR

This report explores a framework of performance measures, designed to support the collaborative decision-making framework (CDMF) being developed by the SHRP 2 Capacity program for additions to highway capacity. The 17 performance factors are linked to key decision points in the CDMF in five broad areas of performance: transportation, environment, economics, community, and cost.

2009; 113 pp.; TRB affiliates, $40.50; nonaffiliates, $54. Subscriber categories: planning and administration (IA), energy and environment (IB), highway and facility design (IIA).

Public and Private Sector Interdependence in Freight Transportation Markets

National Cooperative Freight Research Program (NCFRP) Report 1

A primer on relationships between public-sector and private-sector stakeholders in the freight transportation industry, NCFRP's inaugural report uses examples, case studies, and a broad-based examination of the mutually dependent issues facing public and private investment decision makers in the freight industry. Differences between the public and private sectors in freight transportation are presented, along with a discussion of approaches to overcome the differences.

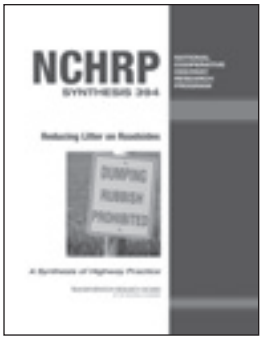
2009; 60 pp.; TRB affiliates, $32.25; TRB nonaffiliates, $43. Subscriber categories: planning and administration (IA), aviation (V), rail (VII), freight transportation (VIII), and marine transportation (IX).

Procedures Guide for Right-of-Way Cost Estimation and Cost Management

NCHRP Report 625

Approaches for developing right-of-way (ROW) cost estimates are examined, along with ways to track and manage ROW cost during project development, including the planning, programming, and preliminary and final design phases. Researchers probe the

TRB PUBLICATIONS *(continued)*



challenges of state highway administrations, transit agencies, and other transportation organizations in developing realistic cost estimates for ROW. Also addressed is the difficulty of tracking and managing estimates to produce accurate and reliable information at all stages of project development.

2009; 213 pp.; TRB affiliates, $49.50; TRB nonaffiliates, $66. Subscriber categories: planning and administration (IA); highway and facility design (IIA).

Tools to Aid State DOTs in Responding to Workforce Challenges
NCHRP Report 636
Tools for the recruitment, development, and retention of a productive and effective workforce are examined in this report, intended for use by officials of state departments of transportation (DOTs). State DOTs need to hire, train, and retain a competent, qualified, and high-performing workforce to meet public expectations. This report describes the tools available to managers and provides guidance in choosing an effective tool for the task at hand. Two appendices are included.

2009; 82 pp.; TRB affiliates, $36.75; TRB nonaffiliates, $49. Subscriber category: planning and administration (IA).

Guidelines for Dowel Alignment in Concrete Pavements
NCHRP Report 637
The effects of dowel misalignment on concrete pavement performance are studied, and measures are highlighted for preventing misalignment and its adverse effects. The report offers guidance to pavement and construction engineers in considering dowel misalignment in pavement design and identifies measures for reducing misalignment during construction and for dealing with misaligned dowels.

2009; 49 pp.; TRB affiliates, $30.75; TRB nonaffiliates, $41. Subscriber categories: pavement design, management, and performance (IIB); materials and construction (IIIB).

Adhesive Anchors in Concrete Under Sustained Loading Conditions
NCHRP Report 639
This report explores a test method designed to help determine an adhesive anchor's ability to resist sustained tensile loads. Building on current methods from the American Association of State Highway and Transportation Officials, American Society for Testing and Materials, state departments of transportation, and other sources, the method considers the creep characteristics of the adhesive over the expected life of the structure, site-specific ultimate strength requirements, and the effects of temperature and moisture.

2009; 132 pp.; TRB affiliates, $42.75; TRB nonaffiliates, $57. Subscriber categories: bridges, other structures, and hydraulics and hydrology (IIC); materials and construction (IIIB).

Quantifying the Benefits of Context-Sensitive Solutions
NCHRP Report 642
The economic impacts of context-sensitive solutions (CSS) are not well documented, despite their great potential value to agencies and stakeholders. This report explores guidelines for quantifying the benefits of applying CSS principles to transportation projects. Also included is a separate document that provides specific guidelines for agencies to assess the benefits of applying the set of CSS principles to their own transportation projects.

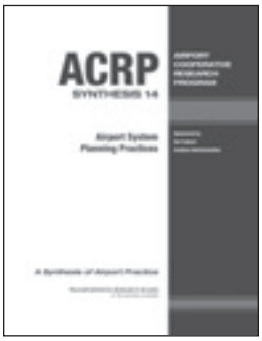
2009; 156 pp.; TRB affiliates, $45; TRB nonaffiliates, $60. Subscriber categories: planning and administration (IA); highway and facility design (IIA).

Reducing Litter on Roadsides
NCHRP Synthesis 394
A survey, literature review, and four case studies provide a comprehensive snapshot of the state of the practice of state DOTs in reducing roadside litter. Included is information on the prevention and removal of roadside litter; education; unfulfilled needs, knowledge gaps, and underperforming activities; enforcement; and engineering methods for litter prevention and litter collection.

2009; 68 pp.; TRB affiliates, $34.50; TRB nonaffiliates, $46. Subscriber categories: energy and environment (IB); maintenance (IIIC).

Bridge Management Systems for Transportation Agency Decision Making
NCHRP Synthesis 397
This synthesis explores how transportation agencies use bridge management systems for network-level decisions on the allocation of resources for bridge programs. The information was gathered from a literature review, a survey, and 15 in-depth interviews with state DOT executives and bridge managers.

2009; 126 pp.; TRB affiliates, $42.75; TRB nonaffiliates, $57. Subscriber categories: planning and administration (IA); bridges, other structures, and hydraulics and hydrology (IIC).



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Cathodic Protection for Life Extension of Existing Reinforced Concrete Bridge Elements
NCHRP Synthesis 398
Information gathered through a literature review, a survey of North American transportation agencies, and selected interviews examines the use of cathodic protection by state transportation agencies for controlling corrosion on existing reinforced concrete bridge elements. Also highlighted are different types of cathodic protection systems, case studies of states using these systems, and reasons that public agencies may or may not employ cathodic protection.

2009; 48 pp.; TRB affiliates, $30.75; TRB nonaffiliates, $41. Subscriber categories: bridges, other structures, hydraulics, and hydrology (IIC); maintenance (IIIC).

Practical Measures to Increase Transit Advertising Revenues
TCRP Report 133
Strategies are presented that have the potential to increase transit's share of total advertising expenditures. Perceptions about current and future transit advertising products are examined and a strategic communications plan is identified to improve perceptions and to increase transit revenue.

2009; 98 pp.; TRB affiliates, $38.25; TRB nonaffiliates, $51. Subscriber category: public transit (VI).

Guidebook for Managing Small Airports
ACRP Report 16
Managers of small airports are responsible for many activities—from financial management and noise control to community relations and security. Managers have varying degrees of experience and a range of backgrounds; however, much of the extant airport management guidance is dated, intended for larger airports, or otherwise unsuitable for the needs of a small-airport manager. This guidebook provides operators and managers of small airports with current, comprehensive advice on resources and techniques that can be applied to meet their responsibilities.

2009; 129 pp.; TRB affiliates, $42.75; TRB nonaffiliates, $57. Subscriber category: aviation (V).

Airport System Planning Practices
ACRP Synthesis 14
This synthesis reviews the literature and explores the extent to which state aviation agencies and regional planning organizations are involved in airport system planning. Also surveyed are the type of studies these organizations perform and how successful their efforts have been in meeting the objectives of the planning process.

2009; 71 pp.; TRB affiliates, $30.75; nonaffiliates, $41. Subscriber category: aviation (V).

Identification of the Requirements and Training to Obtain Driving Privileges on Airfields
ACRP Synthesis 15
Airports throughout the country specify different requirements and training for workers to obtain driving privileges on airfields. This synthesis examines the differences and similarities among the requirements and assembles information for airport operators, including the types of training programs and authorizations available for airport employees.

2009; 43 pp.; TRB affiliates, $28.50; nonaffiliates, $38. Subscriber category: aviation (V).

Compilation of Noise Programs in Areas Outside DNL 65
ACRP Synthesis 16
An online survey of airport staff was compiled to examine alternative actions used by airports to address noise outside the DNL (day–night average noise level) 65 contour. Designed primarily to identify the reasons for addressing noise outside DNL 65, this synthesis also considers noise abatement, mitigation, and communication techniques beyond sound insulation.

2009; 104 pp.; TRB affiliates, $38.25; TRB nonaffiliates, $51. Subscriber category: aviation (V).

Travel Behavior Analysis 2008
Transportation Research Record 2082
The papers in this volume cover such topics as part-day home working, a choice model of residential neighborhood and bicycle ownership, commuter travel behavior changes between 1970 and 2000, travel time in multiple-purpose trips, and route choice under uncertainty. Also examined are accessibility, travel behavior, and new urbanism; traveler responses to real-time information about bus arrivals; travel behavior of elderly women in rural and small urban areas of North Dakota; the influence of urban form on work travel behavior; and more.

2008; 175 pp.; TRB affiliates, $51; TRB nonaffiliates, $68. Subscriber category: planning and administration (IA).

Safety Data, Analysis, and Modeling
Transportation Research Record 2083
A data-driven perspective on safety risk management, macrolevel annual safety performance mea-

TRB PUBLICATIONS *(continued)*

sures, accident modification factors, identification of hazardous road locations, automated analysis of accident exposure, a new simulation-based surrogate safety measure, hit-and-run crashes, the effect of speed limit increases on injury severity, a nested logit model of traffic flow on freeway ramps, intelligent transportation system data for assessing freeway safety, crash prediction models for rural highways, and a methodology for identifying causal factors of accident severity are some of the subjects studied in this volume.

2008; 198 pp.; TRB affiliates, $52.50; TRB nonaffiliates, $70. Subscriber category: safety and human performance (IVB).

Pavement Management Systems and Rehabilitation
Transportation Research Record 2084
The 15 papers in this volume explore statistical modeling, semiautomated and automated pavement distress data collection, Louisiana's pavement management system, a model for regional pavement preservation resource allocation, probabilistic analysis of pavement distress ratings, and optimal pavement maintenance decisions. Also examined are sustainable pavements, optimization for pavement management, a protocol for bituminous surface treatment, the use of a rolling dynamic deflectometer in forensic studies and rehabilitation, long-term field performance of recycled asphalt, reflective cracking, and rehabilitation design of jointed plain concrete pavement.

2008; 138 pp.; TRB affiliates, $45; TRB nonaffiliates, $60. Subscriber category: pavement design, management, and performance (IIB).

Network Modeling 2008
Transportation Research Record 2085
Authors investigate an algorithm for solving stochastic problems of transportation network analysis, simultaneous offline estimation of dynamic origin–destination flows, application of the generalized Wardrop principle in regional transportation, measurement of uncertainty costs using dynamic traffic simulations, stochastic user equilibrium traffic assignment models, an algorithm for the equilibrium signal-setting problem, modeling user responses to pricing, and more.

2008; 143 pp.; TRB affiliates, $45; TRB nonaffiliates, $60. Subscriber category: planning and administration (IA).

Intelligent Transportation Systems and Vehicle–Highway Automation 2008
Transportation Research Record 2086
In this volume's 16 papers, cell phone traffic data are analyzed, along with real-time vehicle classification using inductive loop signature data, vision-based speed sensing, benefits and costs of advanced traffic management components, and more. Also examined are subjects such as traveler information effects on commercial and noncommercial users, determinants of route choice and the value of traveler information, vehicle–infrastructure integration, and adaptive intelligent speed adaptation systems.

2008; 139 pp.; TRB affiliates, $45; TRB nonaffiliates, $60. Subscriber category: highway operations, capacity, and traffic control (IVA).

Pavement Testing and Design 2008
Transportation Research Record 2087
This issue explores extended-life hot-mix asphalt pavement design, the Minnesota Road Research Project, perpetual pavement response to vehicular loading, repeatability of asphalt strain measurements, adaptation of the Mechanistic–Empirical Pavement Design Guide (MEPDG) for design of Minnesota low-volume road concrete pavements, conversion of testing frequency to loading time applied to MEPDG, database support for MEPDG, pavement rutting performance prediction by the integrated Weibull approach, and other subjects.

2008; 141 pp.; TRB affiliates, $45; TRB nonaffiliates, $60. Subscriber category: pavement design, management, and performance (IIB).

Traffic Flow Theory and Characteristics 2008
Transportation Research Record 2088
Traffic flow is examined in this collection of papers, with topics covering the use of speed–flow relationships for microsimulation calibration, calibrations of traffic-flow microsimulation models, accident-free car-following models, freeway oscillation characteristics, on-ramp metering, analysis of a recurrent bottleneck, system-optimal dynamic traffic assignment

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TRB PUBLICATIONS *(continued)*

in a many-to-one network, lane selection model for urban intersections, the ability of Newell's car-following model to reproduce trajectories, driver behavior modeling as a sequential risk-taking task, and speed distributions on two-lane highways.

2008; 226 pp.; TRB affiliates, $54.75; TRB nonaffiliates, $73. Subscriber category: highway operations, capacity, and traffic control (IVA).

Network Analysis for Policy and Logistics
Transportation Research Record 2089
Authors share findings on emergency evacuation planning, a heuristic framework for optimizing hurricane evacuation operations, integration of equity objectives in a road network design model, dynamic shortest-path algorithm for continuous arc travel times for incident management, incorporation of environmental justice measures into equilibrium-based network design, a solution algorithm for long-haul freight network design, and optimization of distance-based fares and headway of an intercity transportation system.

2008; 109 pp.; TRB affiliates, $41.25; TRB nonaffiliates, $55. Subscriber category: planning and administration (IA).

Network Modeling 2009, Vol. 1
Transportation Research Record 2090
Presented are 12 papers on dynamic traffic assignment model calibration, transport network capacity under demand uncertainty, reactive tabu search for combined dynamic user equilibrium and traffic signal optimization, a game theoretic approach for measuring network reliability, real-time control of buses in a transit corridor, dynamic pricing with heterogeneous users, discrete network designs with demand uncertainty, Pareto optimal multiobjective optimization for robust transportation network design, freight transportation network design, and more.

2009; 114 pp.; TRB affiliates, $42.75; TRB nonaffiliates, $57. Subscriber category: planning and administration (IA).

Network Modeling 2009, Vol. 2
Transportation Research Record 2091
This volume investigates the impact of turn delay uncertainties on route choice behavior in signalized road networks, long-haul shipment optimization for less-than-truckload carriers, an adaptive algorithm for a discrete and dynamic berth-scheduling problem, user equilibrium in a bottleneck, a transit-based evacuation plan within a contraflow simulation environment, implementation issues for the reliable a priori shortest path problem, departure time choice under stochastic networks, nonnegative Pareto-improving tolls with multiclass network equilibria, integrated evacuation network optimization and emergency vehicle assignment, a demand and supply model for a short-notice evacuation, and hybrid route choice modeling in dynamic traffic assignment.

2009; 107 pp.; TRB affiliates, $42.75; TRB nonaffiliates, $57. Subscriber category: planning and administration (IA).

Operational Effects of Geometrics and Access Management 2009
Transportation Research Record 2092
The eight papers in this volume examine the relationship between roadway characteristics and speed variation; low-cost safety concepts for two-way, stop-controlled rural intersections; speed prediction along horizontal curves on two-lane highways; the use of driver steering behavior to find desirable spiral lengths for horizontal curves; safety analysis of interchanges; collision prediction models for three-dimensional alignments of two-lane rural highways; prioritizing access management implementation; and the effects of grade on the speed and travel time of vehicles entering driveways.

2009; 74 pp.; TRB affiliates, $39; TRB nonaffiliates, $52. Subscriber category: highway operations, capacity, and traffic control (IVA).

Pavement Management 2009, Vol. 1
Transportation Research Record 2093
Authors explore the quality of automated pavement distress data collection, long-term pavement performance profile data for flexible pavements, a user-oriented model for pavement funding decisions, environmental perspectives to pavement management, axle load spectra, crack prediction methodology, mechanistic–empirical modeling in network-level pavement management, infrastructure assessment, a management framework for rural roads in developing countries, precision of circular track meters and dynamic friction testers, and more.

2009; 135 pp.; TRB affiliates, $46.50; TRB nonaffiliates, $62. Subscriber category: pavement design, management, and performance (IIB).

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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, 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, geology, law, environmental concerns, energy, etc.). Manuscripts should be no longer than 3,000 to 4,000 words (12 to 16 double-spaced, typed pages). Authors also should provide appropriate and professionally drawn line drawings, charts, or tables, and glossy, black-and-white, high-quality photographs with corresponding captions. 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.

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◆ All manuscripts should be supplied in 12-point type, double-spaced, in Microsoft Word 6.0 or WordPerfect 6.1 or higher versions, on a diskette 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 or greater. 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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Investing in Our Transportation Future

Bold Ideas to Meet Big Challenges

Transportation policy makers, practitioners, and researchers are facing manifold challenges: addressing transportation's role in building and maintaining a strong economy, revamping transportation financing and funding programs, working towards zero fatalities on the nation's highways, achieving climate change and energy security targets by 2050, enhancing and preserving the transportation infrastructure, eliminating congestion, and more.

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