Best Practices for Road Weather Management

Version 2.0

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There is a perception that transportation managers can do little about weather. However, three types of mitigation measures may be employed in response to environmental threats: advisory, control, and treatment strategies. Advisory strategies provide information on prevailing and predicted conditions to both transportation managers and motorists. Control strategies alter the state of roadway devices to permit or restrict traffic flow and regulate roadway capacity. Treatment strategies supply resources to roadways to minimize or eliminate weather impacts. Many treatment strategies involve coordination of traffic, maintenance, and emergency management agencies. These road weather management strategies are employed in response to various weather threats including fog, high winds, snow, rain, ice, flooding, tornadoes, hurricanes, and avalanches.

This report contains 30 case studies of systems in 21 states that improve roadway operations under inclement weather conditions. Each case study has six sections including a general description of the system, system components, operational procedures, resulting transportation outcomes, implementation issues, as well as contact information and references. Appendix A presents an overview of environmental sensor technologies. Appendix B is an acronym list. Appendix C contains online resources, including 39 statewide road condition web sites. Appendix D tabulates hundreds of road weather publication titles, abstracts and sources.

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Introduction

Weather threatens surface transportation nationwide and impacts roadway safety, mobility, and productivity. Weather affects roadway safety through increased crash risk, as well as exposure to weather-related hazards. Weather impacts roadway mobility by increasing travel time delay, reducing traffic volumes and speeds, increasing speed variance (i.e., a measure of speed uniformity), and decreasing roadway capacity (i.e., maximum rate at which vehicles can travel). Weather events influence productivity by disrupting access to road networks, and increasing road operating and maintenance costs.

There is a perception that transportation managers can do little about weather. However, three types of road weather management strategies may be employed in response to environmental threats: advisory, control, and treatment Strategies. Advisory strategies provide information on prevailing and predicted conditions to both transportation managers and motorists. Control strategies alter the state of roadway devices to permit or restrict traffic flow and regulate roadway capacity. Treatment strategies supply resources to roadways to minimize or eliminate weather impacts. Many treatment strategies involve coordination of traffic, maintenance, and emergency management agencies. These mitigation strategies are employed in response to various weather threats including fog, high winds, snow, rain, ice, flooding, tornadoes, hurricanes, and avalanches.

This report contains 30 case studies of systems in 21 states that improve roadway operations under inclement weather conditions. Each case study has six sections including a general description of the system, system components, operational procedures, resulting transportation outcomes, implementation issues, as well as contact information and references.

Appendix A presents an overview of environmental sensor technologies. Appendix B is an acronym list. Appendix C contains online resources, including 39 statewide road condition web sites. In Appendix D hundreds of road weather publication titles, abstracts and sources are tabulated.

Alabama DOT Low Visibility Warning System

In March 1995 a fog-related crash involving 193 vehicles occurred on the seven-mile (11.3-kilometer) Bay Bridge on Interstate 10. This crash prompted the Alabama Department of Transportation (DOT) to deploy a low visibility warning system. The warning system was integrated with a tunnel management system near Mobile, Alabama.

System Components: Six sensors with forward-scatter technology are used to measure visibility distance. The visibility sensors are installed at roughly one-mile (1.6-kilometer) intervals along the bridge. Traffic flow is monitored with a Closed Circuit Television (CCTV) surveillance system. Video from 25 CCTV cameras is displayed on monitors in the tunnel control room. Field sensor data are transmitted to a central computer in the control room via a fiber optic cable communication system. The computer controls 24 Variable Speed Limit (VSL) signs and five Dynamic Message Signs (DMS), which are used to display advisories or regulations to motorists.

System Operations: Two system operators staff the tunnel control room 24 hours a day. When fog is observed via CCTV operators consult the central computer, which displays visibility sensor measurements by zone. The warning system is divided into six zones which can operate independently. Depending on visibility conditions in each zone, operators may display messages on DMS and alter speed limits with VSL signs (as shown in Table 1).

Table 1 – Alabama DOT Low Visibility Warning System Strategies

Visibility Distance	Advisories on DMS	Other Strategies
Less than 900 feet (274.3 meters)	"FOG WARNING"	Speed limit at 65 mph (104.5 kph)
Less than 660 feet (201.2 meters)	"FOG" alternating with "SLOW, USE LOW BEAMS"	• "55 MPH" (88.4 kph) on VSL signs • "TRUCKS KEEP RIGHT" on DMS
Less than 450 feet (137.2 meters)	"FOG" alternating with "SLOW, USE LOW BEAMS"	• "45 MPH" (72.4 kph) on VSL signs • "TRUCKS KEEP RIGHT" on DMS
Less than 280 feet (85.3 meters)	"DENSE FOG" alternating with "SLOW, USE LOW BEAMS"	• "35 MPH" (56.3 kph) on VSL signs • "TRUCKS KEEP RIGHT" on DMS • Street lighting extinguished
Less than 175 feet (53.3 meters)	I-10 CLOSED, KEEP RIGHT, EXIT ½ MILE	Road Closure by Highway Patrol

When the speed limit is reduced, notices are automatically faxed to the DOT Division Office, the Highway Patrol, and local law enforcement agencies in Mobile and neighboring jurisdictions (i.e., Daphne and Spanish Ford). If necessary, system operators request that the Highway Patrol utilize vehicle guidance to further reduce traffic speeds. During vehicle guidance operations a patrol vehicle with flashing lights leads traffic across the bridge at a safe speed.

Transportation Outcome: Although labor-intensive, the warning system has improved safety by reducing average speed and minimizing crash risk in low visibility conditions.

Implementation Issues: The original system design included a vehicle detection subsystem, backscatter visibility sensors, and automated activation of signs. Bridge deck construction precluded the installation of inductive loop detectors and vibration prevented the use of microwave vehicle detectors. Thus, the vehicle detection subsystem had to be eliminated. Visibility sensors with backscatter technology were deployed along the bridge in Fall 1999. However, problems with accuracy and reliability caused the DOT to replace them with forward-scatter visibility sensors in 2000.

The tunnel control room was modified to incorporate monitoring and control functions for the warning system, which began operating in September 2000. By 2004, control of the warning system will be transferred to a new Traffic Management Center that is currently under construction.

Contact(s):

- Gerald Criswell, Alabama DOT, Tunnel Maintenance Supervisor, 251-432-4069, criswellg@dot.state.al.us.
- M. R. Davis, Alabama DOT, Division Maintenance Engineer, 251-470-8230, davisr@dot.state.al.us

Reference(s):

- Schreiner, C., “State of the Practice and Review of the Literature: Survey of Fog Countermeasures Planned or in Use by Other States,” Virginia Tech Research Council, October 2000.
- U.S. DOT, “Mobile, Alabama Fog Detection System,” 2001 Intelligent Transportation Systems (ITS) Projects Book, FHWA, ITS Joint Program Office.

Keyword(s): fog, visibility, low visibility warning system, freeway management, speed management, traffic management, law enforcement, traveler information, advisory strategy, traffic control, control strategy, bridge, lighting, high-profile vehicles, motorist warning system, closed circuit television (CCTV), dynamic message sign (DMS), institutional issues, speed, safety

California DOT Motorist Warning System

Freeways in the Stockton-Manteca area of San Joaquin County, California are prone to low visibility conditions. Visibility is reduced by wind-blown dust in the summer and dense, localized fog in the winter. In the past low visibility has contributed to numerous chain-reaction collisions in the San Joaquin Valley. To improve roadway safety on southbound Interstate 5 and westbound State Route 120, the California Department of Transportation (DOT)—also known as Caltrans—implemented an automated system to warn motorists of driving hazards.

System Components: Traffic and weather data are collected from 36 vehicle detection sites and nine Environmental Sensor Stations (ESS) deployed along the freeways, as shown in Figure 1. Detection sites are comprised of paired inductive loop detectors and Caltrans Type 170 controllers, which run software with speed measurement algorithms. Each ESS includes a rain gauge, a forward-scatter visibility sensor, wind speed and direction sensors, a relative humidity sensor, a thermometer, a barometer, and a remote processing unit. Traffic and environmental data are transmitted from the field to a networked computer system in the Stockton Traffic Management Center (TMC) via dedicated, leased telephone lines. The central computer system automatically displays advisories on nine roadside Dynamic Message Signs (DMS).

Figure 1 – California DOT ESS

System Operations: Three central computers control operation of the motorist warning system. A meteorological monitoring computer records and displays ESS data. A traffic monitoring computer uses a program developed by Caltrans operations staff to record, process, and display traffic volume and speed data. Through interfaces with the monitoring computers, a DMS control computer accesses environmental and average speed data to assess driving conditions. Based upon established thresholds for vehicle speed, visibility distance, and wind speed; proprietary control software automatically selects and displays warnings on DMS as shown in Table 2. TMC operators also have the capability to manually override messages selected by the system.

Table 2 – California DOT Motorist Warning System Messages

Conditions	Displayed Message
Average speed between 11 and 35 mph (56.3 kph)	"SLOW TRAFFIC AHEAD"
Average speed less than 11 mph (17.7 kph)	"STOPPED TRAFFIC AHEAD"
Visibility distance between 200 and 500 feet (152.4 meters)	"FOGGY CONDITIONS AHEAD"
Visibility distance less than 200 feet (61.0 meters)	"DENSE FOG AHEAD"
Wind speed greater than 35 mph	"HIGH WIND WARNING"

When visibility falls below 200 feet these advisory strategies are supplemented by vehicle guidance operations carried out by the Department of Emergency Management. On major freeway routes, California Highway Patrol officers use flashing amber lights atop patrol vehicles to group traffic into platoons, which are lead at a safe pace (typically 50 mph or 80.4 kph) through areas with low visibility.

Transportation Outcome: The motorist warning system improved highway safety by significantly reducing the frequency of low-visibility crashes. Nineteen fog-related crashes occurred in the four-year period before the system was deployed. Since the system was activated in November 1996, there have been no fog-related crashes. Vehicle guidance operations improve also safety by minimizing crash risk.

Implementation Issues: Designers considered local conditions and potential safety benefits to assess the feasibility of a warning system. Limited sight distances, converging traffic patterns, and frequent low visibility events factored into the decision to deploy a motorist warning system on selected freeways. These factors also guided development of system requirements. The system had to have the capability to continuously and automatically collect, process, and display information. System designers examined historical crash data to establish a baseline for evaluation of the motorist warning system.

System components include commercially available products as well as hardware and software developed by Caltrans operations staff. The meteorological monitoring system was procured as a turnkey solution. The ESS manufacturer installed field devices, the monitoring computer, and proprietary processing software. Caltrans personnel designed and installed the traffic monitoring and DMS control components using standardized and commercial off-the-shelf products to minimize procurement costs and deployment time. Because display technologies had to be visible in adverse conditions, incandescent DMS were selected based upon their readability in low visibility conditions. After system elements were procured, installed, and calibrated operational procedures were developed, maintenance schedules and contracts were arranged, and traffic operations personnel were trained.

Future system expansion was taken into account by designers. Anticipated enhancements include the integration of the monitoring and control computers into a single workstation, incorporation of a Closed Circuit Television surveillance system for visual verification of roadway conditions, inclusion of a Highway Advisory Radio system to supplement visual warning messages, and testing of Variable Speed Limits and pavement lights. An interface to the California Highway Patrol information system is also expected.

Contact(s):

- Clint Gregory, Caltrans District 10, Electrical Systems Branch Chief, 209-948-7449, clint_gregory@dot.ca.gov.
- Ted Montez, California Highway Patrol, Public Information Officer, 209-943-8666, tmontez@chp.ca.gov.

Reference(s):

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Keywords: fog, dust, wind, visibility, motorist warning system, freeway management, traffic management, emergency management, law enforcement, advisory strategy, traveler information, vehicle guidance, control strategy, vehicle detection, environmental sensor station (ESS), dynamic message signs (DMS), safety

City of Palo Alto, California Flood Warning System

In February 1998 several days of heavy rainfall caused the San Francisquito creek to overflow its banks flooding the City of Palo Alto, California. City residents and emergency managers had no advanced warning of the flood. This event prompted the City to develop a flood warning system. This web-based system has become an integral part of the City's emergency management operations. When flood conditions exist, emergency managers utilize automated surveillance techniques to supply information to the public.

System Components: Water level sensors, a rain gauge, flood basin detectors, tide monitors, and a Closed Circuit Television camera are used to assess field conditions. Ultrasonic sensors were installed at five bridge locations to detect high water or flood conditions. The ultrasonic water level sensors use acoustics or sound waves to measure the distance from a transducer to the water surface. Water level readings are transmitted to the water, gas, and storm drain Supervisory Control and Data Acquisition (SCADA) system via the City's telephone and radio communication networks. A Digital Subscriber Line transmits still video images from one bridge site to the Emergency Operations Center (EOC).

System Operations: Real-time and historical water level data and video images are posted on the City's "Creek Level Monitor" web site for viewing at the EOC and by Palo Alto residents (see Figure 2). Current water level, 12-hour water level trend, 24-hour rainfall, annual rainfall, current temperature, and tidal data are updated every minute on the SCADA system computer and posted on the server for website updates every three minutes.

Emergency managers access this information to plan response actions and to alert residents. In the event of a flood threat, an automatic telephone warning system at the EOC dials all City residents and businesses in threatened areas to advise of potential flood conditions.

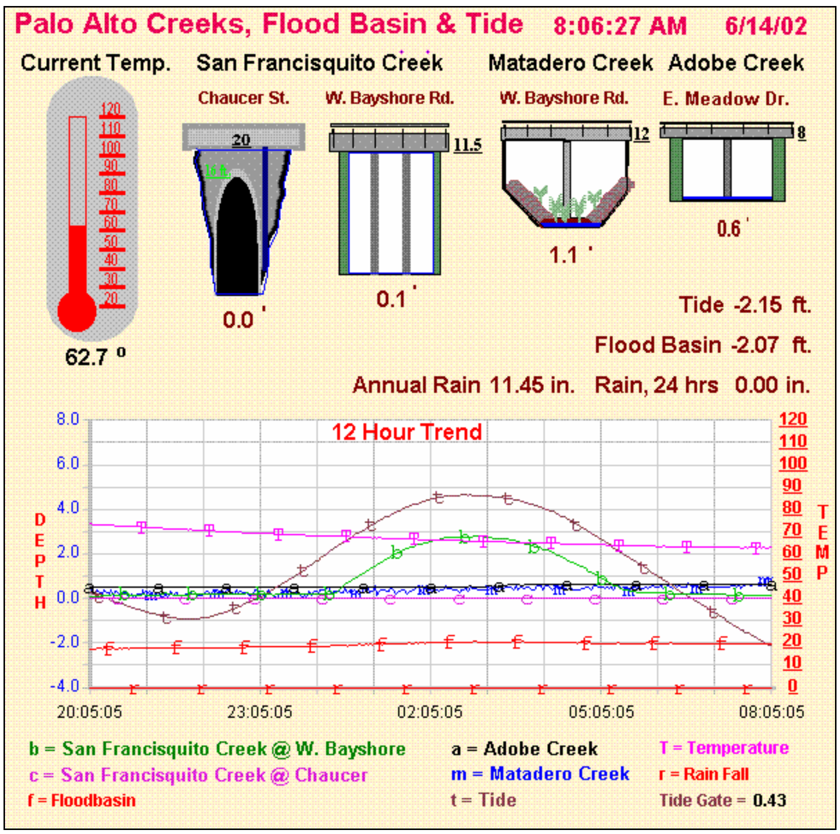

Figure 2 – City of Palo Alto, CA "Creek Level Monitor" Web Page
(*www.city.palo-alto.ca.us/earlywarning*)

Transportation Outcome: Prior to installation of the flood warning system, emergency management personnel traveled to bridge locations to visually monitor the storm drain system and physically check water levels. Drain system status and water level readings were radioed to the EOC every 20 minutes. By eliminating the need for field measurements, the monitoring system has enhanced the productivity of City staff and provided timely access to traveler information to improve public safety. City residents may utilize information to make travel and safety decisions.

Implementation Issues: The warning system project was initiated due to resident complaints following the 1998 flood. The Public Works Operations department conducted a study of the City's bridge locations and wireline communication systems, assessed sensor technologies, and deduced that water level sensors could be deployed and integrated with the existing SCADA system. Non-intrusive sensors were selected over other technologies (e.g., pressure transmitters, bubblers, floats) due to concerns about floating or submerged debris that could damage equipment placed in the creeks.

The original intent of the system was to furnish emergency managers with precipitation and hydrologic data, which would serve as decision support for providing information to the public. After determining hardware, software, and interface requirements system designers decided to add the web-based information dissemination feature to better serve city residents.

Contact(s):

- John Ballard; City of Palo Alto, California; Public Works Operations; 650-496-5935.

References:

- Kulisch, E., "System Monitors Flood-prone Creeks", www.civic.com/civic/articles/2001/0122/web-flood-01-26-01.asp
- City of Palo Alto, "Creek Level Monitor Website: How Do We Do It?" http://www.city.palo-alto.ca.us/earlywarning/how.html.

Keywords: rain, flooding, flood warning system, emergency management, traveler information, advisory strategy, bridge, remote sensing, closed circuit television (CCTV), internet/web site, safety, productivity

City of Aurora, Colorado Maintenance Vehicle Management System

In 1998 the City of Aurora, Colorado deployed a system to monitor the operation of maintenance vehicles, including snowplows and street sweepers. The system has facilitated real-time communication between maintenance managers and vehicle drivers, enhanced productivity, and improved public relations.

System Components: The maintenance vehicle management system is comprised of in-vehicle devices, central control systems, and a wireless communication system. Twenty snowplows are equipped with integrated display, messaging and communication devices. With these in-vehicle devices, text messages can be entered with a keypad, displayed to drivers, and transmitted between maintenance vehicles and central computers via a Cellular Digital Packet Data modem. These devices send position data to a central computer every 20 seconds. Each in-vehicle device (shown in Figure 3) also includes an interface to vehicle systems and a Global Positioning System receiver, which is used to automatically track equipment status and vehicle location from control computers in two central facilities.

Figure 3 – City of Aurora, CO In-Vehicle Device

System Operations: Central control systems allow maintenance managers to transmit pre-programmed or customized messages to a single plow, a selected group of plows, or all snowplows. Managers can monitor road treatment activities with a map display of snowplow locations to assess which routes have been serviced, determine when a plow is off of its designated route, and plan route diversions as needed. The status of vehicle systems may also be monitored to ascertain plow position (i.e., plow up or down) and to determine when treatment materials are being dispensed (i.e., spreader on or off. The management system is utilized for treatment strategy planning, real-time operations monitoring, and post-event analysis.

Transportation Outcome: By using the management system to track maintenance vehicles, managers have minimized treatment costs and improved productivity by 12 percent. Additionally, managers can easily access the system and provide accurate information to citizens who call the City to inquire about plowing of a particular street.

Implementation Issues: The City contracted with a private vendor to furnish and install in-vehicle and central components of the management system. System deployment was expedited by involving the City's information systems staff in planning and design, and by hiring a local system integrator to resolve compatibility issues related to the various component and communications providers.

Contact(s):

- Lynne Center; City of Aurora, Colorado Public Works Department, 303-326-8200, lcenter@ci.aurora.co.us.

Reference(s):

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- Anderson, E. and Nyman, J., "Southeast Michigan Snow and Ice Management (SEMSIM): Final Evaluation at End of Winter Season Year 2000," prepared for the Road Commission of Oakland County, September 2000.

Keywords: winter storm, snow, ice, maintenance vehicle management system, winter maintenance, treatment strategy, advisory strategy, maintenance vehicle, productivity

Florida DOT Motorist Warning System

The tropical climate in south Florida typically causes heavy rainfall in the afternoon. A Florida Department of Transportation (DOT) study of the Florida Turnpike/Interstate 595 interchange found that 69 percent of crashes on a two-lane, exit ramp occurred when the pavement was wet and that only 44 percent of these wet-pavement crashes happened when it was raining. The wet-pavement crash rate on this ramp was three times higher than the national average and nearly four times greater than the statewide average. To demonstrate how advanced warning of the safe travel speed under wet pavement conditions can reduce crash risk, the DOT installed an automated motorist warning system on the ramp, which has a sharp curve and an upgrade.

System Components: As shown in Figure 4, a sensor embedded in the road surface was used to monitor pavement condition (i.e., dry or wet). On a pole adjacent to the ramp, a microwave vehicle detector was installed to record traffic volume and vehicle speed, and a precipitation sensor was mounted to verify rainfall events. A pole-mounted enclosure housed a remote processing unit (RPU), which was hard-wired to flashing beacons atop static speed limit signs. A dedicated telephone line was also connected to the RPU to facilitate data retrieval from an Internet server in the turnpike operations center located in Pompano Beach.

Figure 4 – Florida DOT Pavement Sensor

System Operations: The RPU collected, processed, and stored traffic and pavement data from the sensors. When pavement moisture was detected, the RPU activated the flashing beacons to alert motorists that speeds should not exceed the posted limit of 35 mph (56.3 kph).

Transportation Outcome: The warning system improved safety by reducing vehicle speeds and promoting more uniform traffic flow when the ramp was wet. In light rain conditions, the 85th percentile speed decreased by eight percent from 49 to 45 mph (78.8 to 72.4 kph). During heavy rain, there was a 20 percent decline in 85th percentile speed from 49 to 39 mph (78.8 to 62.7 kph). Speed variance was reduced from 6.7 to 5.7 mph (10.8 to 9.2 kph) in light rain and from 6.1 to 5.6 mph (9.8 to 9.0 kph) in heavy rain. Thus, speed variance decreased by eight to 15 percent, minimizing crash risk. Four crashes occurred during the first week of warning system activation. Three happened when the pavement was wet and one occurred during rainfall. After this initial week, there were no reported crashes the during nine-week evaluation period.

Implementation Issues: The DOT evaluated the geometry, road surface conditions, and crash history of the ramp, which had the highest travel speeds and the highest crash rate of all the ramps in the interchange. It was concluded that wet pavement and excessive travel speeds were the primary factors contributing to run-off-the-road crashes that occurred at the beginning of the sharp ramp curve. These conditions warranted the development and demonstration of a motorist warning system. The demonstration project was a joint effort of the Florida DOT, the University of South Florida, and a private vendor.

The DOT erected a 25-foot (7.6-meter) equipment mounting pole 8 feet (2.4 meters) from the edge of the travel lane, installed flashing beacons on two existing ramp signs, and arranged power and telephone service connections. The pole was installed approximately 180 feet (55 meters) in advance of the speed limit signs. The vendor furnished and installed field sensors, the RPU, and the Internet server. The pavement sensor was installed at the lowest elevation point of the ramp.

After installation, the project partners verified the accuracy and reliability of system components. Vehicle detector data accuracy was validated by comparing speed measurements with those from a hand-held radar gun. The private vendor calibrated the dry-wet threshold of the pavement sensor. Beacon activation by the RPU and field data downloading to the turnpike operations center were successfully tested. Through the server, the University retrieved pavement condition, speed, and volume data at one-minute intervals to evaluate system performance before and after activation.

Contact(s):

- Michael Pietrzyk, University of South Florida, Center for Urban Transportation Research (CUTR), 813-974-9815, pietrzyk@cutr.eng.usf.edu.

Reference(s):

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Keywords: rain, pavement condition, pavement friction, motorist warning system, freeway management, traffic management, advisory strategy, pavement sensor, vehicle detection, speed, driver behavior, crashes, safety

City of Clearwater, Florida Weather-Related Signal Timing

The City of Clearwater, Florida operates a computerized traffic control system with 145 signals. City traffic managers have developed a unique rain preemption feature that modifies signal timing during rain events to clear traffic from Clearwater Beach, which is a prime destination for tourists visiting Orlando and Tampa Bay. Thunderstorms typically occur in the afternoon, causing significant sudden increases in traffic exiting the beach via the Memorial Causeway (i.e., State Route 60), which is shown in Figure 5.

System Components: An electric rain gauge is mounted on top of a traffic signal pole near the beach and connected to the signal controller. Vehicle detectors on the causeway are used to measure the length of traffic queues on inbound lanes. A twisted pair cable communication system connects the rain gauge, vehicle detectors, and controllers to a signal system computer at the City's Traffic Operations Center (TOC).

System Operations: During peak beach hours, the central computer activates the rain gauge with a time-of-day command. When the rain gauge senses a predetermined rainfall amount, the signal system computer issues a preemption command to 14 downtown traffic signals along the Route 60 corridor. These signal controllers execute new timing plans with longer green times for inbound approaches. The computer selects the appropriate timing plan based upon traffic volumes. When the volume returns to normal levels, the central computer restores normal signal timing plans.

Figure 5 – City of Clearwater, FL Map

Transportation Outcome: By modifying traffic signal timing in response to rain events, the signal system computer prevents traffic congestion and enhances roadway mobility.

Implementation Issues: The City of Clearwater was one of the first jurisdictions to deploy an Urban Traffic Control System (UTCS) with the assistance of federal funds. The UTCS included preemption features for drawbridges and railroad crossings. City personnel assessed localized conditions, observed driver behavior during thunderstorms, and determined that a similar feature could be implemented for rain events affecting Clearwater Beach. The City's signal technicians installed a commercially available rain gauge at an intersection that is adjacent to a parking garage used by beach visitors. The signal system engineer modified existing UTCS preemption algorithms to alter signal timing based upon rainfall and traffic volume data.

In 2003 the City's central UTCS will be upgraded from a mainframe computer system to a PC-based system to support adaptive signal control as part of a county-wide, federally-funded Congestion Mitigation and Air Quality project. Closed Circuit Television cameras and Dynamic Message Signs will also be installed on the City's primary corridors to facilitate more efficient incident management and timely dissemination of traveler information. Pinellas County will operate a TOC and utilize a Wide Area Network to facilitate data sharing between the county TOC and TOCs located in the cities of Clearwater and St. Petersburg.

Contact(s):

- Paul Bertels; City of Clearwater, Traffic Operations Manager; 727-562-4794; pbertels@clearwater-fl.com.
- Glen Weaver; City of Clearwater, Signal System Engineer; 727-562-4794.

Reference(s):

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Keywords: rain, weather-related signal timing, arterial management, traffic management, traffic control, control strategy, vehicle detection, volume, mobility

Idaho DOT Anti-Icing/Deicing Operations

In 1996 maintenance managers with the Idaho Department of Transportation (DOT) began an anti-icing program on a 29-mile (47-kilometer) section of US Route 12. This highway segment is located in a deep canyon and is highly prone to snowfall and pavement frost (i.e., black ice) due to sharp curves and shaded areas. An anti-icing chemical is applied to road surfaces as an alternative to spreading high quantities of abrasives. Abrasives are thrown to the roadside by passing vehicles and only improve roadway traction temporarily.

System Components: Winter maintenance managers modified maintenance vehicles for use in anti-icing operations and installed chemical storage tanks. As shown in Figure 6A, trucks with 1,000-gallon (3,785-liter) and 1,500-gallon (5,678-liter) tanks were equipped with spray controls to dispense liquid magnesium chloride. A chemical storage facility with two 6,900-gallon (26,117-liter) storage tanks and an electric pump for chemical circulation and truck loading was located in the Orofino maintenance yard (see Figure 6B).

Figure 6A – Idaho DOT Maintenance Vehicles

Figure 6B – Idaho DOT Chemical Storage Tanks

System Operations: Maintenance managers utilize the Internet to access weather forecast data and identify threatening winter storms or frost events. When an impending threat is predicted, maintenance vehicles are deployed to spray small amounts of the anti-icing chemical on road surfaces before snowfall begins or frost forms. Chemical application rates vary from ten to 50 gallons (37.9 to 189.3 liters) per lane mile, depending on the nature and magnitude of the threat. Maintenance crews regularly check four "indicator areas" along the highway to determine when frost on shoulder lanes begins to migrate into travel lanes. The status of these areas indicates that the road should be retreated to ensure that chemical concentrations are high enough to prevent freezing.

Transportation Outcome: To assess the effectiveness of anti-icing operations, winter road maintenance activities were analyzed for five years prior to the anti-icing program and for three years after implementation. Annual averages of abrasive quantities, labor hours, and winter crashes are shown in Table 3.

Table 3 – Idaho DOT Winter Maintenance Performance Measures
(Annual Averages)

	1992 to 1997 (Without Anti-Icing)	1997 to 2000 (With Anti-Icing)	Percent Reduction
Abrasive Quantities	1,929 cubic yards (1,475 cubic meters)	323 cubic yards (247 cubic meters)	83%
Labor Hours	650	248	62%
Number of Crashes	16.2	2.7	83%

Mobility, productivity, and safety enhancements resulted from the anti-icing treatment strategy. Mobility was improved, as a single application of magnesium chloride was typically effective at improving traction for three to seven days—depending on precipitation, pavement temperature, and humidity. Faster clearing of snow and ice reduced operation costs and enhanced productivity. Safety improvements were realized by reducing the frequency of wintertime crashes.

Implementation Issues: Maintenance managers selected the US Route 12 segment for their anti-icing pilot program due to the high crash rate and high maintenance costs. Relatively mild winter temperatures, hazardous winter road conditions, and moderate traffic volumes also made this roadway a good candidate for anti-icing operations.

Other Idaho DOT maintenance districts had successful anti-icing programs. By consulting other districts and assessing existing vehicles, managers developed treatment equipment requirements. Trucks, previously used to spray weed-killing and other chemicals, were modified to dispense liquid magnesium chloride. After configuring the treatment equipment, crews were trained in all aspects of anti-icing procedures. They learned about various anti-icing chemicals and their properties, chemical application criteria and rates, equipment operation, and progress tracking. As a result of the successful pilot program, anti-icing was expanded to other highways in District 2 and throughout the state.

Contact(s):
- Bryon Breen, Assistant Maintenance Engineer, 208-334-8417, bbreen@itd.state.id.us.

Reference(s):
- Breen, B. D., "Anti Icing Success Fuels Expansion of the Program in Idaho," Idaho Transportation Department, March 2001.

Keywords: snow, ice, winter storm, anti-icing/deicing operations, freeway management, winter maintenance, treatment strategy, internet/web site, forecasts, weather information, maintenance vehicle, chemicals, crashes, mobility, productivity, safety

Idaho DOT Motorist Warning System

The Idaho Department of Transportation (DOT) installed a motorist warning system on a 100-mile (161-kilometer) section of Interstate 84 in southeast Idaho and northwest Utah. This road segment was highly prone to multi-vehicle crashes when blowing snow or dust reduced visibility. From 1988 to 1993, poor visibility contributed to 18 major crashes involving 91 vehicles, 46 injuries, and nine fatalities. While the proportion of trucks on this rural freeway was 33 percent, the percentage of trucks in these crashes was 44 percent. Traffic managers display advisory messages to motorists to influence driver behavior under adverse conditions.

System Components: Road, weather, and traffic condition data are collected by sensor systems and transmitted to a central computer. Environmental Sensor Stations (ESS) detect pavement condition (i.e., dry, wet, or snow-covered), wind speed and direction, precipitation type and rate, air temperature, and relative humidity. Sensors with forward-scatter detection technology measure visibility distance (see Figure 7). Inductive loop detectors record vehicle length (i.e., passenger car or truck), vehicle speed, and travel lane. Warnings of adverse conditions are posted on four roadside Dynamic Message Signs (DMS).

Figure 7 – Idaho DOT Visibility Sensor

System Operations: The central computer records sensor readings every five minutes. When field sensor data indicates that visibility has fallen below a predetermined threshold or that driving conditions are deteriorating, the computer in the Port of Entry control center alerts traffic managers. Based upon prevailing road conditions, traffic managers decide which messages to display and manually activate DMS.

Transportation Outcome: A system evaluation conducted from 1993 to 2000 assessed changes in driver behavior due to road condition data displayed on DMS. The evaluation compared traffic speeds with advisories to speeds without warnings. When traffic managers displayed condition data during high winds (i.e., over 20 mph or 32.2 kph), average speed variance was reduced and average vehicle speed decreased by 23 percent from 54.8 to 42.3 mph (88.1 to 68.0 kph). When high winds occurred simultaneously with moderate to heavy precipitation, average speeds were 12 percent lower. Under these conditions, mean speeds were 47.0 mph (75.6 kph) without advisory information and 41.2 mph (66.2 kph) with warning messages. A 35-percent decline in average vehicle speed occurred when the pavement was snow-covered, wind speeds were high, and warnings were displayed. Average speeds fell from 54.7 to 35.4 mph (87.9 to 56.9 kph). Advisory information presented by traffic managers prompted changes in driver behavior, improving safety and mobility.

Implementation Issues: After determining that a motorist warning system was warranted based upon local traffic patterns, weather conditions, and crash history; traffic managers assessed three different types of visibility sensors. Tests were conducted to determine the accuracy of visibility measurements in a rural setting and to select the most reliable and cost effective sensor. System operators used a Closed Circuit Television (CCTV) surveillance system to evaluate visibility sensors.

A CCTV camera was pointed at five roadside target signs equipped with flashing lights. The target signs were positioned along the interstate at known distances from the camera (i.e., 250, 500, 850, 1,200, and 1,500 feet or 76, 152, 259, 366, and 457 meters). Actual roadway conditions were confirmed by viewing video images of target signs. After field sensors were selected, their locations were determined and power supply and communications systems were designed. To ensure that weather and traffic data was collected at the same location, ESS were installed within a few hundred feet of the vehicle detection sites.

System integration issues arose due to the various field data types and formats, hardware and software incompatibility, as well as communication system and power system failures. For example, the software used to control two of the DMS was not compatible with the central computer. Because leased telephone lines in this rural area were not reliable for transmission of sensor data at the desired frequency, a dedicated telephone cable was installed from the system location to the control center. Power supply reliability was also a concern. Numerous power outages, shortages, and surges damaged field and central components. Uninterruptible power supplies were installed to address these problems.

In the future the Idaho DOT plans to upgrade obsolete field hardware (e.g., DMS with rotating drum technology) and the central control system (e.g., replacing DOS-based software). Other enhancements may include the deployment of addition DMS and a Variable Speed Limit system.

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Keywords: visibility, dust, wind, precipitation, snow, motorist warning system, freeway management, traffic management, advisory strategy, traveler information, vehicle detection, environmental sensor station (ESS), dynamic message signs (DMS), closed circuit television (CCTV), driver behavior, speed, safety, mobility

Michigan Maintenance Vehicle Management System

Four road maintenance agencies and a regional transit authority worked together to implement a management system for maintenance vehicles in southeastern Michigan. Partners include the City of Detroit Department of Public Works, the Road Commission for Oakland County, the Road Commission of Macomb County, the Wayne County Department of Public Services, and the Suburban Mobility Authority for Regional Transportation. The four agencies, who maintain over 15,000 road miles in the region, formed the Southeast Michigan Snow and Ice Management (SEMSIM) partnership in 1998.

System Components: The maintenance vehicle management system consists of snowplow systems, a communication system, and central systems. Snowplow systems include sensors, automated controls, and in-vehicle devices. Environmental sensors are mounted on snowplows to record air temperature and pavement temperature. Vehicle status sensors monitor the position of each snowplow (i.e., location, direction and speed), plow position (i.e., up/down), and material application (i.e., salt on/off, application rate). Each maintenance vehicle, shown in Figure 8, has automated application controls. Computerized salt spreaders automatically adjust the application rate based upon the speed of the snowplow.


Figure 8 – Michigan Maintenance Vehicle

In-vehicle devices integrate display, text messaging, and data communication capabilities. These devices include interfaces to snowplow systems and Global Positioning System receivers, which are used for automated vehicle location. The communication backbone is owned and operated by the regional transit authority. The authority's 900 MHz radio communication system transmits environmental and status data from in-vehicle devices to the transit management center. A Local Area Network, an Integrated Services Digital Network and multiple dial-up telephone lines are used to transmit data from the management center to central computers accessed by both maintenance managers and transit dispatchers.

System Operations: Central computers display a map-based interface that maintenance managers view to identify weather threats, track snowplow locations, monitor treatment activities, and plan route diversions if necessary. Each maintenance vehicle appears on the map with a color-coded trace indicating where plows have been and what treatment has been applied (e.g., spreading salt, plow down). Text messages from managers, such as route assignments, may be displayed to drivers on the in-vehicle devices. With these devices, drivers can send messages to managers, as well as view temperature measurements and salt gauge.

The maintenance vehicle management system can be used to plan treatment strategies, monitor real-time operations, and conduct post-event analysis. Post-event analysis provides maintenance managers with statistics (e.g., driver hours, truck miles, material applied) that can help reduce the costs of future winter maintenance operations. Environmental data from the plows also serves as decision support for transit dispatchers, who utilize this information to make scheduling and routing decisions during winter storms.

Transportation Outcome: SEMSIM partners have improved agency productivity by implementing the maintenance vehicle management system. With the system, managers can identify the most efficient treatment routes, reduce equipment costs, and share resources. Automated salt application controls minimize material costs. The system also improves roadway safety and mobility by allowing the partners to assess changing weather conditions and quickly respond to effectively control snow and ice.

Although each agency had different types of snowplows, with dissimilar equipment, and diverse operational procedures, this project has facilitated interagency communication that benefits both the public and partners. The SEMSIM partners can collectively procure equipment and services at lower costs than individual agencies. Additionally, the partners have agreed to allow snowplows to cross jurisdictional lines to assist one another with road treatment activities when necessary.

Implementation Issues: The SEMSIM project is funded with federal grants and matching contributions (i.e., 20 percent) by each partner. Phase one of the project was initiated in October 1998 and was scheduled for completion by December 1999. The partners developed specifications, issued a request for proposals, and contracted with a private vendor to furnish and install system components. This vendor was familiar with the region as they supplied the automated vehicle location system used to by the transit authority to monitor buses in the region.

The transit authority allowed the partners to use excess capacity in their radio communication system. Implementation problems with communication lines and devices caused delays in system acceptance and evaluation. A temporary dial-up telephone line was used for testing until technical difficulties were resolved. By the end of February 2000, the temporary system was in place and ten snowplows from each maintenance agency were equipped with system components.

A private firm was selected to evaluate each phase of the project. This firm conducted interviews and collected data to assess manager and driver needs, to document technical and institutional issues affecting operational decisions, and to determine whether or not project goals were met. An evaluation report of the first phase was released in June 2000. The partners then met to discuss plans for phases two and three. In June 2001 they contracted with the vendor to equip an additional 290 maintenance vehicles during 2002. System hardware and software will also be improved and the communication system will be web-based. The University of Michigan has enhanced central software by designing an application that will automate snowplow routing. As conditions change, the central software will calculate the most efficient routes and automatically notify drivers via in-vehicle devices.

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Keyword(s): winter storm, snow, ice, maintenance vehicle management system, winter maintenance, treatment strategy, advisory strategy, decision support, maintenance vehicle, air temperature, pavement temperature, pavement sensor, institutional issues, productivity

Minnesota DOT Access Control

Since 1996 several Minnesota Department of Transportation (DOT) maintenance districts have worked with the Minnesota State Patrol and county sheriffs to direct traffic off of freeways and to restrict freeway access at ramps when winter storms create unsafe travel conditions. After maintenance vehicles have cleared snow and ice, freeways are reopened to traffic.

System Components: Two types of gates are used to restrict freeway access. One maintenance district has installed gate arms that are positioned on the side of the road and swing into place when needed. These arms have amber lights. Other districts deployed upright gate arms, with red lights, that are lowered into position. Static fold-down warning signs are located in advance of gates to notify motorists of freeway closures.

System Operations: Traffic and maintenance managers consider several variables to identify threats to highway operations. Weather parameters include winter storm duration and severity (i.e., snowfall rate), and visibility. Pavement condition, time of day, day of the week, seasonal travel patterns, and the capacity of towns to accommodate diverted motorists are transportation system factors. Threat information is used to determine closure locations and times.

When a threat is identified traffic and emergency management personnel execute a systematic, coordinated plan to divert traffic off of freeways with mainline gates and prohibit freeway access using ramp gates. DOT personnel travel to gate locations to open warning signs and activate gate arm lights. As shown in Figure 9, gate arms are then positioned in travel lanes to alert drivers that the freeway is closed. During closure and reopening activities, uniformed law enforcement personnel staff gate locations with patrol vehicles to prevent motorists from interfering with clearing operations.

Figure 9 – Minnesota DOT Ramp Gates and Warning Signs

Transportation Outcome(s): During a severe snowstorm on November 11, 1998 a 50-mile (80.4-kilometer) section of Interstate 90 was closed, while 59 miles (94.9 kilometers) of US Highway 75 remained open. Plows made four passes on Interstate 90 and ten passes on Highway 75 to clear the pavement of snow and ice. The freeways were reopened when the pavement was 95 percent clear. Because Highway 75 was open to traffic, significant snow compaction occurred on this roadway. Delay on Interstate 90 was minimized, as it was cleared four hours before Highway 75. As shown in Table 4, over 24 dollars per lane mile were expended on Highway 75, while it cost less than 20 dollars per lane mile to clear Interstate 90.

Table 4 – Minnesota DOT Access Control and Maintenance Costs

	US Highway 75 (Open to Traffic)	**Interstate 90** (Access Restricted)	**Percent Difference**
Number of Plow Passes	10	4	60%
Total Miles Plowed	590	200	66%
Labor Hours per lane mile	0.41	0.38	7%
Labor Costs per lane mile	$9.98	$9.08	9%
Material Costs per lane mile	$4.59	$4.50	2%
Equipment Costs per lane mile	$9.54	$6.14	36%
Total Costs per lane mile	**$24.11**	**$19.72**	**18%**

The DOT conducted a study of Interstate 90 closures in 1999. Analysis revealed that roughly 80 crashes per year were related to poor road conditions on the freeway. Study results also confirmed that access control operations enhanced mobility by reducing closure time and associated vehicle delay. Examination of this control strategy during a single storm event and over a six-month period indicated that productivity, mobility, and safety were improved.

Implementation Issues: The DOT contracted with a consulting firm to analyze the costs and benefits of deploying gate arms for access control. The consultant used historical operations and crash data to calculate benefits associated with reductions in travel time delay and crash frequency. After deciding to implement gate arms based upon the benefit/cost analysis, the DOT consulted agencies in North and South Dakota. An assessment of gates used in the Dakotas found that snowdrifts could block swinging gates necessitating shoveling before they could be positioned in the road. The upright gates also had disadvantages. In some cases, the pulley mechanism failed causing the gate arm to slam down unexpectedly. Individual maintenance districts selected the type of arm most appropriate for their operations. Ice and high winds occasionally interfered with the opening of warning signs.

The DOT plans to test remote operation of gates and Closed Circuit Television surveillance at one interchange. Remote monitoring and control via a secure web site will be tested during the 2002/2003 winter season.

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Keywords: winter storm, snow, ice, access control, freeway management, treatment strategy, winter maintenance, control strategy, traffic control, law enforcement, advisory strategy, motorist warning system, institutional issues, gates, maintenance vehicle, safety, mobility, productivity

Minnesota DOT Anti-Icing/Deicing System

Several Minnesota Department of Transportation (DOT) districts have installed fixed maintenance systems on curved and super-elevated bridges that are prone to slippery pavement conditions. On Interstate 35 an automated anti-icing system was installed on a 1,950-foot (594-meter), eight-lane bridge near downtown Minneapolis. The bridge deck was susceptible to freezing due to moisture rising from the Mississippi River below. On average 25 winter crashes occurred on the bridge each year causing significant traffic congestion.

System Components: The automated anti-icing system is comprised of a small enclosure, storage tanks, a pump and delivery system, environmental sensors, four motorist warning signs with flashing beacons, and a control computer located in the district office. The enclosure houses the pump, a 3,100-gallon (11,734-liter) chemical storage tank, a 100-gallon (379-liter) water storage tank, and control mechanisms. Liquid potassium acetate is pumped through the delivery system to 38 valve bodies installed in the median barrier. The valves direct the anti-icing chemical to 76 spray nozzles. Sixty-eight nozzles are embedded in the bridge decks of both northbound and southbound lanes. These nozzles are installed in the center of travel lanes at a spacing of 55 feet (16.8 meters). Eight barrier-mounted nozzles are located at the north end of the bridge to spray approach and exit panels.

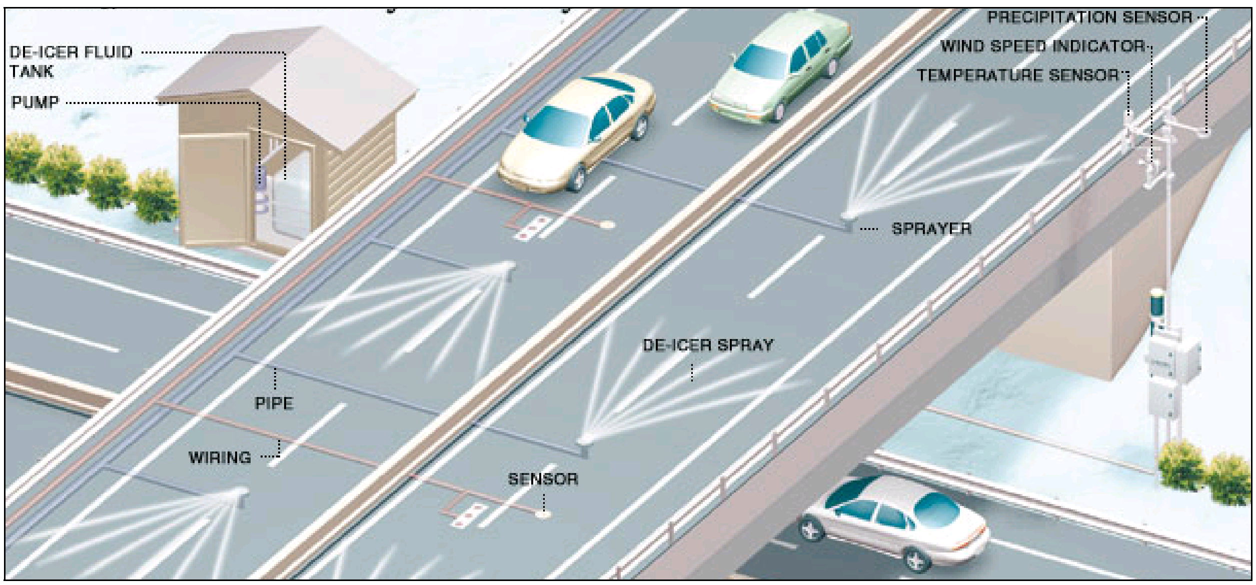

Figure 10 – Minnesota DOT Bridge Anti-icing System Components

Two types of environmental sensors that are installed on the bridge. An Environmental Sensor Stations (ESS) is equipped with air and subsurface temperature sensors, pavement temperature and pavement condition sensors, as well as precipitation type and intensity sensors. The second sensor site includes only pavement temperature and condition sensors. These environmental sensors determine whether the pavement is wet or dry and whether the pavement temperature is low enough for surface moisture to freeze. System components are depicted in Figure 10.

System Operations: The control computer continuously polls the environmental sensors to gather data used to predict or detect the presence of black ice or snow. When predetermined threshold values are met, the computer automatically activates flashing beacons on bridge approach ramps to alert motorists, checks the chemical delivery system for leaks, and initiates one of 13 spray programs. Each program activates different valves, in various spray sequences, at different spray frequencies based upon prevailing environmental conditions. An average spray cycle dispenses 34 gallons (128.7 liters) of potassium acetate (i.e., 12 gallons or 45.4 liters per lane mile) over ten minutes. Conventional treatment strategies (e.g., plowing, sanding, and salting) supplement automated anti-icing when slush or snow accumulates on the bridge deck.

At the end of each winter season the anti-icing system is inspected and reconfigured to spray water instead of potassium acetate. Over the summer, the system is manually activated on a monthly basis to ensure proper operation of the pump and delivery. The system is re-inspected in the fall before being configured for anti-icing during winter operations.

Transportation Outcome: In the first year of operation the automated anti-icing treatment strategy significantly improved roadway safety through a 68-percent decline in winter crashes. Mobility enhancements resulted from reduced traffic congestion associated with such crashes. Installing the bridge anti-icing system also improved productivity by lowering material costs and enhancing winter maintenance operations throughout the district.

Implementation Issues: The Minnesota DOT conducted a feasibility analysis to assess potential benefits and to estimate the costs of deploying an automated anti-icing system on the Interstate 35W bridge. The DOT then contracted with a private vendor to design and install the proprietary hardware and software components, as well as to provide system documentation, training, and support. System installation was completed in December 1999 and calibration and testing was conducted during the 1999/2000 winter season.

Minor hardware and software issues precluded automatic operation until the winter of 2000. Barrier-mounted nozzles were frequently blocked by plowed snow and other nozzles were clogged by sand. Negligible leaking was discovered around some valves. A filter failure in the pump enclosure caused a chemical spill, which reacted with galvanized metals and seeped through the building foundation. The ESS malfunctioned and had to be replaced. Potassium acetate was purchased and delivered in 4,400-gallon quantities necessitating the purchase of an additional chemical storage tank. Software issues included difficulty accessing data and modifying operational parameters. As part of system support, the vendor diagnosed and remedied these problems.

In order to evaluate the anti-icing system, the DOT analyzed weather conditions to identify prior winters that were comparable to the 2000/2001 season. The system evaluation included an analysis of environmental detection capabilities, delivery system pressures, spray characteristics, software alarms, and effects on traffic flow. The evaluation found that the system was activated 501 times, dispensing over 17,000 gallons (64,000 liters) of potassium acetate during winter 2000/2001.

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Keywords: ice, snow, winter storm, pavement condition, pavement temperature, anti-icing/deicing system, freeway management, traveler information, advisory strategy, winter maintenance, treatment strategy, chemicals, bridge, environmental sensor station (ESS), crashes, safety, mobility, productivity

Montana DOT Anti-Icing/Deicing Operations

On December 14, 2000 a winter storm threatened State Route 200 in Montana. The Missoula Maintenance Division of the Montana Department of Transportation (DOT) maintains the Plains section of this route. The Thompson Falls section is maintained by the Kalispell Maintenance Division. Although temperatures were comparable, only eight inches (20 centimeters) of snow fell on the Plains section. In the Thompson Falls area, the storm was more severe with 15 inches (38 centimeters) of snow followed by eight hours of freezing rain. The divisions applied different operational techniques to treat snow and ice.

System Components: Winter maintenance managers in both areas employ mobile treatment strategies in response to winter storm threats. Maintenance vehicles equipped with liquid chemical storage and spray systems are used to treat roads. Liquid magnesium chloride is applied to anti-ice and deice pavement. Abrasives are also spread on roadways to improve traction.

System Operations: In the Plains section, maintenance vehicles applied 3,000 gallons (11,355 liters) of magnesium chloride during and after the storm, resulting in bare pavement conditions. On the road section in Thompson Falls, 800 gallons (3,028 liters) of chemical were used to pre-wet abrasives before application to compacted snow. Another 750 gallons (2,839 liters) of magnesium chloride were used for anti-icing and deicing in an air quality non-attainment area.

Once the storm passed, numerous complaints were received from drivers due to striking differences in road surface conditions in the area separating the Plains and Thompson Falls road sections. The pavement was bare in Plains section, while the Thompson Falls section was compacted with snow and ice (see Figure 11).

Thompson Falls Section

Plains Section

Figure 11 – Montana Freeway with Snow-Covered and Dry Pavement

Transportation Outcome: To understand what caused the differences, the DOT’s Maintenance Review Section interviewed maintenance managers and analyzed material usage and operating costs from 1997 to 2000. Four-year averages are listed in Table 5. The treatment strategy utilized in the Plains section costs 37 percent less than the approach used in Thompson Falls, representing increased productivity. A higher roadway level of service was achieved in the Plains section resulting in safety and mobility enhancements. Environmental outcomes were improved by minimizing abrasive usage; which contributes to poor air quality, drainage facility damage, and negative impacts on wildlife habitats.

Table 5 – Montana DOT Winter Maintenance Performance Measures
(Annual Averages)

	Thompson Falls Section	Plains Section	Percent Difference
Sand Quantities	73 cubic yards (56 cubic meters)	43 cubic yards (33 cubic meters)	41%
Sand Costs per lane mile	$724	$407	44%
MgCl Costs per lane mile	$136	$233	N/A
Material Costs per lane mile	$860	$640	26%
Equipment Costs per lane mile	$327	$182	44%
Labor Costs per lane mile	$564	$273	52%
Total Costs per lane mile	**$1,750**	**$1,095**	**37%**

Implementation Issues: Interviews conducted by the DOT's Maintenance Review Section revealed that institutional factors impact winter maintenance operations. The review of operational procedures and roadway impacts revealed that managers had varying interpretations of level of service guidelines and different budgetary concerns. A comparison of treatment strategies demonstrated the benefits of preventive versus reactive treatment strategies. By applying anti-icing chemicals before or at the beginning of a storm event, compacted snow was avoided or easily removed. Reactive treatment required multiple material applications and only temporarily improved traction on snow-covered roads.

Managers in the Plains section typically ordered anti-icing chemicals for an average winter and allowed field supervisors to order additional chemicals as needed. Due to adequate material supplies, anti-icing chemicals were readily dispensed and a relatively high chemical content (i.e., 7.5 percent salt-to-sand) was used in abrasive applications. Kalispell maintenance managers estimated chemical quantities at the beginning of winter and did not purchase additional materials through the season. This more conservative approach was employed to ensure that materials were available throughout the winter. Consequently, the chemical content of abrasives applied in Thompson Falls was only four percent salt-to-sand. Liquid magnesium chloride was used primarily for pre-wetting of abrasives and direct application to pavement was limited to non-attainment areas. Since the Maintenance Review Section has shown that proactive treatment is cost effective, Kalispell managers have increased the chemical content of salt-to-sand from four to seven percent. Maintenance managers plan to conduct further evaluations of anti-icing strategies and to examine and modify operational guidelines, as appropriate.

Contact(s):

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Keywords: snow, ice, winter storm, anti-icing/deicing operations, winter maintenance, freeway management, treatment strategy, institutional issues, maintenance vehicle, chemicals, safety, mobility, productivity

Montana DOT High Wind Warning System

When high winds blow across Interstate 90 in the Bozeman/Livingston area the Montana Department of Transportation warns motorists and manages vehicle access. Severe wind tunnel conditions pose a safety risk to high-profile vehicles traveling on a 27-mile (43-kilometer) section of the freeway, shown in Figure 12.

System Components: Traffic managers utilize an Environmental Sensor Station (ESS) to monitor wind direction and wind speed. The ESS is part of a statewide Road Weather Information System (RWIS), which collects and transmits environmental data to district offices via a Wide Area Network. Four Dynamic Message Signs (DMS) are installed on the roadway to display messages to eastbound and westbound motorists.

Figure 12 – Montana DOT High Wind Warning System Location

System Operations: Traffic managers employ an advisory strategy to alert motorists of high wind conditions and a control strategy to restrict high-profile vehicle access during severe crosswinds. Traffic and maintenance managers are alerted by the RWIS when wind speeds in the area exceed 20 mph (32 kph). A warning message—"CAUTION: WATCH FOR SEVERE CROSSWINDS"—is displayed on DMS when wind speeds are between 20 and 39 mph. When severe crosswinds (i.e., over 39 mph (63 kph)) are detected, a restriction message is posted on DMS to direct specified vehicles to exit the freeway and take an alternate route through Livingston. A typical restriction message reads "SEVERE CROSSWINDS: HIGH PROFILE UNITS EXIT". DMS may also be used to warn drivers of poor pavement conditions (i.e., snow or ice) during winter months.

Transportation Outcome: Before DMS were installed, maintenance personnel had to erect barricades on the freeway to prevent high-profile vehicles from entering the affected highway section and being blown over or blown off of the road. Advising drivers and restricting access under high wind conditions has improved roadway safety, as well as the productivity and safety of maintenance staff.

Implementation Issues: Two DMS were strategically located on each end of the affected road segment to warn motorists traveling in both directions. The third and fourth DMS were installed in the middle of the 27-mile segment. Wind tunnel conditions are most severe between mileposts 330 and 338. One DMS was placed at milepost 311 for eastbound traffic approaching the area. Two DMS were mounted back-to-back at milepost 330 for both directions. The last DMS was positioned at milepost 338 to inform westbound drivers as they enter the threatened section.

Contact(s):

- Ross Gammon, Bozeman Area Maintenance Chief, 406-586-9562, rgammon@state.mt.us.

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Keywords: wind, snow, ice, high wind warning system, freeway management, traffic management, traveler information, advisory strategy, motorist warning system, control strategy, access control, environmental sensor station (ESS), road weather information system (RWIS), dynamic message signs (DMS), high-profile vehicles, safety, productivity

Nebraska Road Weather Information for Travelers

The Nebraska Department of Transportation (DOT) and the Nebraska State Patrol have partnered with a private company to provide the public with road weather information. In October 2001, Nebraska became the first state to provide statewide traveler information via 511. Information provided via 511—the national traveler information telephone number designated by the Federal Communication Commission—is also posted on agency web sites.

System Components: The private company—Meridian Environmental Technology—operates a system that ingests data from various sources including the DOT's roadside Environmental Sensor Stations, the Agricultural Weather Network managed by the University of Nebraska, National Weather Service (NWS) Doppler Radar, NWS satellite data, Federal Aviation Administration surface weather observations, as well as field reports from DOT and State Patrol personnel. The data are transmitted, via various communications systems, to computers at Meridian's North Dakota office that perform advanced weather forecast processing. These computers generate data for 6.2-mile (ten-kilometer) grids across the state and disseminate tailored road weather information via an interactive telephone system and the Internet. The DOT has installed road signs, depicted in Figure 13, along state highways to advise motorists of the 511 service.

Figure 13 – Nebraska 511 Road Sign

System Operations: When travelers dial 511, from cellular or landline telephones, the system asks for the caller's route of interest (i.e., highway and direction). The information system integrates weather analysis and forecast data with road attribute data to provide the caller with a customized, route-specific pavement condition report and six-hour weather forecast extending roughly 60 miles (or one hour) in their direction of travel.

Traveler information provided via 511 is also available on the Internet (*www.safetravelusa.com,* soon to be *www.511bystate.com*). Users can view a state map and detailed regional maps with color-coded highways. When a colored freeway segment is selected, a textual road condition and weather report is displayed, as shown in Figure 14. This information can also be accessed via links on the State Patrol and DOT web sites (*www.nebraskatransportation.org*). Travelers can also access road weather data for neighboring states including Minnesota, Montana, North Dakota, and South Dakota.

Location:

For travelers on Nebraska U.S. Highway 20 between Valentine and Newport.

Road Information:

Roadway is reported as having 75 to 100% coverage of snow or slush between milepost 197 and 202. Roadway is reported as having 25 to 50% coverage of snow or slush between milepost 203 and 221. Roadway is reported as having 75 to 100% coverage of snow or slush between milepost 222 and 270.

Weather Forecast:

The forecast until 4 o'clock Central Time this Wednesday afternoon. Skies will be mostly cloudy becoming partly cloudy. Visibility will be 5 miles changing to 10 miles. There will be occasional very light snow ending. Winds will be 8 miles per hour from the north changing to 7 miles per hour from the north-northeast. Temperatures will range from 2 to 4 degrees increasing to 6 to 8 degrees.

Figure 14 – Nebraska Textual Road Weather Report

Transportation Outcome: This advisory strategy allows the public to make more informed travel decisions (e.g., departure time, route selection) than can be made with less specific road weather information. Decision support provided by the road weather information system can enhance roadway safety. On July 6-7, 2002 usage of the system peaked due to a flash flood that washed out bridge approaches on Interstate 80.

The system improved productivity by replacing labor-intensive condition reporting procedures. In the past, State Patrol officers in the field visually observed and reported road weather conditions, which were compiled for voice recording at least five times per day. Condition reports were then made available to the public via a toll-free telephone number. During severe weather events, the 511 service relieves officers of reporting duties and allows them to focus on public safety and law enforcement activities.

Implementation Issues: Nebraska's Department of Administrative Services is monitoring implementation of the 511 service. The state has negotiated cooperative agreements with local telephone companies and cellular service providers in order to provide the service free of charge to the public. The state's Public Service Commission advertised the 511 service with announcements placed in local telephone directories.

Contact(s):

- Jaimie Huber, Nebraska Department of Roads, 511 Operations Manager, 402-471-1810, jhuber@dor.state.ne.us.
- Bryan Tuma, Nebraska State Patrol, Major, Administrative Services, 402-479-4950, btuma@nsp.state.ne.us.
- Leon Osborne, Meridian Environmental Technology, Chief Executive Officer, 701-787-6044, leono@meridian-enviro.com.

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Keyword(s): adverse weather, road weather information system (RWIS), freeway management, law enforcement, advisory strategy, traveler information, pavement condition, weather information, decision support, environmental sensor station (ESS), internet/web site, institutional issues, safety

Nevada DOT High Wind Warning System

The Nevada Department of Transportation (DOT) operates a high wind warning system on a seven-mile (11-kilometer) section of US Route 395. This highway segment, which is located in the Washoe Valley between Carson City and Reno, often experiences very high crosswinds (up to 70 mph or 113 kph) that pose risks to high-profile vehicles. The system provides drivers with advanced warning of high wind conditions and prohibits travel of designated vehicles during severe crosswinds.

System Components: An Environmental Sensor Station (ESS) is installed on the highway to collect and transmit environmental data to a central control computer in the Traffic Operations Center. The ESS measures wind speed and direction, precipitation type and rate, air temperature and humidity, as well as pavement temperature and condition (i.e., wet, snow or ice). During high wind conditions advisory or regulatory messages are displayed on Dynamic Message Signs (DMS) located at each end of the valley, as shown in Figure 15. Traffic managers may also broadcast pre-recorded messages via three Highway Advisory Radio transmitters in the area.

Figure 15 – Nevada DOT High Wind Warning on DMS

System Operations: The central control computer polls the ESS every ten minutes to compare average wind speeds and maximum wind gust speeds to preestablished threshold values. If the average speed exceeds 15 mph (or 24 kph) or the maximum wind gust is over 20 mph (or 32 kph) the computer prompts display of messages as shown in Table 6 below. This is accomplished through an interface with a DMS computer, which runs proprietary software to control the roadside signs. Roadway access to high-profile vehicles is restricted when winds are extreme. Static signs identify critical vehicle profiles and direct specified vehicles to exit the highway and travel on an alternate route when "PROHIBITED" messages are displayed.

Table 6 – Nevada DOT High Wind Warning System Messages

Average Wind Speeds	Maximum Wind Gust Speeds	Displayed Messages
15 mph to 30 mph	20 mph to 40 mph	High-profile vehicles "NOT ADVISED"
Greater than 30 mph (48 kph)	Greater than 40 mph (or 64 kph)	High-profile vehicles "PROHIBITED"

Transportation Outcome: Dissemination of traveler information and access control have enhanced safety by significantly reducing high-profile vehicle crashes caused by instability in high winds.

Implementation Issues: In the early 1980s the first high wind warning system was constructed on US Route 395. It was comprised of an anemometer (or wind speed sensor), message signs, a relay, and a timer. Because this legacy system needed extensive repairs, it was replaced in the 1990s. A solar-powered ESS was installed in place of the anemometer and relay components, and each message sign was substituted with a DMS.

While developing equipment requirements and operational procedures for the system upgrade, the DOT worked with the University of Nevada to determine warning threshold values. The University analyzed the stability of various vehicle profiles, configurations, and loadings to calculate critical wind speeds (i.e., sufficient speeds to blow vehicles over).

In 1996 the DOT's statewide telephone communication system and Very High Frequency radio network were replaced with a digital, wireless radio communication system. A Wide Area Network (WAN) facilitated the integration of voice, video, and data using open system protocols. The WAN also allowed dissemination of traveler information via the Internet (*www.nvroads.com)* and through telephone systems (*1-877-NVROADS*) with interactive voice response technologies. The computing and communication networks were designed with the flexibility to easily incorporate new technologies or components.

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- Denise Inda, Traffic Engineer (ITS), Nevada DOT District 2, 775-834-8320, dinda@dot.state.nv.us.

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Keywords: wind, high-profile vehicles, high wind warning system, freeway management, traffic management, control strategy, access control, advisory strategy, traveler information, internet/web site, environmental sensor station (ESS), dynamic message signs (DMS), highway advisory radio (HAR), safety

New Jersey Turnpike Authority Speed Management

The New Jersey Turnpike Authority (NJTA) operates an Advanced Traffic Management System (ATMS) to control 148 miles (237.9 kilometers) of the turnpike, which is one of the nation's most heavily traveled freeways. Various subsystems are employed to monitor road and weather conditions, manage traffic speeds, and notify motorists of hazardous conditions. Speed management and traveler information techniques have improved roadway safety in the presence of fog, snow, and ice.

System Components: ATMS control computers are located at the turnpike Traffic Operations Center (TOC) in New Brunswick. Data transmission between field components and central control systems is accomplished via a wireless communication system using Cellular Digital Packet Data technology. A vehicle detection subsystem, which is comprised of inductive loop detectors and Remote Processing Units, is utilized to collect speed and volume data and to detect traffic congestion. A Closed Circuit Television subsystem may also be used to visually verify road conditions.

The turnpike's Road Weather Information System (RWIS) includes 30 Environmental Sensor Stations (ESS). Three types of environmental sensors are deployed along the turnpike to gather road weather data. Nine ESS detect wind speed and direction, precipitation type and rate, barometric pressure, air temperature and humidity, as well as visibility distance. Pavement temperature and condition data are collected at 11 sites, while ten ESS simply monitor visibility distance.

Traveler information is conveyed to motorist through 113 Dynamic Message Signs (DMS), 12 Highway Advisory Radio (HAR) transmitters, and a Variable Speed Limit (VSL) subsystem. Over 120 VSL sign assemblies are positioned along the freeway at two-mile (3.2-kilometer) intervals. Sign assemblies include VSL signs and speed warning signs, which display "REDUCE SPEED AHEAD" messages and the reason for speed reductions (i.e., "FOG", "SNOW", or "ICE").

System Operations: Traffic and emergency management personnel in the TOC monitor environmental data to determine when speed limits should be lowered. When reductions are warranted, sign assemblies are manually activated to decrease speed limits in five-mph (eight-km) increments from 50, 55, or 65 mph (80.4, 88.4, or 104.5 kph) to 30 mph (48.2 kph) depending on prevailing conditions. System operators may also disseminate regulatory and warning messages via DMS and HAR. State police officers enforce the lower speed limits by issuing summonses to drivers exceeding the posted limit. When the vehicle detection and RWIS subsystems indicate that traffic and weather conditions have returned to normal, the original speed limits are restored.

Transportation Outcome: This control strategy effectively decreases traffic speeds in adverse conditions. Speed management and traveler information dissemination have improved safety by reducing the frequency and severity of weather-related crashes.

Implementation Issues: The turnpike's VSL subsystem is one of the oldest in the country. In the 1950s, before the system was installed, state police officers would patrol the freeway in inclement weather and temporarily nail up plywood signs to reduce speed limits. The VSL system was originally installed in the 1960s and upgraded in the 1980s.

Contact(s):

- Solomon Caviness, NJTA Operations Department, 732-247-0900, caviness@turnpike.state.nj.us.

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Keywords: fog, visibility, adverse weather, snow, ice, winter storm, speed management, freeway management, traffic management, emergency management, law enforcement, traffic control, control strategy, motorist warning system, advisory strategy, traveler information, vehicle detection, environmental sensor station (ESS), road weather information system (RWIS), dynamic message sign (DMS), variable speed limit (VSL), highway advisory radio (HAR), crashes, safety

City of New York, New York Anti-Icing/Deicing System

The New York City Department of Transportation (DOT) developed a fixed anti-icing system prototype for a portion of the Brooklyn Bridge. The system sprays an anti-icing chemical on the bridge deck when adverse weather conditions are observed. Anti-icing reduces the need to spread road salt, which has contributed to corrosion of bridge structures.

System Components: The anti-icing system is comprised of a control system, a chemical storage tank containing liquid potassium acetate, a pump, a network of PVC pipes installed in roadside barriers, check valves with an in-line filtration system, 50 barrier-mounted spray nozzles, and a Dynamic Message Sign (DMS). The DMS displays warnings to alert motorists during spray operations. A Closed Circuit Television (CCTV) camera allows operators to visually monitor the anti-icing system.

Each self-cleaning nozzle delivers up to three gallons (11.4 liters) of chemical per minute at a 15-degree spray angle. This angle minimizes misting that could reduce visibility. Two nozzle configurations were implemented to investigate different spray characteristics. On both sides of one bridge section, nozzles were installed 20 feet (6.1 meters) apart for simultaneous spraying. On another section, sequential spray nozzles were mounted on only one side of the bridge.

System Operations: System operators consult television and radio weather forecasts to make road treatment decisions. When anti-icing is deemed necessary, "ANTI-ICING SPRAY IN PROGRESS" is posted on the DMS and the system is manually activated to spray potassium acetate on the pavement for two to three seconds, delivering a half-gallon per 1,000 square feet (1.9 liters per 92.9 square meters).

Operators then review forecasts and view CCTV video images to monitor weather and pavement conditions. If there is a 60 percent or greater chance of precipitation and pavement temperatures are predicted to be lower than the air temperature, maintenance crews are mobilized to supplement anti-icing operations with plowing to remove snow and ice. The operational sequence is depicted in Figure 16.

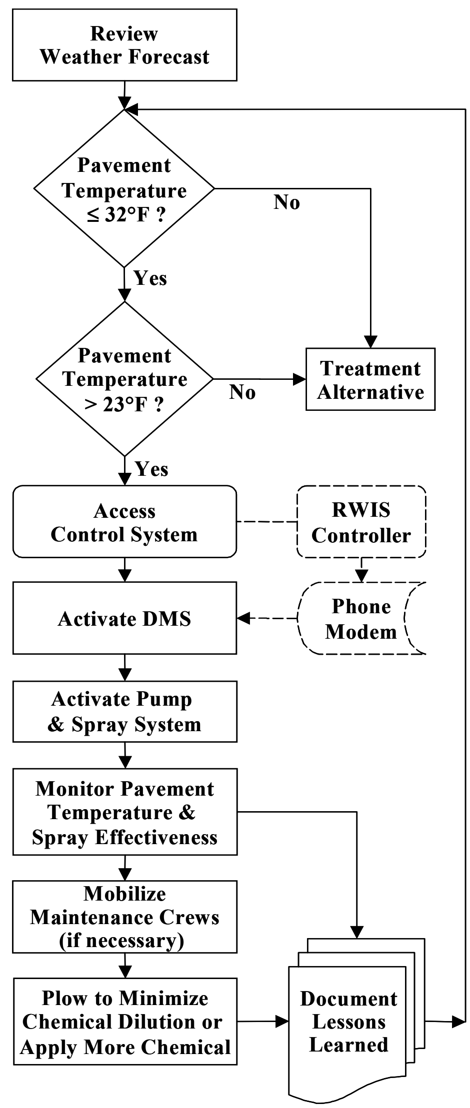

Figure 16 – City of New York, NY Anti-icing/Deicing System Operational Sequence

Transportation Outcome: An analysis of maintenance operations found that bridge sections treated with the anti-icing system had a higher level of service than segments treated by snowplows and truck-mounted chemical sprayers. Road segments treated by the anti-icing system have less snow accumulation than sections treated conventionally. Pavement conditions during a snow event in January 1999 are depicted below in Figures 17A and 17B.

Evaluation results indicated that the anti-icing system improves roadway mobility and safety in inclement weather. The system was most effective when chemical applications were initiated at the beginning of weather events. If potassium acetate was sprayed more than an hour before a storm, vehicle tires dispersed the chemical necessitating subsequent applications. The system also improves productivity by extending the life of bridges and minimizing treatment costs associated with mobilizing maintenance crews, preparing equipment, and traveling to treatment sites on congested roads.

Figure 17A – City of New York, NY Bridge Section Treated with Anti-Icing System

Implementation Issues: Corroded steel grid members were observed in the concrete bridge deck during routine repaving operations in the summer of 1998. The anti-icing system prototype was designed to apply a less corrosive chemical than salt and to minimize the need for road infrastructure repairs. During system design and testing various chemical delivery configurations were examined to determine the appropriate spray pattern, angle, and pressure. Due to concerns about bridge deck integrity, nozzles were barrier-mounted rather than embedded in the road surface.

Figure 17B – City of New York, NY Bridge Section Treated with Truck-Mounted Sprayer

System performance was evaluated over the 1998/1999, 1999/2000, and 2000/2001 winter seasons. The evaluation included an assessment of the capabilities and reliability of system components, documentation of spray area coverage, a review of road treatment procedures and results, and a cost analysis comparing the anti-icing system to conventional treatment techniques.

The DOT would like to expand the anti-icing system by integrating a Road Weather Information System (RWIS) with the control system, the CCTV camera, and the DMS to improve treatment decision-making. A wireless or fiber optic cable communication network is envisioned for connectivity of these elements. Deployment of the system on the entire Brooklyn Bridge and on other local bridges is also anticipated.

Contact(s):

- Brandon Ward, New York City DOT, Project Manager, 212-788-1720, bward2@dot.nyc.gov.

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Keywords: snow, ice, winter storm, anti-icing/deicing system, freeway management, winter maintenance, bridge, forecasts, treatment strategy, chemicals, maintenance vehicle, air temperature, pavement temperature, pavement condition, traveler information, advisory strategy, dynamic message sign (DMS), closed circuit television (CCTV), safety, mobility, productivity

City of Charlotte, North Carolina Weather-Related Signal Timing

In North Carolina, the City of Charlotte Department of Transportation (DOT) manages the operation of 615 traffic signals with a computerized control system. In the central business district weather-related signal timing plans are utilized at 149 signals to reduce traffic speeds during severe weather conditions. Weather-related signal timing can also be employed at over 350 intersections controlled by closed-loop signal systems.

System Components: The traffic signal control system is comprised of signal controllers located at City intersections, a Closed Circuit Television (CCTV) surveillance system, twisted pair cable and fiber optic cable communication systems, and a signal system control computer in the Traffic Operations Center (TOC). Images from over 25 CCTV cameras on major arterial routes are transmitted to the TOC and displayed on video monitors. Various timing plan patterns, which are stored in the computer, can be selected and downloaded to field controllers via the communication systems.

System Operations: System operators assess traffic and weather conditions by viewing CCTV video images and receiving weather forecasts. Forecast data is available through radio and television broadcasts, the National Weather Service (NWS) website, and a private weather service vendor. When heavy rain, snow, or icy conditions are observed operators access the signal computer and manually implement weather-related timing plans. To slow the progression speed of traffic these signal timing plans increase the cycle length—which is typically 90 seconds—while offsets and splits remain the same. During off-peak periods operators may also select peak period timing patterns, which are designed for lower traffic speeds.

System operators monitor roadway operations after weather-related signal timing plans have been executed. If warranted by field conditions, operators can increase cycle lengths to further reduce traffic speeds. When road weather conditions return to normal, operators access the central computer to restore normal time-of-day/day-of-week timing plans.

Transportation Outcome: By selecting signal timing plans based upon prevailing weather conditions traffic managers have improved roadway safety by reducing speeds and minimizing the probability and severity of crashes. Travel speeds decrease by five to ten mph (eight to 16 kph) when weather-related signal timing is utilized.

Implementation Issues: The City's TOC is typically staffed during AM and PM peak periods. However, traffic managers may extend the hours of operation when adverse weather is predicted or observed. System operators may be required to come in early or stay late depending upon the timing and nature of a storm event.

The signal operations staff is very experienced. Most system operators have worked for the City of Charlotte for over ten years. Decisions to execute weather-related signal timing are based upon operator observations, knowledge, and judgment. Road weather conditions are closely monitored to determine the type of storm and its area of influence. Operators modify signal timing only when weather impacts are widespread and affect a significant portion of the City's intersections.

Renovation of the TOC is expected to be complete by the end of 2002. The signal system control computer will be replaced, a new projection screen and new video monitors will be installed, a six-workstation control console will be positioned in the control room, and a fiber optic cable communication link will be established with the North Carolina DOT Traffic Management Center. This link will allow the City to access video from roughly 30 state-owned CCTV cameras as well as facilitate data sharing and coordination between the city and the state.

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- Bill Dillard; City of Charlotte DOT, Chief Traffic Engineer; 704-336-3912, wdillard@ci.charlotte.nc.us.

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Keywords: rain, snow, ice, weather-related signal timing, arterial management, traffic management, traffic control, control strategy, forecasts, weather information, closed circuit television (CCTV), speed, crashes, safety

Oklahoma Environmental Monitoring System

Public safety officials with various agencies utilize OKlahoma's First-response Information Resource System using Telecommunications (OK-FIRST) to accurately identify weather threats and make effective public safety decisions. OK-FIRST is a decision support system that facilitates data sharing and provides emergency managers with web-based, real-time environmental data.

System Components: Through the information system, emergency managers obtain agency-specific, county-level weather data from the Oklahoma mesoscale environmental monitoring network (i.e., mesonet) and various radar systems. The mesonet includes over 110 Environmental Sensor Stations (depicted in Figure 18). The OK-FIRST web site and electronic bulletin board system also foster communication and information sharing among various public safety agencies in different jurisdictions. The Oklahoma Department of Public Safety maintains a leased-line, digital communication network named the Oklahoma Law Enforcement Telecommunications System (OLETS). Over 200 participants access OK-FIRST through OLETS including law enforcement, emergency management, and fire service agencies.

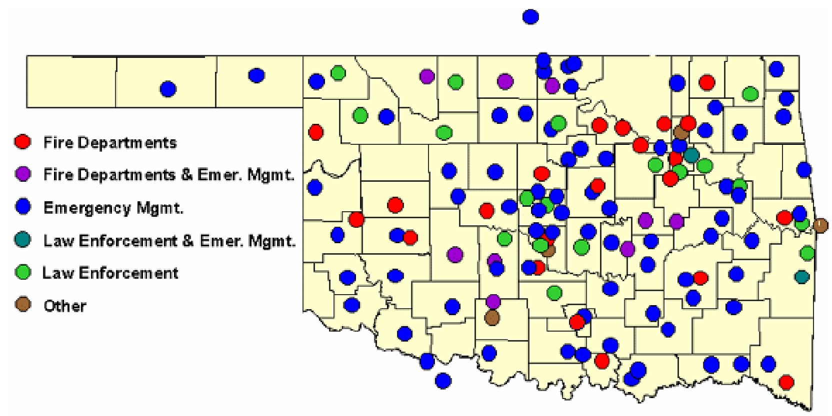

Figure 18 – Oklahoma Environmental Monitoring System Map

System Operations: Mesonet data is packaged into five-minute observations and transmitted via OLETS and a radio communication system to the University of Oklahoma for quality assurance, integration with National Weather Service data, and dissemination via the web. Emergency managers access OK-FIRST to identify and respond to severe storms, tornadoes, flooding, and wild fires.

Transportation Outcome: On May 3, 1999 over 50 tornadoes impacted northern and central Oklahoma damaging nearly 10,000 buildings, and causing 44 fatalities and over 700 injuries. In Seminole County emergency response vehicles were traveling to the Oklahoma City area on Interstate 40. With information from OK-FIRST the county's emergency manager identified a developing tornado that would cross the freeway in front of the emergency vehicle convoy. When responders were notified they stopped near Shawnee, Oklahoma and closed the interstate to prevent response and passenger vehicles from driving into the tornado's path.

Emergency managers in Logan County spotted a tornado in the path of an ambulance transporting a critically injured victim from Crescent to a hospital in Guthrie, Oklahoma. Ambulance personnel were instructed to halt the vehicle until the tornado had passed. These decisions ensured the safety of both response personnel and the traveling public.

Emergency managers have also used OK-FIRST to respond to flood events. In one county, emergency managers monitored rainfall amounts during a storm, and closed a susceptible bridge before it was washed away. In another county, emergency managers observed water levels within six inches (15.2 centimeters) of flood stage, but decided to do nothing. Information from OK-FIRST indicated that the threat had passed as waters were receding. In addition to enhancing safety OK-FIRST results in productivity improvements by decreasing the number of storm spotters and by minimizing overtime for winter road maintenance personnel.

Implementation Issues: In 1996 OK-FIRST was funded by a grant from the Technology Opportunities Program (formerly the Telecommunications Information and Infrastructure Assistance Program), sponsored by the US Department of Commerce. The DPS has provided support funding since that time. After system components were installed, integrated, and tested all participating agencies were offered training on the Oklahoma Mesonet to learn how access to environmental information could enhance their operations. An independent evaluation found that the knowledge and skills of OK-FIRST users were significantly enhanced.

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Keywords: adverse weather, tornado, flooding, environmental monitoring system, emergency management, law enforcement, decision support, advisory strategy, institutional issues, weather information, environmental sensor station (ESS), internet/web site, safety

South Carolina Hurricane Evacuation Operations

In September 1999 roughly three million people were evacuated from coastal areas in Florida, Georgia, North Carolina, and South Carolina prior to landfall of Hurricane Floyd. Over 500,000 South Carolinians evacuated from six coastal counties. Because managers with the South Carolina Department of Transportation (DOT) and the South Carolina Department of Public Safety had not agreed on a lane reversal plan prior to Hurricane Floyd, contraflow (i.e., lane reversal) was not employed during the evacuation. Consequently, there was severe congestion on Interstate 26 between Charleston and Columbia. Traffic and emergency managers quickly developed a contraflow plan for reentry operations after the hurricane.

System Components: Managers utilized storm track, wind speed, and precipitation forecast data in combination with population density and topographic information to identify areas threatened by storm surge and inland flooding. Emergency managers consulted various information sources including the National Weather Service, the National Hurricane Center, the Federal Emergency Management Agency, as well as decision support applications such as HURREVAC (*www.hurrevac.com*) and HurrTrak (*www.weathergraphics.com/ht/*). Traffic managers monitored traffic flow with two permanent vehicle detection sites along the highway and portable detection equipment on other road facilities. During reentry operations, portable Dynamic Message Signs (DMS) and Highway Advisory Radio (HAR) transmitters were positioned along the interstate to alert drivers of contraflow operations.

System Operations: DOT managers worked closely with Highway Patrol personnel during evacuation and reentry operations. Traffic and emergency managers also coordinated with other local, state, and federal agencies. Before traffic flow on westbound lanes could be reversed for reentry (i.e., contraflowed from Columbia to Charleston as shown in Figure 19), DOT and DPS personnel were mobilized and equipment was prepositioned. Lanes to be reversed were cleared of all traffic, and traffic control devices and barricades were erected. Access ramps to westbound lanes and some minor interchanges were closed. Highway Patrol personnel staffed all closed ramps and patrol vehicles were stationed along the 95-mile (152.7-kilometer) contraflow route to manage incidents. Traffic managers continuously polled vehicle detectors to monitor traffic operations.

Figure 19 – South Carolina DOT Contraflow Operations

Transportation Outcome: On Tuesday, September 14th the Governor issued a voluntary evacuation order at 7:00 AM followed by a mandatory evacuation order at noon. In response, over 350,000 people evacuated on Tuesday and roughly 160,000 departed on Wednesday. The timing of evacuation orders, the public's response to the orders, the lack of lane reversal operations, and unmanned traffic signals in small towns contributed to severe congestion on Interstate 26 between Charleston and Columbia. Travel time, which is normally 2½ hours, ranged from 14 to 18 hours during the evacuation. The maximum per lane volume on the interstate was 1,445 vehicles per hour.

The Governor ordered contraflow operations to minimize travel times during reentry. Traffic and emergency managers quickly developed a contraflow plan to accommodate reentry traffic in reversed westbound lanes. DMS and HAR were deployed to notify travelers of closures and alternate routes. As a result of contraflow, the maximum volume during reentry was 2,082 vehicles per hour per lane—a 44 percent increase over evacuation volumes. Contraflow operations and dissemination of traveler information significantly improved mobility by increasing roadway capacity and traffic volumes.

Implementation Issues: When planning contraflow operations managers must designate routes, determine initiation and termination points, select a contraflow strategy, establish criteria for implementation, arrange enforcement and incident management, promote institutional coordination, as well as communicate with political officials and the public. Geometric modifications to the roadway or special traffic control patterns may be required at contraflow initiation and termination points. After Hurricane Floyd, the South Carolina DOT constructed and X-shaped median crossover with a 45-mph (72-kph) design speed. During normal traffic operations, a water-filled barrier prevents vehicles from crossing into the wrong lanes. The barrier can be drained and removed by two people when lanes are reversed. Short connecting roads may have to be constructed between ramps and freeway lanes to facilitate access in the opposite direction. In Charleston, the DOT constructed a short road segment between a ramp from Interstate 526 to Interstate 26 in order to provide outbound traffic access to inbound lanes.

Other geometric and operational considerations include the condition and width of shoulder lanes, bridge widths, guardrail treatments, and separating traffic flows at termination points to prevent congestion caused by merging normal and reversed lanes. Where contraflow terminates in Columbia, traffic in normal lanes will be detoured onto Interstate 77. After the Interstate 26/Interstate 77 interchange, traffic in reversed lanes will cross the median to access the normal westbound lanes of Interstate 26.

After initiation and termination points are designed, one of four contraflow strategies must be selected. The first strategy reverses all coast-bound lanes. The second contraflow strategy reverses all but one coast-bound lane for use by emergency and patrol vehicles involved in incident management. In addition to emergency and patrol vehicles, the third contraflow strategy allows passenger vehicles to use the single coast-bound lane. The fourth strategy utilizes an inbound shoulder lane for evacuating traffic and reverses all but one coast-bound lane.

Traffic control devices and law enforcement officers should be positioned at initiation points, termination points, and closed facilities to ensure roadway safety. The National Guard may be activated to assist with these duties. Construction work zones should also be removed and shoulders should be cleared of debris before contraflow operations begin.

Traffic volumes and speeds should be monitored throughout contraflow operations. This information may be useful in determining when lane reversal should be terminated or when alternate routes should be considered. Vehicle detection devices on reversed lanes and processing software must to be capable of counting vehicles and calculating speeds in the opposite direction.

Criteria and procedures for implementing and terminating contraflow must be established prior to hurricane season. Implementation criteria may include mobilization time, minimum traffic volumes, and daylight hours. Contraflow must be terminated in time to clear the route of all traffic prior to landfall, secure or remove susceptible equipment, and ensure the safety of personnel in the field. Lane reversal operations typically end two hours before hurricane landfall is expected.

Dissemination of pre-trip and en-route traveler information, as well as institutional coordination are other considerations. Emergency and traffic managers at county and state levels must communicate effectively. Multi-state coordination is also critical. During the Hurricane Floyd evacuation managers in South Carolina worked with managers in Georgia to facilitate smooth traffic flow across the state boundary.

Contact(s):

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- Brett Harrelson, South Carolina DOT, 803-737-1623, harrelsodb@dot.state.sc.us.

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Keywords: hurricane, wind, precipitation, flooding, hurricane evacuation operations, freeway management, emergency management, law enforcement, traffic management, institutional issues, control strategy, traffic control, access control, advisory strategy, traveler information, forecasts, weather information, decision support, vehicle detection, dynamic message sign (DMS), highway advisory radio (HAR), volume, mobility

South Carolina DOT Low Visibility Warning System

As a result of a federal court decision the South Carolina Department of Transportation (DOT) was required to incorporate fog mitigation technologies during construction of the Interstate 526 Cooper River Bridge. The DOT deployed a low visibility warning system on seven miles (11.3 kilometers) of the freeway to inform drivers of dense fog conditions, reduce traffic speeds, and guide vehicles safely through the fog-prone area.

System Components: Warning system components include an Environmental Sensor Station (ESS), five forward-scatter visibility sensors spaced at 500-foot (152.4-meter) intervals, pavement lights installed at 110-foot spacing (33.5-meter), adjustable street light controls, eight Closed Circuit Television (CCTV) cameras, eight Dynamic Message Signs (DMS), a Remote Processing Unit (RPU), a central control computer, and a fiber optic cable communication system. The ESS measures wind speed and direction, air temperature, and humidity. The on-site RPU transmits field sensor data to the control computer, which is located in a DOT district office.

System Operations: The central computer's decision support software predicts or detects foggy conditions, correlates environmental data with predetermined response strategies, and alerts traffic managers in the district office. When alerted by the computer, system operators view images from the CCTV cameras to verify reduced visibility conditions. Operators may accept or decline response strategies recommended by the computer system. Potential advisory and control strategies include displaying pre-programmed messages on DMS, illuminating pavement lights to guide vehicles through the fog, extinguishing overhead street lights to minimize glare, and closing the freeway and detouring traffic to Interstate 26 and US Highway 17. When warranted, Highway Patrol officers erect barricades to close the freeway. Response strategies for various visibility ranges are shown in Table 7.

Table 7 – South Carolina DOT Low Visibility Warning System Strategies

Visibility Conditions	Advisory Strategies	Control Strategies
700 to 900 feet (213.4 to 274.3 meters)	"POTENTIAL FOR FOG" and "LIGHT FOG CAUTION" on DMS	"LIGHT FOG TRUCKS 45 MPH" and "TRUCKS KEEP RIGHT" on DMS
450 to 700 feet (137.2 to 213.4 meters)	"FOG CAUTION" and "FOG REDUCE SPEED" on DMS	Pavement lights illuminated
		"FOG REDUCE SPEED 45 MPH" and "TRUCKS KEEP RIGHT" on DMS
300 to 450 feet (91.4 to 137.2 meters)	"FOG CAUTION" on DMS	Pavement lights illuminated and overhead street lighting extinguished
		"FOG REDUCE SPEED 35 MPH" and "TRUCKS KEEP RIGHT" on DMS
Less than 300 feet	N/A	Pavement lights illuminated and overhead street lighting extinguished
		"DENSE FOG REDUCE SPEED 25 MPH" and "TRUCKS KEEP RIGHT" on DMS
		If warranted, "PREPARE TO STOP", "I-526 BRIDGE CLOSED AHEAD USE I-26/US 17", and "ALL TRAFFIC MUST EXIT" on DMS

Transportation Outcome: The low visibility warning system enhances mobility by providing traveler information and clearly delineating travel lanes with pavement lights. Regarding safety, no fog-related crashes have occurred since the system was deployed.

Implementation Issues: The owner of a paper mill near the Cooper River Bridge site filed a lawsuit against the South Carolina DOT as they planned construction of the bridge in the mid-1980s. The bridge was to be built at the same height as the paper mill's smoke stacks. After reviewing various fog mitigation techniques recommended by a consulting firm, a federal judge required that a low visibility warning system be included in the bridge construction project.

The warning system began operating in 1992. Initially, there were several system reliability problems related to the harsh, outdoor environment. In order to prevent unnecessary activations system software was calibrated to average visibility distance observations and disregard low readings caused by smoke plumes from the paper mill. Components of the microwave communication system, which was originally deployed, were struck by lightning and ultimately replaced by the fiber optic cable communication system. The DOT permitted the installation of privately owned communication cables in the state's right-of-way in exchange for dedicated fibers from the project site to the district office.

Contact(s):

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Keywords: fog, visibility, low visibility warning system, freeway management, traffic management, advisory strategy, motorist warning system, traveler information, control strategy, speed management, access control, decision support, environmental sensor station (ESS), closed circuit television (CCTV), dynamic message sign (DMS), vehicle guidance, lighting, high-profile vehicles, safety, mobility

Tennessee Low Visibility Warning System

On December 11, 1990 the visibility distance on a segment of Interstate 75 in southeastern Tennessee was less than 10 feet (3.1 meters). In both northbound and southbound lanes extremely low visibility contributed to chain-reaction collisions involving 99 vehicles, 42 injuries, and 12 fatalities. This crash prompted the design and implementation of a low visibility warning system on the interstate freeway. The system covers 19 miles (30.6 kilometers) including a three-mile (five-kilometer), fog-prone section above the Hiwassee River and eight-mile (13-kilometer) road sections on each side of the river.

System Components: Managers with the Tennessee Department of Transportation (DOT) and the Tennessee Department of Safety access a central computer system that collects field data from two Environmental Sensor Stations, eight forward-scatter visibility sensors, and 44 vehicle detectors. Underground fiber optic cables transmit sensor data from the roadway to an on-site computer for processing. Data from the on-site computer is relayed via a microwave communication system to the central computer in the Highway Patrol office in Tiftonia.

Figure 20 – Tennessee VSL Sign

Traffic and emergency managers employ both advisory and control strategies. Motorists are notified of prevailing conditions via flashing beacons atop six static signs, two Highway Advisory Radio (HAR) transmitters, and ten Dynamic Message Signs (DMS). Roadside delineator posts with highly reflective stripping are spaced roughly 80 feet (24.4 meters) apart throughout the project area for visual observation of visibility conditions. Speed management is accomplished by controlling ten Variable Speed Limit (VSL) signs, shown in Figure 20. When necessary, access to the affected highway section is restricted with eight gates located on interchange ramps.

System Operations: By continually monitoring sensor data, the on-site computer predicts and detects conditions conducive to fog formation and detects significant reductions in traffic speed. The central computer sounds an audible alarm in the Highway Patrol office when established threshold criteria are met. When alerted dispatchers post a reduced speed message on DMS and notify Highway Patrol troopers. Troopers are stationed in the project area from 5:00 AM to 10:00 AM when most fog events occur. Within five minutes of an alarm troopers verify conditions by counting the number of visible delineator posts.

Control software provides decision support by correlating field sensor data with pre-determined response scenarios. When troopers confirm low visibility conditions, managers select pre-programmed DMS messages, pre-recorded HAR messages, and appropriate speed limits based upon scenarios proposed by the central computer. The system also allows the display or broadcasting of customized messages.

Managers are notified if visibility distance is less than 1,320 feet (402.3 meters) or if average speed falls below 45 mph (74 kph). The speed limit is reduced from 65 to 50 mph (105.4 to 80.4 kph) when visibility is between 480 feet (146.3 kph) and 1,320 feet. The limit is lowered to 35 mph (56.3 kph) for visibility distances between 240 and 480 feet. Managers also notify local media when the warning system is activated.

Under the worst-case scenario—visibility less than 240 feet or 73.2 meters—Highway Patrol troopers activate automatic ramp gates to close the interstate and detour traffic to US Highway 11 (see Figure 21). Low visibility has caused freeway closures twice since the warning system was deployed; once due to fog and once due to smoke from a nearby fire. Advisory and control strategies are summarized in Table 8.

Figure 21 – Tennessee Ramp Gate

Table 8 – Tennessee Low Visibility Warning System Strategies

Conditions	Advisories on DMS	Other Strategies
Speed Reduced	"CAUTION" alternating with "SLOW TRAFFIC AHEAD"	N/A
Fog Detected	"CAUTION" alternating with "FOG AHEAD TURN ON LOW BEAMS"	• "FOG" displayed on VSL signs
Speed Limit Reduced	"FOG AHEAD" alternating with "ADVISORY RADIO TUNE TO XXXX AM" "FOG AHEAD" alternating with "REDUCE SPEED TURN ON LOW BEAMS" "FOG" alternating with "SPEED LIMIT XX MPH"	• "FOG" & Reduced Speed Limits displayed on VSL signs • HAR messages broadcasted
Roadway Closed	"DETOUR AHEAD" alternating with "REDUCE SPEED MERGE RIGHT" "I-75 CLOSED" alternating with "DETOUR" "FOG AHEAD" alternating with "ADVISORY RADIO TUNE TO XXXX AM"	• "FOG" displayed on VSL signs • HAR messages broadcasted • Ramp Gates closed

Transportation Outcome: From October to March, the low visibility warning system is typically activated about once a week. Ninety-five percent of system activations result in a speed limit reduction to 50 mph. Approximately 13 percent of activations required further reduction to 35 mph. There have been over 200 crashes, 130 injuries and 18 fatalities on this highway section since the interstate opened in 1973. Safety improved significantly after deployment of the warning system in 1994, as only one crash has occurred in fog.

Implementation Issues: After the multi-vehicle crash in 1990, a DOT and Department of Safety task force investigated fog-related crashes on the affected freeway segment, which was near settling ponds owned by a local paper mill, and recommended deployment of a fog warning system. When planning the Interstate 75 system, managers assessed another low visibility warning system in Charleston, South Carolina.

Field device technologies, system components, and operational procedures were evaluated to assist Tennessee managers with system design. After developing requirements for equipment, communications, and power supply DOT managers determined system scope (i.e., coverage of the most fog-prone area), field equipment locations, and warning messages. To ensure system reliability, backup radio and telephone communication systems, as well as an emergency power system were designed. Construction was completed in 1992 and the system began operating in 1993.

Some system integration problems were experienced during implementation. There were minor complications associated with hardware failures due to the harsh outdoor environment. Lightning protection systems were installed to prevent hardware damage. Communication failures were minimized by mounting stabilization devices on microwave antennas to prevent misalignment in high winds. Traffic managers have been unable to observe system status or receive alerts due to trouble with data transmission from the project site to the regional DOT office.

System designers addressed system maintenance and expandability. Both routine and emergency maintenance are performed regularly on all system components. The system was planned to accommodate future integration of new technologies or components, including an upgrade to the microwave communications system and a new digital Closed Circuit Television surveillance system.

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- John Savage, Tennessee Department of Safety, Chattanooga District Supervisor, 423-634-6898.

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Keywords: fog, visibility, low visibility warning system, freeway management, traffic management, emergency management, law enforcement, advisory strategy, motorist warning system, traveler information, control strategy, speed management, access control, decision support, vehicle detection, environmental sensor station (ESS), variable speed limit (VSL), dynamic message signs (DMS), highway advisory radio (HAR), gates, crashes, safety

City of Dallas, Texas Flood Warning System

In May 1995 a rain event caused widespread flooding in the City of Dallas, Texas resulting in seven roadway fatalities. The City deployed an automated system to monitor water levels at over 40 stream locations near roads and warn motorists of high water until maintenance personnel can barricade dangerous roads.

System Components: The flood warning system consists of stilling wells, Remote Processing Units (RPUs), Dynamic Message Signs (DMS), a radio communication system, and a central computer system. A stilling well is comprised of a 3-foot (0.9-meter) long pipe, a pressure transducer, and a float switch to measure stream levels. When high water is detected, RPUs activate sign assemblies and report stream levels to the central computer. Each RPU—which is housed in a pole-mounted enclosure—includes radio communication devices, solar or electrical power systems, and controls to reset sign assemblies. At each monitoring site, one to four sign assemblies are installed near the road to alert motorists. Sign assemblies include electromechanical DMS, two flashing beacons, radio communication devices, and power systems.

Figure 22 – City of Dallas, TX Flood Warning System Sign Assembly

System Operations: When water reaches the roadway edge RPUs automatically activate flashing red beacons and change sign messages from “HIGH WATER WHEN FLASHING” to “DO NOT ENTER HIGH WATER”. Sign assemblies, shown in Figure 22, send a message back to the RPU to verify proper operation. Remote processing units transmit water level and sign status to the central computer every hour via the radio communication system. When high water is detected by field components, the central computer is immediately alerted and sends alphanumeric pages to maintenance staff who then erect barricades on threatened roads. The central computer also posts road closures on the City’s “Flooded Roadway Warning System” web site (*www.ci.dallas.tx.us/sts/html/frws.html*). When the water recedes, maintenance staff are paged again to notify them that barricades can be removed and signs assemblies can be reset.

Transportation Outcome: The flood warning system improves roadway safety, as most motorists heed sign warnings and avoid hazardous conditions. Further, since the system was installed in April 2000 no claims related to flooded roads have been filed against the City.

Implementation Issues: During system design the City identified sites warranting motorist notification. Locations with a history of flooding or where drowning deaths had occurred were selected. After field equipment locations were selected, system requirements were established. The City desired a cost effective warning system that could be integrated with existing hydrologic monitoring systems, including the Automated Local Evaluation in Real-Time (ALERT) system and the Supervisory Control and Data Acquisition (SCADA) system.

System designers considered using gate arms to restrict roadway access. Gate configurations were eliminated due to their high costs and history of damage by vehicles attempting to circumvent them. To reduce deployment costs, solar power supply systems were designed for most monitoring sites. Electric power service was arranged for a few sites in shaded areas. Incorporating RPUs that technicians were familiar with further minimized deployment costs associated with training.

Because the City could be held liable if warning signs do not activate during flooding, all field equipment is serviced and tested frequently. All field components are inspected, cleaned, and calibrated every six months. Once a month, maintenance personnel travel to each monitoring site and manually activate sign assemblies to ensure proper operation.

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Keywords: rain, flooding, flood warning system, arterial management, traffic management, advisory strategy, motorist warning system, dynamic message signs (DMS), control strategy, access control, safety

Houston, Texas Environmental Monitoring System

Four agencies in the Greater Houston area have partnered to provide transportation management and emergency management services to the region. The Houston TranStar consortium includes the Texas Department of Transportation (DOT), City of Houston Traffic Operations, Harris County (i.e., Traffic Operations and the Office of Emergency Management (OEM), and the Metropolitan Transit Authority of Harris County. TranStar partners—who are collocated in a combined management center—utilize an environmental monitoring system to identify and respond to weather threats (e.g., flooding, ice, high winds). Partners also disseminate environmental data to the traveling public.

System Components: The monitoring system includes 164 Environmental Sensor Stations (ESS), 314 Closed Circuit Television (CCTV) cameras, as well as communication and central control systems. The Harris County OEM owns 127 ESS that measure rainfall rate, rainfall accumulation, and water levels (see Figure 23A). The DOT's ESS detect these same conditions as well as wind speed and direction, pavement temperature, air temperature, humidity, ice and/or roadway water depth (i.e., flooding). The CCTV cameras are used to visually monitor environmental and traffic conditions on freeways.

Figure 23A – Houston, TX Water Level Gauge

Video from CCTV cameras is sent to the TranStar management center via fiber optic cable. A low-frequency radio communication system transmits ESS data from the field to central systems. Data from DOT and county ESS are stored in a database and posted on the TranStar website (*www.hcoem.org)*, which can be viewed by maintenance personnel and travelers. Four static warning signs with flashing beacons (see Figure 23B), 13 Highway Advisory Radio (HAR) transmitters, and 153 Dynamic Message Signs (DMS) may also be used to notify motorists of prevailing conditions.

System Operations: Traffic and emergency managers use central computers to monitor CCTV video, ESS data, and information from the National Weather Service and private vendors (e.g., radar, river forecasts). When established threshold criteria are met, the Emergency Operations Center (EOC) in the TranStar facility is activated and computers send alarms to maintenance managers (via email and pager). Managers from each agency coordinate to plan appropriate responses and to warn motorists. The transit authority uses ESS data to manage operations in High Occupancy Vehicle (HOV) lanes, which are prone to icing and flooding. If warranted, maintenance personnel will erect barricades to close flooded roadways.

Figure 23B – Houston, TX Static Warning Sign

Transportation Outcome: The environmental monitoring system enhances agency productivity by eliminating trips to bridge locations, by providing decision support to managers, by fostering interagency coordination, and by facilitating efficient transportation management in inclement conditions. Roadway safety is improved by controlling access to flooded roads and through the provision of weather-related advisories that allow travelers to make informed decisions.

Implementation Issues: Researchers with the Texas Transportation Institute evaluated the operation of the monitoring system and designed a survey to determine how motorists access and interpret road weather information. Survey results indicated that 43 percent of respondents utilize the Internet to obtain hazard information.

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- Robert Benz, Texas Transportation Institute, Associate Research Engineer, 713-686-2971, r-benz@tamu.edu.

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Keyword(s): rain, precipitation, flooding, ice, wind, environmental monitoring system, freeway management, traffic management, emergency management, decision support, institutional issues, traveler information, weather information, advisory strategy, control strategy, environmental sensor station (ESS), closed circuit television (CCTV), dynamic message sign (DMS), highway advisory radio (HAR), road weather information system (RWIS), internet/web site, safety, productivity

Utah DOT Fog Dispersal Operations

In northern Utah widespread, super-cooled fog (i.e., less than 32 degrees F) can persist in mountain valleys for weeks. Utah Department of Transportation (DOT) maintenance personnel use liquid carbon dioxide to disperse fog and improve visibility along segments of Interstates 15, 70, 80, and 84; US Highways 40, 89, and 91; as well as secondary roads in Cache Valley and Bear Lake Valley. This treatment strategy includes the application of anti-icing chemicals as fog is dispersed to prevent moisture from freezing on the pavement.

System Components: Fog dispersal equipment, comprised of commercially available products, is installed on roughly 70 maintenance vehicles or 15 percent of the fleet. As shown in Figure 24, each truck is equipped with a compressed gas cylinder, a manual valve assembly, mounting brackets, copper pipe, and a dispensing nozzle. Each cylinder holds liquid carbon dioxide at a pressure of 2,000 pounds per square inch.

System Operations: Before vehicles leave the maintenance yard for normal patrol duties, the cylinder and valve assembly are attached. Dispensers are turned on when maintenance vehicles leave the yard and turned off when they return. As the vehicles travel through super-cooled fog, very small amounts of liquid carbon dioxide are sprayed into the slipstream of the truck. The carbon dioxide quickly evaporates removing heat from water droplets in the fog. The droplets form ice crystals and precipitate as fine snow or ice.

To prevent the precipitate from freezing on the road surface, anti-icing chemicals are simultaneously applied. If the air temperature is below 20 degrees F (-6.7 degrees C), common road salt is prewetted with liquid magnesium chloride and applied to pavements. Road salt or sodium chloride brine is spread when the air temperature is above 20 degrees F.

Figure 24 – Utah DOT Maintenance Vehicle with Fog Dispersal Equipment

Transportation Outcome: The fog dispersal treatment strategy improves roadway mobility and safety. This strategy can increase visibility distance behind the maintenance vehicle from 33 feet (10 meters) to 1,640 feet (500 meters) in less than 30 minutes. The treatment remains effective for 30 minutes to 4 hours, depending upon air temperature and wind speed. Improved visibility has significantly reduced rear-end crashes into maintenance vehicles, enhancing the safety of DOT personnel and the public.

Implementation Issues: In 1990 the DOT's Research Division sponsored a University of Utah research grant to investigate fog control at a bridge location. During the study university researchers noticed that a tunnel of clear visibility formed in the fog as carbon dioxide was dispensed. In 1992 DOT and university researchers developed a prototype with customized hardware components and began the field testing of mobile fog dispersal techniques. The Research Division published field trial results in 1993.

Based upon recommendations in the field trial report and lessons learned from anti-icing operations near Salt Lake International Airport, maintenance personnel configured a truck with fog dispersal equipment composed of commercial-off-the-shelf products. This configuration was more cost effective than the customized configuration developed by the University, which was prohibitively expensive.

Before fog dispersal equipment was deployed in 2000, the DOT developed a two-hour training course to ensure employee safety when working with compressed liquid carbon dioxide. Training course topics included oxygen-displacement properties of the chemical, chemical handling techniques, and operation of the high-pressure dispenser.

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Keywords: fog, visibility, air temperature, wind, fog dispersal operations, freeway management, winter maintenance, treatment strategy, maintenance vehicle, chemicals, anti-icing/deicing, crashes, safety, mobility

Utah DOT Low Visibility Warning System

Due to high traffic volumes and local conditions conducive to dense fog formation, the Utah Department of Transportation (DOT) deployed a low visibility warning system on Interstate 215 to notify motorists of safe travel speeds and to promote more uniform traffic flow. The warning system was installed on a low-lying, two-mile (three-kilometer) highway segment above the Jordan River in Salt Lake City where several multi-vehicle, fog-related crashes have occurred. In 1988 there was a 66-vehicle crash and in 1991 ten crashes, with three fatalities, occurred on one day.

System Components: Four forward-scatter visibility sensors and six vehicle detection sites are installed on the freeway to collect data on prevailing conditions. Visibility distance is measured in real-time and inductive loop detectors record the speed, length, and lane of each vehicle. Through Ultra-High Frequency radio modems these data are transmitted to a central computer system that records field data in a database, processes field data, and posts advisories on two roadside Dynamic Message Signs (DMS).

System Operations: The central computer identifies threats by using visibility distance, vehicle speed, and vehicle classification data in a weighted average algorithm to determine when conditions warrant motorist warnings. When visibility distance falls below 820 feet (250 meters), the computer automatically displays a warning on DMS. Based on stopping sight distances, safe travel speeds are posted on DMS when visibility is less than 656 feet (200 meters). Messages displayed for various visibility ranges are shown in Table 9.

Table 9 – Utah DOT Low Visibility Warning System Messages

Visibility Conditions	Displayed Messages
656 to 820 feet (200 to 250 meters)	"FOG AHEAD"
492 to 656 feet (150 to 200 meters)	"DENSE FOG" alternating with "ADVISE 50 MPH"
328 to 492 feet (100 to 150 meters)	"DENSE FOG" alternating with "ADVISE 40 MPH"
197 to 328 feet (60 to 100 meters)	"DENSE FOG" alternating with "ADVISE 30 MPH"
Less than 197 feet (60 meters)	"DENSE FOG" alternating with "ADVISE 25 MPH"

Transportation Outcome: An evaluation of the warning system indicated that overly cautious drivers sped up when advisory information was displayed, resulting in a 15 percent increase in average speed from 54 to 62 mph (86.8 to 99.7 kph). This increase caused a 22 percent decrease in speed variance from 9.5 to 7.4 mph (15.3 to 11.9 kph). Reducing speed variance enhanced mobility and safety by promoting more uniform traffic flow and minimizing the risk of initial, secondary, and multi-vehicle crashes.

Implementation Issues: In 1993 DOT researchers responded to a federal solicitation to prototype a low visibility warning system. The DOT contracted with a consultant in 1994 to design and install the system on Interstate 215 due to recurring fog. During winter 1995/1996 the DOT collected visibility distance and traffic data before DMS were deployed to assess driver behavior in fog without advisories. By the end of 1997 field, central, and communication equipment was installed, calibrated, and integrated. DMS calibration and verification was carried out with the assistance of the Utah Highway Patrol.

The system was operational by winter 1999/2000 and traffic managers began collecting traffic speed data, vehicle classification data, visibility data, as well as displayed messages. The DOT partnered with the University of Utah to conduct an evaluation of system effectiveness. The University analyzed traffic speeds by time-of-day, lane and direction, vehicle classification, and visibility distance with data collected over four winter seasons. Based on positive results, it was recommended that speed and pavement condition data be incorporated into control logic, that the warning system be integrated with the DOT's Advanced Traffic Management System, and that further evaluation be conducted. The DOT plans to enhance the system by deploying an Environmental Sensor Station to detect weather and pavement conditions, upgrading the DMS, and replacing the radio communication system with fiber optic cable.

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Keywords: fog, low visibility warning system, freeway management, traffic management, control strategy, speed management, advisory strategy, motorist warning system, traveler information, vehicle detection, dynamic message sign (DMS), driver behavior, safety, mobility

Virginia DOT Weather-Related Incident Detection

The Virginia Department of Transportation (DOT) operates an Advanced Traffic Management System (ATMS) to control the highway network in Northern Virginia. The ATMS includes an Incident Detection subsystem and a Closed Circuit Television (CCTV) subsystem, which are used for traffic and road condition surveillance on 27 miles (43.4 kilometers) of Interstate 66 and nearly 29 miles (46.6 kilometers) of Interstate 395. Traffic managers are able to modify incident detection parameters based upon observed weather conditions.

System Components: The Incident Detection subsystem is comprised of inductive loop detectors, Type 170 controllers housed in roadside cabinets, and a central incident detection computer. Traffic flow data is collected at over 120 vehicle detection sites installed every half mile (0.8 kilometers) along the freeways. The CCTV subsystem includes over 50 cameras, video transmission devices, and three monitor walls for display of video images. Fiber optic cable and coaxial cable communication systems transmit data and video from the field to control computers in the Smart Traffic Center (STC) located in Arlington.

System Operations: Incident detection computer software contains statistical algorithms that continuously analyze field data to identify traffic flow disruptions caused by incidents. Traffic managers may select databases containing detection algorithms for “clear”, “rainy” or “snowy” conditions. When rain or snow events are observed on the monitor walls traffic managers access the incident detection computer and select the detection database most appropriate for prevailing conditions. The CCTV subsystem is also used to visually verify detected incidents and support incident management activities.

Transportation Outcome: Use of algorithms tailored to specific weather events improves roadway mobility and safety by facilitating incident detection under non-ideal conditions. Weather-related incident detection enhances mobility by minimizing response time and traffic delays associated with temporary capacity reductions. Safety is improved through expedited incident response and clearance, which reduce the risk of secondary crashes.

Implementation Issues: The Virginia DOT contracted with a consulting firm to design, install, and integrate ATMS components and subsystems. In 1985 system integration and testing efforts were completed and the STC began operating. The ATMS was expanded in 1999 through the deployment of additional monitoring, control, and communication devices along Interstates 66 and 95.

Hardware and software components in the STC were upgraded in 2000. The original mainframe computer was replaced with redundant servers. New operator workstations and video walls were also installed. In the future, the DOT plans to expand weather-related incident detection capabilities to Interstate 495 (i.e., the Capital Beltway) and plans to integrate the ATMS with research facilities at the University of Virginia.

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Keywords: rain, snow, pavement condition, weather-related incident detection, freeway management, control strategy, incidents, vehicle detection, closed circuit television (CCTV), safety, mobility

Washington State DOT Road Weather Information for Travelers

The Washington State Department of Transportation (DOT) has collaborated with the University of Washington to provide travelers with comprehensive, integrated road weather information. The DOT maintains one of the most advanced traveler information web sites, which allows users to access current and predicted road weather conditions on an interactive, statewide map.

System Components: The DOT owns 50 Environmental Sensor Stations (ESS) that collect air temperature, atmospheric pressure, humidity, wind speed, wind direction, visibility distance, precipitation, pavement temperature and subsurface temperature. Some stations are equipped with Closed Circuit Television (CCTV) for visual monitoring of pavement and traffic flow conditions. The DOT is also a member of the Northwest Weather Consortium, which collects and disseminates real time data from an extensive environmental monitoring network. This network gathers and disseminates data from over 450 ESS owned by nine local, state and federal agencies. A statewide communication network transmits this ESS data to the Seattle Traffic Management Center (TMC) and to a computer at the University's Department of Atmospheric Sciences for data fusion and advanced modeling.

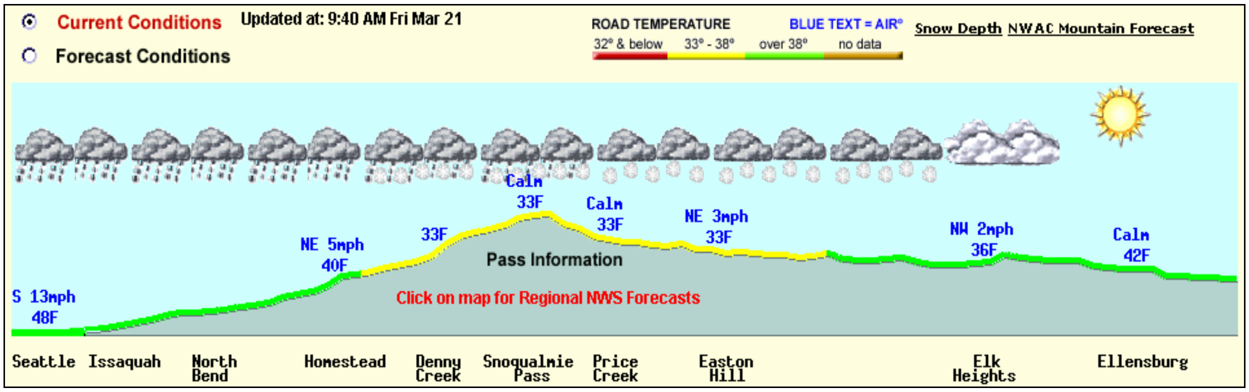

Figure 25 – Washington State DOT Route-Specific Road Weather Information Display

System Operations: A sophisticated computer model developed by the university ingests ESS data to determine prevailing and predicted pavement temperatures and generate high-resolution, numerical weather forecasts for the entire state. Observed environmental data is integrated with other information including National Weather Service (NWS) forecasts, satellite and radar images, video from 350 CCTV cameras, traffic flow data from inductive loop detectors, incident and construction data, ten mountain pass reports, and audio broadcasts from four Highway Advisory Radio (HAR) transmitters. As shown in Figures 25 and 26, route-specific traveler information is disseminated through the DOT's Traffic and Weather web site (*www.wsdot.wa.gov/traffic*) and via an interactive voice response telephone service (*800-695-ROAD*).

Figure 26 – Washington State DOT Video of Selected Route with Vehicle Restrictions

To make travel decisions, the public may access the web site to view state, regional and local maps with environmental observations, weather and pavement condition forecasts, video from freeway CCTV cameras, information on road maintenance operations, and travel restrictions on mountain passes (e.g., reduced speed limits, prohibited vehicle types).

Transportation Outcome: Road weather data available through the web site and telephone service allows users to avoid hazardous conditions, modify driving behavior, and reduce crash risk. A user survey found that travelers feel safer when they have access to real-time road weather information. The survey also revealed that users frequently access the web site to prepare for prevailing conditions along a selected route (i.e., 90 percent of respondents), for general weather conditions (i.e., 86 percent), to check weather for a specific recreational activity (i.e., 66 percent), and to determine travel routes or travel time.

Usage logs from the web site indicate that travelers access condition data more frequently during adverse weather events. On average, there were over 3,700 user sessions per day in February 2001. During a snowstorm on Friday, February 16th (before a three-day weekend) site usage increased to nearly 13,000 user sessions. The interactive telephone service typically receives one million calls each winter (i.e., an average of 8,000 calls per day) with call volumes increasing during inclement conditions or major incidents.

Maintenance managers also benefit from access to detailed road weather data. This data serves as support for operational decisions, such as resource allocation and treatment planning. More effective and efficient resource decisions reduce labor, equipment and material costs. The ability to employ proactive road treatment strategies, such as anti-icing, also improves roadway mobility.

Implementation Issues: The web site project was funded by a grant from U.S. Department of Transportation and a 20 percent match from Washington State DOT. To collect environmental data for the site, the DOT wanted to procure ESS from different vendors and display field data on a single user interface. Project managers developed functional specifications and issued a request for proposals to furnish ESS capable of communicating with an existing server using National Transportation Communications for ITS Protocol (NTCIP) standards. After resolving technical issues related to object definitions, one vendor successfully demonstrated that their sensor stations could communication with another vendor's server.

This simplified management of environmental data and avoided the need for additional hardware, software and communications infrastructure. By using the open communication standard the DOT encouraged competition among vendors that reduced ESS procurement costs by nearly 50 percent. The NTCIP will also facilitate future expansion of the environmental monitoring system.

The Washington State DOT has initiated a project to deliver traveler information via 511, the national traveler information telephone number. The agency is developing a program with natural language speech recognition to read web site data and disseminate tailored information. The DOT is in negotiation with local cellular telephone companies to offer 511 free of charge. The toll-free telephone number will be phased out as the 511 implementation project proceeds.

Contact(s):

- Larry Senn, Washington State DOT, Olympia Traffic Operations Office, 206-543-6741, larsenn@u.washington.edu.
- Eldon Jacobson, Washington State DOT, 511 Project Manager, 206-685-3187, eldon@u.washington.edu.

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Keyword(s): adverse weather, road weather information for travelers, traveler information, advisory strategy, weather information, pavement temperature, environmental sensor station (ESS), closed circuit television (CCTV), Internet/web site, decision support, institutional issues, road weather information system (RWIS), safety, productivity

Washington State DOT Speed Management

Interstate 90, which is the primary east-west route across Washington State, experiences rain and fog in summer months and snow and ice in the winter. This freeway crosses the Cascade Mountains through Snoqualmie Pass, which is a popular tourist destination. Roadway geometry, the volume of truck traffic (i.e., 22 percent), and recreational travelers unfamiliar with local conditions contributed to a winter crash rate that was four times the annual average. The Washington State Department of Transportation (DOT) employs a speed management technique on a 40-mile (64-kilometer) segment of the freeway to improve roadway safety in the presence of fog, snow, and ice.

System Components: The speed management system is comprised of six Environmental Sensor Stations (ESS), 22 radar vehicle detectors, Remote Processing Units (RPUs) housed in roadside cabinets, 13 Dynamic Message Signs (DMS), Variable Speed Limit (VSL) signs, a central control system, as well as digital radio and microwave communication systems. The ESS are installed along the interstate to detect air temperature and humidity, precipitation, wind speed, pavement temperature and condition (e.g., dry, wet, icy), and pavement chemical concentration. ESS data and vehicle speed data are collected by RPUs and transmitted to a control computer in the maintenance office located in Hyak. Advisory messages and reduced speed limits are posted on the DMS and VSL signs, as shown in Figure 27.

Figure 27 – Washington State DOT Reduced Speed Limit on DMS

System Operations: The central control computer provides decision support by utilizing software algorithms to process field data, calculate safe speeds, and suggest speed limit reductions during adverse conditions. If system operators agree with the recommendations DMS and VSL signs are activated to display road weather advisories, reduced speed limits, and the reasons for lower speeds. The control computer allows system operators to modify speed limits by direction and by road section. DMS may also be used to alert drivers of roadway closures necessitated by winter maintenance and avalanche control activities.

When warranted, the speed limit is reduced in 10-mph (16-kph) increments from 65 mph (104.5 kph) to 35 mph (56.3 kph) based upon prevailing road, weather, and traffic conditions. Vehicle equipment (e.g., tire chains) may be regulated to improve vehicle traction. Control strategies for various road weather conditions are shown in Table 10.

Table 10 – Washington State DOT Speed Management Control Strategies

Weather Conditions	Pavement Conditions	Control Strategies
• Light to moderate rain • Visibility distance greater than 0.5 mi. (0.80 km)	• Dry • Wet	Speed limit at 65 mph (104.5 kph) No tire regulations
• Heavy rain • Fog • Visibility distance less than 0.2 mi. (0.32 km)	• Slushy • Icy	Speed limit reduced to 55 mph (88.4 kph) Traction tires advised
• Heavy rain or snow • Blowing snow • Visibility distance less than 0.1 mi. (0.16 km)	• Shallow standing water • Compacted snow/ice • Deep slush	Speed limit reduced to 45 mph (72.4 kph) Traction tires required
• Freezing rain • Heavy rain or snow • Blowing snow • Visibility distance less than 0.1 mi. (0.16 km)	• Deep standing water • Deep snow/slush	Speed limit reduced to 35 mph (56.3 kph) Tire chains required

Transportation Outcome: Speed management has improved roadway safety by prompting drivers to significantly decrease speed in inclement conditions. A University of Washington study found that although speed variance increased slightly, speed management reduced average speed by up to 13 percent.

Implementation Issues: An examination of historical crash statistics determined that the winter crash rate was significantly higher than the annual average. Crash frequency in the presence of snow was five times the rate under clear conditions. The crash rate in January was 12 times higher that the July crash rate. High travel speeds and speed variance were found to contribute to winter crashes, which were primarily rear-end, sideswipe, and run-off-the-road type. Based upon these findings, the Washington State DOT decided to employ speed management to enhance roadway safety under low visibility or slippery pavement conditions.

The DOT hired a consultant to provide design, integration, and support services for system components. The DOT selected field equipment locations, designed sign support structures, assessed communication system options, and purchased DMS hardware. The DOT's Radio Operations department considered the licensing, installation, and maintenance issues associated with telephone, radio, microwave, and satellite communications technologies. The cost of installing 40 miles (64 kilometers) of telephone cable through the mountainous terrain of the Snoqualmie Pass was prohibitive. High costs and topography also precluded utilization of satellite communications. Thus, multiple microwave and radio communication links were designed to transmit data from the roadway to the mountaintop and from the mountaintop to the Hyak maintenance office. The DOT chose a DMS with light-emitting diode technology for high visibility in adverse weather conditions and procured the signs under a separate contract to ensure that performance criteria were met.

After system components were deployed in winter 1997, the Washington State DOT established policies and procedures to guide system operation. Traffic managers, system operators, maintenance personnel, state police, and others involved with the system were consulted during development of these policies. Policies and procedures covered staffing and training requirements, the reporting structure, message sets, and various response scenarios.

Contact(s):

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Keywords: fog, visibility, snow, ice, winter storm, speed management, freeway management, traffic management, traffic control, law enforcement, access control, control strategy, motorist warning system, traveler information, advisory strategy, decision support, high-profile vehicles, vehicle detection, environmental sensor station (ESS), pavement condition, dynamic message sign (DMS), variable speed limit (VSL), driver behavior, speed, crashes, safety

Wyoming DOT Avalanche Warning System

US Highway 189 near Jackson, Wyoming is a steep, mountain road that winds through Hoback Canyon (see Figure 28). Along the highway, there is an avalanche path with a 35-degree slope that poses a threat to the traveling public and to Wyoming Department of Transportation (DOT) personnel engaged in snow and ice control activities. In the past, maintenance personnel have been caught in avalanches while clearing snow and debris from a prior slide. The DOT has deployed a warning system on the highway to detect avalanches, warn approaching motorists, and alert maintenance personnel working in the area.

System Components: The avalanche warning system is comprised of a sensor assembly, a radio communication system, a controller, two static warning signs equipped with flashing beacons, and audible alarms in maintenance vehicles. The sensor assembly includes tilt switch sensors enclosed in galvanized steel pipes. The pipes are hung on weighted wire ropes attached to a ¾-inch (19-mm) diameter cable, which is strung across the slide path. The cable is suspended roughly 8 feet (2.5 meters) above the ground and anchored to steel posts embedded in concrete. The sensor assembly is installed 980 feet (298.7 meters) above the roadway.

Figure 28 – Wyoming DOT Avalanche Warning System Location

The controller monitors sensor status, records sensor data, and activates warning systems via radio when the onset of an avalanche is detected. The roadside warning signs are located 1,300 feet (396.2 meters) in advance of the affected highway segment. Batteries with solar panel chargers supply power to all field sensors, control devices, and communications hardware. Portable alarm devices are placed in maintenance vehicles—primarily rotary snowplows and front-end loaders—operating in the area.

System Operations: Controller software is programmed to continuously monitor the sensor assembly and detect switch closure based upon established threshold values. When an avalanche is detected, warning devices are instantly activated. Tilt switches within the steel pipes pivot from vertical to horizontal positions when impacted by a slide causing a circuit to close. The controller automatically prompts a radio to transmit a modulated tone to activate beacons atop motorists warning signs and to sound 97-decibel sirens in maintenance vehicles. The audible alert gives maintenance personnel about ten seconds to move out of the slide path.

Transportation Outcome: The avalanche warning system improves roadway safety by minimizing risks to drivers and to maintenance personnel. The system also facilitates timely inspection of the roadway after an avalanche, snow and debris removal activities, and road closure or rescue operations.

Implementation Issues: The warning system project was initiated as a multi-state, pooled fund study involving Colorado, Idaho, Utah, Washington State, and Wyoming. After developing equipment requirements, designers of the Wyoming system decided where the sensor assembly should be installed based upon starting zones and slide speeds of prior avalanches. If sensors were located too far above the highway, the system could initiate warnings for avalanches that did not reach the road. If placed too close to the road, there would not be sufficient time for the system to warn those in danger.

Designers considered system expandability through the integration of new components. A preliminary test of non-invasive avalanche sensors is underway. Two geophones, which measure ground motion, were installed adjacent to the slide path roughly 98 and 197 feet (30 and 60 meters) below the tilt switch sensor assembly. When the tilt switch sensors are activated, the controller simultaneously samples the geophones. By detecting the time lag in the arrival of an avalanche waveform, the controller can distinguish avalanches from other events and determine slide velocity. Further experimentation is necessary to establish criteria for warning system activation.

In a coordinated effort, local winter maintenance managers and emergency managers plan to examine hardware and communication interface reliability, document system operation, and assess roadway impacts. Evaluation results will be used to optimize the system and supplement training.

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- Leroy "Ted" Wells, Wyoming DOT District 3, 307-352-3000, leroy.wells@dot.state.wy.us.
- Rand Decker, University of Utah, 801-581-3403, rdecker@civil.utah.edu.

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Keywords: snow, avalanche warning system, freeway management, winter maintenance, advisory strategy, traveler information, motorist warning, maintenance vehicle, safety

Environmental Sensor Technologies

This appendix presents an overview of environmental sensor technologies including fixed environmental sensor stations (ESS), mobile sensing devices, and remote sensing systems. The conclusion summarizes weather impacts on roads, traffic, and operational decisions and discusses ESS implementation issues, such as data sharing and institutional coordination.

Transportation managers must access data on environmental conditions to effectively and efficiently mitigate weather impacts on traffic operations. This data serves as decision support to managers, who disseminate relevant road weather information to the public. There are many operational applications for environmental data. Environmental data may be integrated into automated motorist warning systems, road weather information systems (RWIS), advanced traffic management systems (ATMS), emergency management systems (EMS), and advanced traveler information systems (ATIS) as depicted in Figure 29. This information may also be used to enhance forecasts and supplement mesoscale environmental monitoring networks (i.e., mesonets).

Winter maintenance managers utilize road weather information to assess the nature and magnitude of threats, make staffing decisions, plan treatment strategies, minimize costs (i.e., labor, equipment, materials), and assess the effectiveness of treatment activities (by agency staff or subcontractors). Traffic managers may access road weather data to control traffic flow and warn motorists. Based upon prevailing or predicted conditions, managers may alter traffic signal timing parameters, modify incident detection algorithms, vary speed limits, and restrict access to designated routes, lanes or vehicle types (e.g., tractor-trailers). Some Traffic Management Centers utilize ATMS that integrate weather data with traffic monitoring and control software. Emergency managers may employ decision support systems that integrate weather observations and forecasts with population data, topographic data, as well as road network and traffic data. When faced with flooding, tornadoes, hurricanes, or wild fires; emergency managers may use this data to evacuate vulnerable residents, close threatened roadways and bridges, and disseminate information to the public.

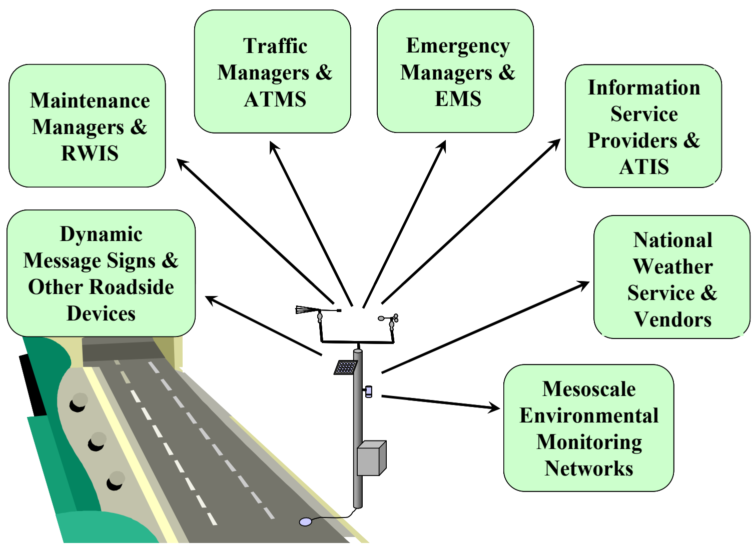

Figure 29 – ESS Operational Applications

Transportation managers disseminate road weather information to motorists in order to influence their travel decisions. This allows travelers to make choices about travel mode, departure time, route selection, vehicle type and equipment, and driving behavior. Road weather advisories and regulations may be furnished via roadway warning systems, interactive telephone systems, web sites, kiosks, and media broadcasts.

Environmental Sensor Stations (ESS)

An ESS is a fixed roadway location with one or more sensors measuring atmospheric, surface (i.e., pavement and soil), and/or hydrologic (i.e., water level) conditions. These stations are typically deployed as field components of RWIS. Data collected from environmental sensors in the field are stored onsite in a Remote Processing Unit (RPU) located in a cabinet. In addition to the RPU, cabinets typically house power supply and battery back-up devices. The RPU transmits environmental data to a central location via a communication system. Central RWIS hardware and software collect field data from numerous ESS, process data to support various operational applications, and display or disseminate road weather data in a format that can be easily interpreted by a user.

Atmospheric Sensors

Atmospheric sensors measure various weather conditions including air temperature, barometric pressure, relative humidity, wind speed and direction, precipitation, visibility distance, and cloud cover (an indication of solar radiation). Air temperature can be measured with liquid, gas or electrical thermometers. Electrical thermometers, which are normally used in automated sensor stations, contain metal wires that exhibit increased resistance to electrical current as the temperature rises. Platinum and copper are commonly utilized due to a nearly linear relationship between resistance of these materials and temperature. Electrical thermometers, also known as resistance thermometers and thermoelectric thermometers, provide accurate readings over a wide range of temperatures.

Mercury and aneroid barometers are employed to detect atmospheric pressure or the pressure due to the force of gravity on air molecules in a column of air. Because they are more accurate than mercury barometers, aneroid barometers are typically used in meteorological applications. An aneroid barometer contains an aneroid cell—a sealed, flexible metal box or pair of thin circular disks—that expands or contracts as atmospheric pressure changes.

Relative humidity—a measure of air's water vapor content—can be measured by three types of hygrometers. Dew-point, capacitor, and electrical hygrometers detect humidity by sensing changes in a substance caused by moisture. A dew-point hygrometer ascertains humidity by cooling a mirror until condensation forms. The temperature at which condensation forms can be used to calculate humidity, given the prevailing temperature and pressure. Capacitor hygrometers measure the capacitance of a material, such as polymer film, which varies as humidity changes. Electrical hygrometers accurately detect resistance to electrical current in a material, which changes with humidity. These devices typically contain a carbon-coated plastic strip that absorbs moisture from the air. As humidity rises or falls, changes in the resistance of the carbon coating can be ascertained.

Wind vanes are employed to determine the direction from which wind is blowing. A conventional wind vane, shown in Figure 30, indicates wind direction with a tail fin mounted on a horizontal shaft that is attached to a vertical axis. The tail causes the wind vane to rotate in the horizontal plane. Wind speed is typically measured by anemometers with propellers or cups. A vane-oriented propeller anemometer uses two to four blades, which rotate about a horizontal shaft, and a vane attached to the shaft to indicate direction (see Figure 31).

Wind Vane

Propeller Anemometer

Rotating cup anemometers have three to six hemispherical cups that revolve around a vertical axis, as depicted in Figure 32. Speed is calculated based upon the rotation rate of propeller blades or cups. Wind speed can also be determined with non-mechanical sensors, such as hot wire and sonic anemometers. Hot wire anemometers ascertain the degree of cooling of a heated metal wire, which is a function of air speed. Shown in Figure 33, a sonic anemometer gauges wind speeds based upon properties of wind-borne sound waves.

Precipitation measurements are made with rain gauges that sense precipitation type, measure the amount and rate of rainfall (or the liquid equivalent of snow or sleet), as well as determine the start and end times of a precipitation event. Tipping bucket rain gauges and weighing rain gauges are commonly used in ESS. In tipping bucket gauges, a cylinder collects and funnels rainfall into a small bucket that holds 0.01 inches (0.30 mm) of water. In climates with frequent snowfall, the bucket is heated and equipped with a wind shield (as shown in Figure 34). When it is full, the bucket tips and empties the water while another bucket is lifted into position under the funnel. Every time a bucket tips an electrical contact is closed sending a signal to a recorder. Weighing rain gauges are capable of measuring all types of precipitation without heaters. Precipitation is funneled into a bucket that is weighted to assess amounts. These gauges require more maintenance than tipping bucket gauges. Float-type rain gauges use a float on the water surface to measure the amount liquid precipitation. Rain-intensity gauges or rate-of-rainfall gauges measure the instantaneous rate at which rain falls onto a surface.

Figure 32 – Cup Anemometer

Figure 33 – Sonic Anemometer

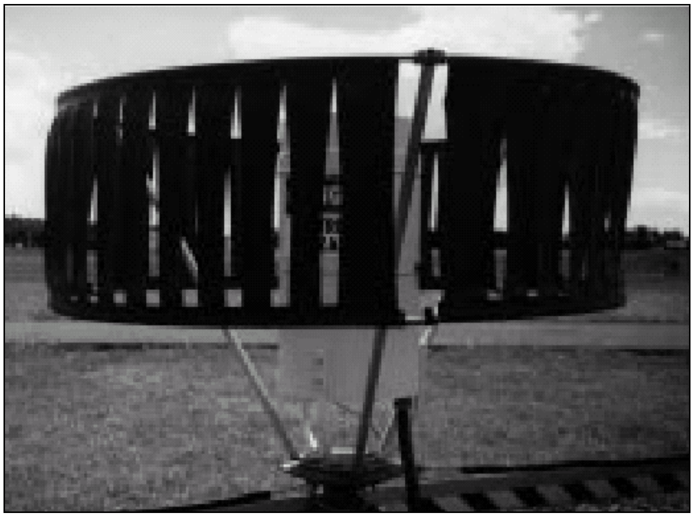

Figure 34 – Heated Tipping Bucket Rain Gauge

Visibility can be reduced by various weather phenomena including fog, heavy precipitation, drifting snow, and wind-blown dust. Visibility distance can be measured directly with sensors or remotely via Closed Circuit Television (CCTV) cameras. Objects suspended in the air—such as minute water droplets forming fog—scatter energy. Visibility sensors detect the amount of scattered light to compute visibility distances. As shown in Figure 35, a forward-scatter visibility sensor has a projector that emits a pulsed flash of light in a cone-shaped beam. A detector is positioned 33 to 70 degrees from the projector axis, such that the beam does not fall directly on the detector lens. Thus, the detector senses only the light scattered by fog or dust. Backward-scatter visibility sensors have aligned projectors and detectors and operate in a manner similar to forward-scatter sensors. Visibility distance can also be discerned by aiming a CCTV camera at objects at known distances, such as roadside signs with flashing beacons.

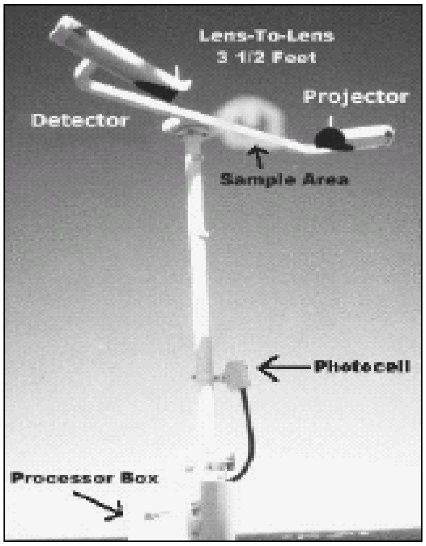

Figure 35 – Forward-Scatter Visibility Sensor

Surface Sensors

Surface sensors measure pavement conditions (e.g., temperature, dry, wet, ice, freeze point, chemical concentration), and subsurface or soil conditions. There are two basic types of surface sensors; active and passive. Active sensors generate and emit a signal and measure the radiation reflected by a targeted surface. Passive sensors detect energy radiating from an external source. Passive pavement temperature sensors are normally buried in the road surface. These sensors are designed with thermal properties similar to pavement so that they are heated and cooled at the same rate.

Pavement condition can be monitored with sensors embedded in road surfaces, friction measuring devices, cameras, and microphones. As shown in Figure 36, embedded sensors typically distinguish between two or three pavement states (e.g., dry or wet). The surface of an active pavement condition sensor is cooled below ambient air temperature. If pavement moisture is present, dew or frost will form on the cooled surface. This type of sensor can also be used to assess the effectiveness of road treatment chemicals and determine the temperature at which pavement moisture will freeze. Another type of pavement condition sensor emits microwaves from an overhead transmitter. If moisture is present on the pavement, microwaves reflect off of the water surface and the road surface. A receiver detects the pattern created by the reflections to compute the thickness and salinity of a film of water.


Figure 36 – Pavement Sensor

Friction measurement devices assess the pavement coefficient and classify conditions based upon assigned ranges of values. Video signals from CCTV cameras and audio signals recorded by microphones can also be analyzed to distinguish differences in pavement appearance or tire sounds caused by water, snow, or ice. Subsurface conditions (e.g., soil temperature, soil moisture, freeze/thaw cycles) may be detected with a soil thermometer or geothermometer, which measures values at various depths. These conditions characterize the transfer of heat between the soil and the pavement.

Hydrologic Sensors

Various hydrologic sensors detect water levels in streams and rivers, and tide levels to assess flood and storm surge hazards. Ultrasonic water level sensors make use of acoustics or sound waves to measure the distance from a transducer to the water surface. Stilling wells contain float sensors to measure water levels (see Figure 37). The float is typically enclosed in a pipe or cylinder, which protects the sensor and allows the free movement of water. Tide gauges may be used to measure storm surge caused by a tropical storm. These gauges operate in a manner similar to stilling wells to measure the height of tide.

Figure 37 – Stilling Well

Mobile Sensing

Mobile sensing involves the integration of environmental sensors with vehicle systems. In combination with global positioning system (GPS) technologies, truck-mounted sensor systems can be utilized to sense pavement conditions (e.g., temperature, friction) and atmospheric conditions (e.g., air temperature). Transportation agencies in Iowa, Michigan and Minnesota have partnered to deploy and evaluate advanced maintenance vehicles equipped with mobile sensors.

Pavement friction coefficient can be assessed with deceleration devices, locked wheels, and variable slip systems. Deceleration devices measure a signal generated by a strain gauge when a vehicle brakes. The signal, which is proportional to the deceleration rate, is used to compute the friction coefficient. Friction can also be determined by a locked wheel that is towed behind a vehicle traveling at 30 to 40 mph (49 to 64 kph). Brakes are applied to lock the wheel for one second while the resistive drag force is measured. Variable slip systems calculate pavement friction as a function of the degree of slip between a tire and the road. A friction meter being tested by the partners is shown in Figure 38.

The friction meter is mounted on the frame of a maintenance vehicle and contains a variable slip wheel with an electric brake. The wheel speed is measured as the brake is applied and released by a computerized control system. This rotational speed is used to calculate torque, which is converted into a friction coefficient value. The control system displays friction levels to the driver in five color-coded categories (i.e., "Hazardous," "Very Slippery," "Slippery," "Acceptable," and "Good").

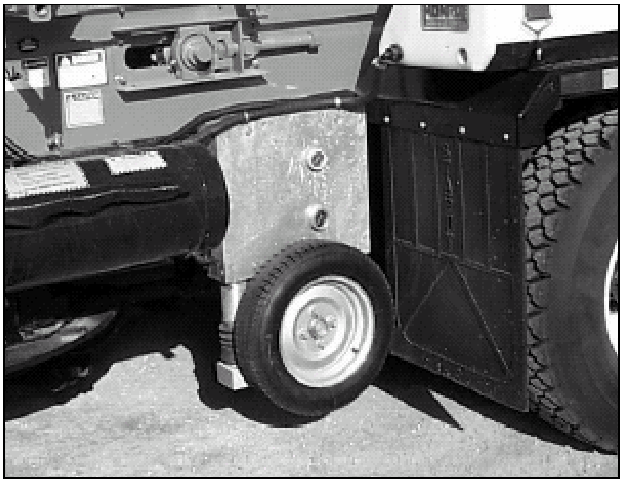

Figure 38 – Friction Meter Mounted on Snowplow

The automotive industry has introduced traction control systems and anti-lock braking systems that can also be employed for mobile pavement friction measurement. Traction control systems can detect traction of vehicle wheels as they rotate. While, anti-lock braking systems only operate during braking, resulting in fewer measurements.

Agencies in Iowa, Michigan and Minnesota are also evaluating mobile sensors to determine pavement freeze point temperature. The freeze point sensor is composed of a receptacle that collects liquid from tire spray, as shown in Figure 39. A computer system closes the receptacle lid, calculates the freeze point of the liquid, and blows air over the sensor to prepare for the next measurement cycle. Additional research is needed due to the complexities of mobile pavement condition sensing. Researchers in the U.S., Europe, and Japan are currently prototyping and evaluating various devices that ascertain pavement conditions.

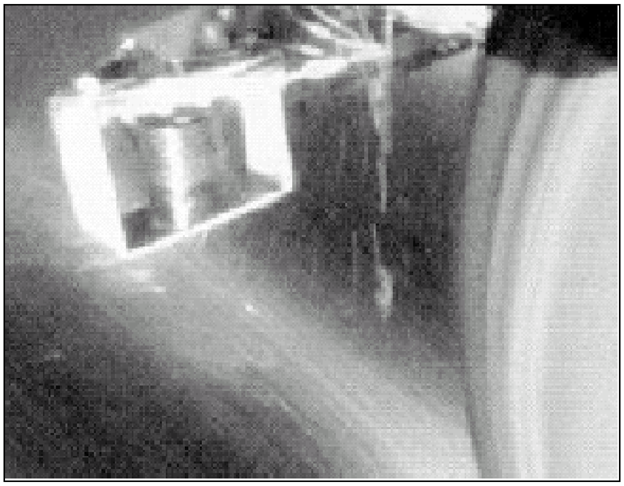

Figure 39 – Freeze Point Temperature Sensor

Remote Sensing

In remote sensing, a detector is located at a significant distance from a target. The sensor is typically part of a radar or satellite system used for surveillance of meteorological and oceanographic conditions. Images and observations from remote sensors are used for weather monitoring and forecasting from local to global scales. Remote sensing is used for quantitatively measuring atmospheric temperature and wind patterns, monitoring advancing fronts and storms (e.g., hurricanes, blizzards), imaging of water (i.e., oceans, lakes, rivers, soil moisture, vapor in the air, clouds, snow cover), as well as estimating runoff and flood potential from thawing.

Water in its gaseous state (or water vapor) is essential in the development and propagation of weather. Water vapor has historically been a poorly characterized meteorological variable because its distribution fluctuates widely (both spatially and temporally) and it is difficult to measure using traditional atmospheric observing systems. The Federal Highway Administration (FHWA) has collaborated with the National Oceanic and Atmospheric Administration (NOAA), the National Geodetic Survey/Continuously Operating Reference Station (NGS/CORS), and the Coast Guard to develop a Nationwide Differential Global Positioning System (NDGPS) capable of observing precipitable water vapor.

The NDGPS is comprised of systems that measure satellite signal delays caused by atmospheric vapor. Twenty-four GPS satellites in Earth's orbit emit radio signals to ground instruments, which accurately compute precipitable water vapor data every 30 minutes. NDGPS is more precise than the civilian GPS system, known as the standard positioning service, providing three-foot (one-meter) accuracy. This high accuracy is expected to improve to 0.8 to 8.0 inches (2 to 20 centimeters) in the near future. The NDGPS data—available on the project web site, *www.gpsmet.noaa.gov/jsp/index.jsp*—has been used to improve the accuracy of short-term, precipitation forecasts disseminated by the National Weather Service (NWS).

Conclusion

Weather acts through visibility impairments, precipitation, high winds, and temperature extremes to affect driver capabilities, vehicle performance (i.e., traction, stability and maneuverability), pavement friction, and roadway infrastructure. Fixed ESS, mobile sensors, and remote sensing systems can provide valuable data that can be used to improve roadway safety, maintain roadway mobility, enhance agency productivity, and facilitate dissemination of traveler information to the public. Table 11 summarizes the impacts of various weather events on roadways, traffic flow, and operational decisions.

Table 11 – Weather Impacts on Roads, Traffic and Operational Decisions

Road Weather Variables	Roadway Impacts	Traffic Flow Impacts	Operational Impacts
Air temperature and humidity	N/A	N/A	• Road treatment strategy (e.g., snow and ice control)
Wind speed	• Visibility distance (due to blowing snow, dust) • Lane obstruction (due to wind-blown snow, debris)	• Traffic speed • Travel time delay • Accident risk	• Vehicle performance (e.g., stability) • Access control (e.g., restrict vehicle type, close road) • Evacuation decision support
Precipitation (type, rate, start/end times)	• Visibility distance • Pavement friction • Lane obstruction	• Roadway capacity • Traffic speed • Travel time delay • Accident risk	• Vehicle performance (e.g., traction) • Driver capabilities/behavior • Road treatment strategy • Traffic signal timing • Speed limit control • Evacuation decision support • Institutional coordination
Fog	• Visibility distance	• Traffic speed • Speed variance • Travel time delay • Accident risk	• Driver capabilities/behavior • Road treatment strategy • Access control • Speed limit control
Pavement temperature	• Infrastructure damage	N/A	• Road treatment strategy
Pavement condition	• Pavement friction • Infrastructure damage	• Roadway capacity • Traffic speed • Travel time delay • Accident risk	• Vehicle performance • Driver capabilities/behavior (e.g., route choice) • Road treatment strategy • Traffic signal timing • Speed limit control
Water level	• Lane submersion	• Traffic speed • Travel time delay • Accident risk	• Access control • Evacuation decision support • Institutional coordination

Several issues must be considered when planning to deploy ESS and implement RWIS. Concerns include procurement and maintenance, data sharing, and institutional issues. Partnerships with neighboring public agencies and the private sector can facilitate data sharing and help defray the initial and recurring costs of field sensors, communications infrastructure, central hardware, and processing software. Another alternative is to fund RWIS component installation as part of larger construction or Intelligent Transportation Systems (ITS) projects. Preventive maintenance funds must also be secured to ensure that sensors are properly calibrated and provide accurate data.

Exchanging environmental data and information with other agencies can minimize surveillance costs. Environmental monitoring networks can be created to collect and integrate data from many sources, store relevant data in centralized databases, and disseminate information in useful formats. Potential data sources include surface weather observation systems deployed by the NWS, the Federal Aviation Administration, the U.S. Geological Survey, the Department of Agriculture, the Forest Service, and the Environmental Protection Agency. The need for redundant infrastructure can be eliminated by coordinating with other agencies.

Because environmental sensors are available from various vendors in numerous configurations, technological compatibility and communications standards must be considered in joint efforts. The U.S. DOT promotes interoperable systems through the ITS Standards Program, which develops standards detailing how various systems are interconnected within the framework of the National ITS Architecture. The National Transportation Communications for ITS Protocol (NTCIP) is a set of standards that facilitate interoperability of roadside devices made by different vendors. The NTCIP includes object definitions for ESS, which were initially published in October 1998 and amended in January 2001. The object definitions document (i.e., NTCIP 1204)—which describes data collected from weather, pavement, and air quality sensors—can be used to integrate disparate field devices into a central system with common data sets and communications protocols. Release of version two of the ESS object definitions document is expected in June 2004.

In 2005, another document (i.e., NTCIP 1301) describing message sets for disseminating road weather information to managers and travelers will be released. The NTCIP ESS standard has been successfully tested in Minnesota and Washington State. Additional information about ESS standards can be found on the ITS Standards Program web site (*www.its-standards.net/Documents/ess_advisory.htm*) and the Road Weather Management Program web site (*ops.fhwa.dot.gov/weather/publications/ rwis_brochure.pdf*).

Another major institutional issue is system acceptance. Potential benefits from ESS and RWIS deployments will not be realized if transportation managers do not use them. The organizational culture, decision-making processes, and technical capabilities of users must be carefully considered during design and implementation. All users desire "timely, relevant, accurate" road weather information. However, these criteria may be defined differently depending on the operational application. For example, a maintenance manager may consider a 24-hour precipitation forecast "timely" for treatment strategy planning, while a traffic manager needs real-time snow accumulation data to adjust traffic signal timing parameters. "Relevant" environmental data is presented to the user in a format that is easily interpreted and suitable for decision support. Software programs must be developed to customize raw data (such as soil temperature) into useful information (such as a pavement temperature forecast based upon air and soil temperatures). Managers have various technological options depending on their weather information needs, operational procedures, and mitigation strategies.

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Acronym List

AFWS	Automated Flood Warning System
AASHTO	American Association of State Highway and Transportation Officials
ATIS	Advanced Traveler Information System
ATMS	Advanced Traffic Management System
AVCS	Advanced Vehicle Control System
B/C	Benefit/Cost
BMP	Best Management Practice
CCTV	Closed Circuit Television
CDPD	Cellular Digital Packet Data
CMAQ	Congestion Mitigation and Air Quality
DMS	Dynamic Message Sign
DOT	Department of Transportation
DPS	Department of Public Safety
DSL	Digital Subscriber Line
DSS	Decision Support System
EOC	Emergency Operations Center
ESS	Environmental Sensor Station
FHWA	Federal Highway Administration
GPS	Global Positioning System
HAR	Highway Advisory Radio
HAZMAT	Hazardous Material
ISP	Information Service Provider
ITS	Intelligent Transportation System
MMDI	Metropolitan Model Deployment Initiative
NCHRP	National Cooperative Highway Research Program
NWS	National Weather Service
OFCM	Office of the Federal Coordinator for Meteorology
OK-FIRST	Oklahoma's First-response Information Resource System using Telecommunications
OLETS	Oklahoma Law Enforcement Telecommunications System
PC	Personal Computer
PVC	Polyvinyl Chloride
RPU	Remote Processing Unit
RWIS	Road Weather Information System
SCADA	Supervisory Control And Data Acquisition

SHEP	State Highway Emergency Patrol
STC	Smart Traffic Center
TCC	Traffic Control Center
TOC	Traffic Operations Center
TMC	Traffic Management Center
TRIS	Transportation Research Information Services
UHF	Ultra-High Frequency
US	United States
USDOT	United States Department of Transportation
UTCS	Uniform Traffic Control System
VHF	Very High Frequency
VSL	Variable Speed Limit
WAN	Wide Area Network

Online Resources

WEB SITE	INTERNET ADDRESS (URL)
FHWA Road Weather Management Program	http://www.ops.fhwa.dot.gov/weather/index.htm
Maintenance Decision Support System (MDSS)	http://www.rap.ucar.edu/projects/rdwx_mdss/index.html
ITS Resource Guide	http://www.its.dot.gov/itsweb/guide.html
ITS America	http://www.itsa.org
Aurora Program	http://www.aurora-program.org/
Enterprise Program	http://www.enterprise.prog.org/
Evacuation Traffic Information System (ETIS)	http://www.fhwaetis.com/etis/
Snow and Ice Cooperative Program (SICOP)	http://www.sicop.net/
Cooperative Program for Operational Meteorology, Education and Training (COMET)	http://www.comet.ucar.edu/cometprogram.htm
The Office of the Federal Coordinator for Meteorology (OFCM)	http://www.ofcm.gov/
American Meteorological Society (AMS)	http://www.ametsoc.org/AMS/
National Weather Service (NWS)	http://www.nws.noaa.gov/
NWS Tropical Prediction Center, National Hurricane Center	http://www.nhc.noaa.gov/
World Road Association (PIARC)	http://www.aipcr.lcpc.fr/index-e.htm
Standing International Road Weather Commission (SIRWEC)	http://www.sirwec.org

WEB SITE	INTERNET ADDRESS (URL)
Alaska DOT Winter Road Condition Report	http://www.dot.state.ak.us/stwdplng/planresc/road_cond.html
Arizona DOT Highway Condition Reporting System	http://www.azfms.com/HCRSv3/arizona.html
Arkansas State Highway and Transportation Department Weather Related Road Conditions	http://www.ahtd.state.ar.us/road/map.htm
California DOT Highway Information	http://www.dot.ca.gov/hq/roadinfo/
Colorado DOT Road and Weather Information	http://www.cotrip.org/rWeather/All_Regions_031203_075345.html
Delaware DOT Real-Time Travel Advisory	http://www.deldot.net/public.ejs?command=PublicTrafficReportDisplay&location=DE
Idaho Transportation Dept. Road/Weather Integrated Data System	http://164.165.237.41/RWIDS_Public/default.asp
Illinois DOT Statewide Winter Road Conditions	http://www.dot.state.il.us/operations/mo_state.html
Indiana State Police Road Information	http://www.ai.org/isp/roadinfo/weather.html
Iowa State Patrol Winter Road Conditions	http://www.iowaroadconditions.org/
Kansas DOT RWIS Roadway Map and Weather Information	http://kdot1.ksdot.org/public/kdot/burcompser/generatedreports/weather.htm
Kentucky Transportation Cabinet Roadway Weather Information System	http://www.kytc.state.ky.us/RWIS/index.htm
Maine DOT Travel Information Service	http://216.17.172.232/default.asp?display=roadConditions&area=ME_statewide&date=&t
Maryland State Highway Administration Roadway Weather	http://www.chart.state.md.us//mapping/CHARTMap.asp?tab=Emergency
Michigan State Police Weather/Road Conditions	http://www.michigan.gov/msp/0,1607,7-123--19938--,00.html
Minnesota DOT Road Traveler Information Service	http://www.511mn.dot.state.mn.us:8080/MN_TRIP/index.jsp

WEB SITE	INTERNET ADDRESS (URL)
Mississippi Department of Public Safety Weather/Road Conditions	http://www.dps.state.ms.us/dps/dps.nsf/roadmap?Openform
Missouri DOT Winter Road Conditions	http://www.modot.state.mo.us/roadcond/statemap.htm
Montana DOT Remote Weather Information System	http://www.mdt.state.mt.us/departments/maintenance/rwis/mdtrwis.html
Nebraska Department of Roads Travel and Weather Information	http://www.nebraskatransportation.org
Nevada DOT Road Weather Information System	http://www.nevadadot.com/traveler/rwis/
New Hampshire DOT Traveler Information	http://www.state.nh.us/dot/traveler/weather/weather.htm
New York State DOT Winter Weather Traveler Advisory System	http://www.dot.state.ny.us/travel/
North Carolina DOT Traveler Information Management System	http://apps.dot.state.nc.us/tims/Main.ASP
North Dakota DOT Maintenance Forecasts	http://www.meridian-enviro.com/ndot/
Ohio DOT Road and Weather Information System	http://www.odotonline.org/rwis/default.asp
Oklahoma Department of Public Safety Road Conditions	http://www.dps.state.ok.us/cgi-bin/weathermap.cgi
Oregon DOT Road Conditions	http://www.tripcheck.com/RoadCond/roadcondindex.htm
Pennsylvania DOT Road Weather Information System	http://208.9.196.31/site/site.nsf/mainpage
South Carolina DOT Winter Interstate Conditions	http://www.scdot.org/getting/winterinterstate.asp
South Dakota DOT Winter Road Condition Report	http://www.sddot.com/Operations/Road_Conditions_Report/Index.htm
Tennessee Interstate Highway Conditions	http://www.tdot.state.tn.us/roadconditions/currentmap.asp
Texas DOT Road Reports by Conditions	http://www.dot.state.tx.us/hcr/main.htm

WEB SITE	INTERNET ADDRESS (URL)
Utah DOT Weather/Road Conditions	http://www.dot.state.ut.us/public/road_conditions.htm
Virginia DOT Road Information and Conditions	http://www.virginiadot.org/comtravel/eoc/eoc-main.asp
Washington State DOT Traffic and Weather Information	http://www.wsdot.wa.gov/traffic
West Virginia DOT Road Conditions for Major Highways	http://www.wvdot.com/14_roadconditions/14_roadcond.cfm
Wisconsin DOT Winter Road Conditions	http://www.dot.wisconsin.gov/travel/road/winter-roads.htm
Wyoming DOT Road Report	http://wyoroad.info/highway/text_road.html

Publication Listing

TITLE	ABSTRACT	SOURCE
511 DEPLOYMENT IN RURAL STATE: A CASE STUDY OF MONTANA	Montana's 511 system is scheduled for a winter 2002 deployment. This rural system is unique in that its focus is on road and weather information and will incorporate a pavement thermal model and a weather model into the 511 system. Information about mountain passes will be included and both travelers and maintenance crews will utilize the system, which will cover 8,200 miles of interstate and primary roadways in Montana. This paper will focus on the deployment of 511 from the perspective of a rural state including project stakeholders, system content, data collection methods, and the marketing plan.	2002 Joint Meeting of the CAATS and the RATTS, http://www.caats.org/Press%20Releases/CRCD.htm
A BENEFIT/COST ANALYSIS OF INTELLIGENT TRANSPORTATION SYSTEM APPLICATIONS FOR WINTER MAINTENANCE	Washington State DOT assessed the benefits and costs of deploying an automated anti-icing system on a high-accident corridor.	Washington State Department of Transportation, Transportation Research Board 80th Annual Meeting
A CASE STUDY IN HIGHWAY MAINTENANCE MANAGEMENT: OHIO'S COUNTY WORK PLANS	Over the past three years, ODOT adopted Strategic Initiatives to revamp the department's maintenance management methods, improve practices and optimize resource utilization. Focused on redefining, prioritizing and tracking all maintenance resources, the department set out to combine planning, implementation, quality review and cost accounting data into one manageable, easily-accessed system. The product of this intensive effort, the ODOT County Annual Work Plans, is revolutionizing the way the department approaches maintenance management. Prior to the implementation of the work plans in July of 2001, roadside conditions and maintenance efforts varied widely across the state. Following the inaugural year of the County Work Plans, conditions are meeting statewide standards, reflecting the state's new focus on more effectively managing Ohio's transportation investment.	Transportation Research Board 82nd Annual Meeting, Search TRIS http://199.79.179.82/sundev/search.cfm
A CORRELATION TECHNIQUE FOR ESTIMATING TRAFFIC SPEED FROM CAMERAS	This paper presents a new algorithm to estimate Speed from roadside cameras in uncongested traffic, congested traffic, favorable weather conditions, and Adverse weather conditions. Individual vehicle lanes are identified and horizontal vehicle features are emphasized using a gradient operator. The features are projected into a one-dimensional subspace and transformed into a linear coordinate system using a simple camera model. A correlation technique is used to summarize the movement of features through a group of images and estimate mean Speed for each lane of vehicles.	Transportation Research Board 82nd Annual Meeting, Search TRIS http://199.79.179.82/sundev/search.cfm

TITLE	ABSTRACT	SOURCE
A DECISION SUPPORT SYSTEM FOR SNOW EMERGENCY VEHICLE ROUTING: ALGORITHMS AND APPLICATION	Summarizes results of research to develop a decision support system to assist the Maryland State Highway Administration Office of Maintenance staff design snow emergency routes for Calvert County, MD and achieve improvements in service and savings in operational costs.	Transportation Research Board 80th Annual Meeting, Search TRIS http://199.79.179.82/sundev/search.cfm
A GUIDE FOR SELECTING ANTI-ICING CHEMICALS, V1.0	The purpose of the guide is to specify the key performance measures that are required from an anti-icing chemical, and suggest ways of grading chemicals according to those performance measures. It also provides a method whereby an agency can weight these measures according to the specific needs of that agency.	www.anti-ice-guide.com
A LIFE CYCLE COST-BENEFIT MODEL FOR ROAD WEATHER INFORMATION SYSTEMS	Describes a decision tool supporting implementation of RWIS and quantification of costs and benefits.	Transportation Research Board 77th Annual Meeting, Search TRIS http://199.79.179.82/sundev/search.cfm
A METHOD FOR RELATING TYPE OF CRASH TO TRAFFIC FLOW CHARACTERISTICS ON URBAN FREEWAYS	A method is developed to determine how crash characteristics are related to traffic flow conditions at the time of occurrence. Crashes are described in terms of the type and location of the collision, the number of vehicles involved, movements of these vehicles prior to collision, and severity. A case study using data for more than 1,000 crashes in Southern California identified twenty-one traffic flow regimes for three different ambient conditions: dry roads during daylight, dry roads at night, and wet conditions. Each of these regimes has a unique profile in terms of the type of crashes that are most likely to occur, and a matching of traffic flow parameters and crash characteristics reveals ways in which congestion affects highway safety.	Transportation Research Board 82nd Annual Meeting, Search TRIS http://199.79.179.82/sundev/search.cfm
A PORTABLE METHOD TO DETERMINE CHLORIDE CONCENTRATION ON ROADWAY PAVEMENTS	Studies have shown that the ability to measure the salt concentration on roadway surface would bring dramatic advances in the effective use of deicers. Concentration measurement devices currently in use are only for point measurement and are dangerous for field personnel because they require manual on-site measurement. A new portable concentration system developed in this project is mounted on a truck and enables safer and continuous measurement of salt concentration.	Transportation Research Board 81st Annual Meeting, Search TRIS http://199.79.179.82/sundev/search.cfm

TITLE	ABSTRACT	SOURCE
A TEMPORAL ANALYSIS OF WEATHER-RELATED COLLISION RISK FOR OTTAWA, CANADA: 1990-1998	This study examines temporal variations in weather-related collision and injury risk using collision and weather data for Ottawa, Canada over the period 1990-1998. A matched-pair approach was used to define precipitation events and corresponding controls in order to estimate and compare the risk of collision and injury during precipitation relative to normal seasonal conditions for weekdays versus weekends, nighttime versus daytime, peak-period versus other daytime; and early-winter season versus late-winter season. Results indicate that collision risk increased significantly---by more than 100 percent for rain and approximately 50 percent for winter precipitation events. Injury risk was also elevated, but to a lesser extent. Increases in precipitation-related collision risk during the winter were higher on weekends relative to weekdays. Also, collision risks were especially high during the early part of the winter season.	Transportation Research Board 82nd Annual Meeting, Search TRIS http://199.79.179.82/sundev/search.cfm
ADVANCED COLLISION WARNING SYSTEM FOR THE ROADVIEW SNOWPLOW DRIVER ASSISTANCE SYSTEM	Research program conducted in California and Arizona on Advanced Snowplow with a multi-lane, radar-based Advanced Collision Warning system and a magnetic Lateral Sensing System for use in low visibility conditions. A visual display provides two-dimensional driver assistance information.	7th World Congress on ITS, University of California - Davis.
ADVANCED TRAVELER INFORMATION SERVICE (ATIS): WHAT DO ATIS CUSTOMERS WANT?	This is the second of two white papers written for the “ATIS Data Gap” workshop with the objective of providing insights from MMDI Customer Satisfaction ATIS evaluations and other USDOT-sponsored ATIS research. The paper synthesizes findings from research and evaluations dating back to 1996, including several field operational tests.	www.itsdocs.fhwa.dot.gov/\JPODOCS\REPTS_TE/9H801!.PDF
ADVANCED VEHICLE CONTROL SYSTEMS (AVCS) FOR MAINTENANCE VEHICLE APPLICATIONS	Highway maintenance operations most suitable for the application of AVCS are snow removal and work zone following by a shadow vehicle. This study explores opportunities for AVCS-based snow removal and work zone following vehicles. A description of these operations, and their suitability for the application of AVCS is presented. Previous and on-going work related to vehicle automation for these operations is introduced, along with recommendations for the future, based on an assessment of technical feasibility of AVCS and the attitudes of the highway and airport maintenance communities towards this technology.	http://www.itsdocs.fhwa.dot.gov/%5CJPODOCS%5CREPTS_TE/1VW01!.PDF
ADVERSE WEATHER TRAFFIC SIGNAL TIMING	Study conducted for Minnesota DOT to determine the impact of bad weather on a coordinated signal system (three-mile section of Trunk Highway 36 with five signals) and to determine if it would be beneficial to develop timing plans to accommodate adverse weather conditions.	www.trafficware.com/documents/1999/00005.pdf

TITLE	ABSTRACT	SOURCE
AN ANALYSIS OF THE WORST COMMUTING DAYS IN WASHINGTON, DC (JUNE 1, 2000 to MAY 31, 2001)	This report explores how much benefit pre-trip traveler information provides on some of the worst commuting days in Washington, DC. It analyzes the impacts on a commuter who does not utilize traveler information services, and examines what would have happened to his commute if he had made use of a notification-based pre-trip traveler information service on those days. The worst days were determined as those that had high travel times, travel disutility cost, travel-expenditure, late and early schedule delays, and poor on-time reliability and just-in-time reliability. When possible, contributing factors that made the days the worst with respect to a particular measure were identified from data on incidents, weather and high-demand.	http://www.itsdocs.fhwa.dot.gov/JPODOCS/REPTS_TE/13782.html
AN APPLICATION OF NEURAL NETWORK ON TRAFFIC SPEED PREDICTION UNDER ADVERSE WEATHER CONDITION	A neural network model for predicting traffic speed under adverse weather conditions is proposed. One link located in Chicago was chosen and all the data involved was collected from the Internet. The Back Propagation algorithm was used to train the neural network model for approaching the best prediction results. The MATLAB software was used to solve this model. The result has demonstrated that, neural network is an effective tool theory to predict traffic situation if appropriate model architecture and input data are available.	Transportation Research Board 82nd Annual Meeting, Search TRIS http://199.79.179.82/sundev/search.cfm
AN ASSESSMENT OF SELECT METROPOLITAN WASHINGTON PUBLIC SAFETY AND TRANSPORTATION AGENCIES USER NEEDS	Study of integrated information projects within the transportation community nationwide.	www.capwinproject.com/extras/reports/user_needs_assessment.pdf
AN IMPROVED DISPLACEMENT SNOWPLOW	Describes the research on improving the design of snowplows, as well as design, fabrication and testing of plows incorporating improvements. The primary goal was to decrease energy consumption during plowing by twenty percent.	http://gulliver.trb.org/publications/shrp/SHRP-H-673.pdf
AN INDEPENDENT EVALUATION OF THE OK-FIRST DECISION-SUPPORT SYSTEM	The Oklahoma Climatological Survey (OCS) implemented a DSS known as OKlahoma's First-response Information Resource System using Telecommunications to provide public safety officials with customized, county-level environmental information within minutes of observation.	http://okfirst.ocs.ou.edu/press/preprints/2envapps/1_11.pdf

TITLE	ABSTRACT	SOURCE
AN INTRODUCTION TO STANDARDS FOR ROAD WEATHER INFORMATION SYSTEMS (RWIS)	This brochure describes three categories of standards being considered for RWIS applications: siting standards, calibration standards, and communication standards. Note that the term "standard" refers to guidelines, recommended procedures, protocols, and other practices that formalize some of the processes involved in deploying and maintaining RWIS sensors. The standards described here are still being developed and are not mandated by the U.S. Department of Transportation. The U.S. DOT encourages agencies to use this brochure as a starting point to learn about RWIS standards and to consider how they might use these standards to reinforce their own RWIS operations.	http://www.ops.fhwa.dot.gov/weather/Publications/RWIS_brochure.pdf
AN INVESTIGATION OF INCIDENT FREQUENCY, DURATION AND LANES BLOCKAGE FOR DETERMINING TRAFFIC DELAY	Traffic delay caused by incidents is closely related to three variables: incident frequency, incident duration, and the number of lanes blocked by an incident. Relatively, incident duration has been more extensively studied than incident frequency and the number of blocked lanes. In this study, we provided an investigation of the influencing factors for all of these three variables based on an incident data set that was collected in New York City. The information about the incidents derived from the identification can be used by incident management agencies in New York City for strategic policy decision making and daily incident management and traffic operation. Rain is the only factor that significantly influenced incident frequency.	Transportation Research Board 81st Annual Meeting, Search TRIS http://199.79.179.82/sundev/search.cfm
AN OVERVIEW OF FEDERAL HIGHWAY ADMINISTRATION ROAD WEATHER MANAGEMENT PROGRAM ACTIVITIES	The Road Weather Management program of the Federal Highway Administration (FHWA) seeks to understand weather impacts on roads and promote techniques to improve roadway operations in inclement weather. This paper presents an overview of program objectives, various research and outreach projects, as well as tools used by traffic, emergency and maintenance managers.	Mitretek Systems
AN OVERVIEW OF SURFACE TRANSPORTATION WEATHER RESEARCH CONDUCTED THROUGH THE COOPERATIVE PROGRAM FOR OPERATIONAL METEOROLOGY, EDUCATION AND TRAINING (COMET)	In 2001, the National Weather Service (NWS) and the Federal Highway Administration (FHWA) began a joint research effort to evaluate how ESS data can best be used for both road condition forecasting and broader weather forecasting. This paper will describe the five research projects and their results to date. The five projects selected are located in Iowa, Nevada, New York, Pennsylvania, and Utah.	Mitretek Systems

TITLE	ABSTRACT	SOURCE
ANALYSIS OF WEATHER IMPACTS ON TRAFFIC FLOW IN METROPOLITAN WASHINGTON, D.C.	The Federal Highway Administration's (FHWA) Road Weather Management Program (RWMP) has been sponsoring research into the impacts of weather on surface transportation. One specific research task involved attempting to quantify the amount of travel delay imposed upon drivers due to the effects of inclement weather. This paper describes two different methods used to approximate travel delay impacts of weather along specific roadway segments around metropolitan Washington, D.C.	Mitretek Systems
ANALYSIS OF WEATHER-RELATED CRASHES ON U.S. HIGHWAYS	This paper presents results of an analysis of crashes on U.S. highways in poor road weather conditions. The objectives of the analysis were to update a March 2001 report titled "A Preliminary Analysis of U.S. Highway Crashes Against an Exposure Index", and to identify trends in the frequency of weather-related crashes.	Mitretek Systems
ANALYSIS OF WEB-BASED WSDOT TRAVELER INFORMATION: TESTING USERS' INFORMATION RETRIEVAL STRATEGIES	This report details the findings of a usability study of the Washington State Department of Transportation (WSDOT) traffic and weather information on the web. The purpose of this test was to examine the user experience associated with retrieving traveler information, such as road conditions, traffic congestion, pass information, construction, and weather from the WSDOT Traffic and Weather web site.	http://www.depts.washington.edu/trac/bulkdisk/pdf/552.1.pdf
ANALYZING THE EFFECTS OF WEB-BASED TRAFFIC INFORMATION AND WEATHER EVENTS IN THE SEATTLE PUGET SOUND REGION: DRAFT REPORT	Analysis of web-based ATIS usage logs against observed weather conditions, and generation of a new profile of ATIS market penetration. Simulation results were analyzed and compared to results from Mitretek's earlier MMDI study. Analysis showed that non-uniform ATIS utilization rate related to severe weather has a small positive impact on road system efficiency.	Mitretek Systems, ITS Division
ANOTHER STEP TOWARD A NATIONALLY INTEGRATED TRAVELER INFORMATION SYSTEM	Overview of traveler information including definition, explanation of growth, USDOT role and vision, and next steps.	www.itsdocs.fhwa.dot.gov/jpodocs/periodic/8ph01!.htm
ANTI ICING SUCCESS FUELS EXPANSION OF THE PROGRAM IN IDAHO	Idaho Transportation Department anti-icing success story on section of US Highway 12.	www.sicop.net/US-12%20Anti%20Icing%20Success.pdf

TITLE	ABSTRACT	SOURCE
ANTI-ICING STUDY: CONTROLLED CHEMICAL TREATMENTS	Correlations between meteorological parameters and chemical effectiveness can indicate the optimum conditions for a particular anti-icing chemical application. Anti-icing chemical treatments are more efficient when used for adhesion prevention than for removing snow and ice already in place	http://gulliver.trb.org/publications/shrp/SHRP-H-683.pdf
APPLICATION OF ADVANCED ITS INTERFACING THAT IMPROVES MAINTENANCE OPERATIONAL EFFECTIVENESS AND WINTER SAFETY IN RURAL AREAS	In 1995, the state DOT's of Iowa, Michigan, and Minnesota formed a consortium to define and develop the next-generation highway maintenance vehicle that would utilize the latest maintenance operational technologies and interface with Intelligent Transportation Systems. This advanced technology highway maintenance vehicle functions as both an operational truck and a mobile data-gathering platform. Sensors mounted on the vehicle record air and roadway surface temperature, roadway surface condition, and roadway surface friction characteristics.	http://www.ctre.iastate.edu/pubs/midcon/Smithson.pdf
APPLICATION OF JETTING TECHNOLOGY TO PAVEMENT DEICING	Over 20 years ago, the Connecticut DOT investigated the use of pressurized salt brine jets to enhance the deicing performance. Despite promising results from several field trails, technical difficulties led to abandonment of this technology in the early 80's. Recent advances in high pressure jetting technology suggest that the use of high pressure jets in conjunction with improved chemical agents for pavement deicing may now be practical. In this study, the application of modern high pressure jetting technology as a means of pavement deicing is explored. The proposed system removes ice and snow through the combined action of mechanical jetting forces and controlled use of deicing chemicals.	Transportation Research Board 81st Annual Meeting, Search TRIS http://199.79.179.82/sundev/search.cfm
APPLICATION OF ROAD WEATHER INFORMATION SYSTEMS IN THE WESTERN UNITED STATES	MesoWest software links weather observations from roughly 350 stations in the NWS surface aviation network and 2,100 additional stations, including RWIS stations. MesoWest collects and processes data from over 40 organizations. MesoWest data is available in Montana, Nevada, Utah and Wyoming through cooperative agreements between local NWS offices and state DOT agencies.	www.met.utah.edu/jhorel/html/mesonet/rwis.pdf
APPLICATION OF THE ADVANCED TRAVELER INFORMATION SYSTEMS (ATIS) MESSAGE STANDARD	Mitretek demonstrated an information system that provides route-specific travel forecasts that contain weather, traffic, and road closure information using eXtensible Markup Language (XML). The demonstration used XML data sets from a DOT's web site containing manual weather observations and RWIS data, as well as data from a web-based Pavement Condition Reporting System (PCRS).	8th World Congress on ITS, Mitretek Systems ITS Division

TITLE	ABSTRACT	SOURCE
APPLICATIONS OF A ROADWAY FROST PREDICTION SYSTEM IN IOWA	Various predictive systems have been explored to determine the best method to predict frost formation. Several different road frost, weather, and road temperature forecasts were examined and verified against human observations of frost on a bridge in Ames, Iowa during the winter of 2001-02. A frost deposition model was used to determine accumulated frost depth.	http://ams.confex.com/ams/annual2003/techprogram/paper_56029.htm
APPLICATIONS OF INTELLIGENT TRANSPORTATION SYSTEMS FOR WINTER MAINTENANCE	This paper describes potential applications of ITS for winter maintenance and provides examples of case studies. Moreover, the paper identifies and discusses the institutional, technical and operational barriers to the implementation of advanced technologies for ice and snow removal.	Transportation Research Board 80th Annual Meeting, Search TRIS http://199.79.179.82/sundev/search.cfm
APPLICATIONS OF INTELLIGENT TRANSPORTATION SYSTEMS FOR WINTER MAINTENANCE	This paper describes potential applications of ITS systems for winter maintenance and provides examples of case studies. Moreover, the paper identifies and discusses the institutional, technical and operational barriers to the implementation of advanced technologies for ice and snow removal.	Transportation Research Board 80th Annual Meeting, Search TRIS http://199.79.179.82/sundev/search.cfm
ARE SIMPLISTIC WEATHER-RELATED MOTORIST WARNING SYSTEMS "ALL WET"?	On a two-lane exit ramp in Ft. Lauderdale, Florida; an automated motorist warning system (including a wet pavement sensor and vehicle detector) that activates flashing beacons atop static speed limit signs. Speed reductions and reduced crash frequency resulted.	7th World Congress on ITS, University of South Florida.
AURORA PROGRAM RWIS SPECIFICATIONS	The goal of the "Compilation of RWIS Specifications" project is to develop a database of Aurora member RWIS construction, maintenance, and forecast specifications. This resource includes specifications from agencies in Arizona, Illinois, Iowa, Minnesota, Pennsylvania, Tennessee, Virginia, and Wisconsin	http://www.aurora-program.org/matrix.cfm
AVALANCHE HAZARD REDUCTION FOR TRANSPORTATION CORRIDORS USING REAL-TIME DETECTION AND ALARMS	Presents configurations of systems that detect and provide warning to motorists and highway maintainers of the onset of avalanching onto the roadway. Warnings include on-site traffic control signing and in-vehicle audio alarms for winter maintenance vehicles.	www.sicop.net/annals-paper%20total.pdf

TITLE	ABSTRACT	SOURCE
BENEFIT/COST STUDY OF RWIS AND ANTI-ICING TECHNOLOGIES	Report describes anti-icing and RWIS research and implementation efforts, and summarizes anti-icing technologies. Benefits and costs as reported in the literature and supplemented with interviews of highway professionals.	www.sicop.net/NCHRP20-7(117).pdf
BEST PRACTICES OF OUTSOURCING WINTER MAINTENANCE SERVICES	Contract language and provisions being used by various owner-agencies in the public sector. Best practices include clear contractual language placing responsibility on private sector to develop, train and equip personnel; confine language to measurable outcome-based performance measures; connect producer-contractor to user-customer; producers proactively responding to RWIS-based predictions and encouraged to utilized anti-icing; seek the sharing of knowledge; and maximize opportunities for the private sector to be responsive, efficient and effective. Appendix D contains sample contract provisions.	www.vmsom.com/images/pdf/Best%20Practices%20Outsourcing%20Winter%20Maintenance%20Services.pdf
CLOSING THE DATA GAP: GUIDELINES FOR QUALITY ADVANCED TRAVELER INFORMATION SYSTEM (ATIS) DATA	ITS America's ATIS Committee developed guidelines to assist public agencies and private firms in generating and using data to support the expansion of ATIS products and services. The focus of these guidelines is limited to real-time or dynamic traffic-related information necessary to offer traveler information services envisioned in the near-term.	www.itsdocs.fhwa.dot.gov//jpodocs/rept_mis/13580.html
COLLECTION OF VEHICLE SPEED DATA USING TIME-LAPSE VIDEO RECORDING EQUIPMENT	This paper describes an innovative application of time-lapse video recording to assist in a highway safety improvement evaluation. The highway safety improvement is an icy curve warning system near Fredonyer Summit in northern California that activates real-time motorist warnings via extinguishable message signs, based on weather readings collected from road weather information systems. One measure of effectiveness of the project is whether motorist speed is reduced as a result of real-time warnings to drivers.	Transportation Research Board 82nd Annual Meeting, Search TRIS http://199.79.179.82/sundev/search.cfm
CONSIDERATION OF ENVIRONMENTAL FACTORS IN TRANSPORTATION PLANNING: REVIEW AND ANALYSIS OF CURRENT POLICIES, PRACTICES AND TRENDS	This paper reviews current trends and practices for considering environmental factors in transportation planning at a systems level, in state DOTs and MPOs. The study is based on a review of the literature, and a survey and case studies of state DOTs and MPOs.	Transportation Research Board 82nd Annual Meeting, Search TRIS http://199.79.179.82/sundev/search.cfm

TITLE	ABSTRACT	SOURCE
CURRENT PRACTICES IN TRANSPORTATION MANAGEMENT DURING INCLEMENT WEATHER	Best practices include road weather and traffic surveillance to assess threats to transportation system performance, arterial and freeway management to regulate roadway capacity, as well as dissemination of advisory information to influence traveler decisions and driver behavior. These management practices are employed in response to various weather threats including low visibility, high winds, precipitation, hurricanes, flooding, and avalanches. Weather-related transportation management practices (1) improve mobility by increasing roadway capacity and promoting uniform traffic flow, (2) increase public safety by minimizing crash risk and exposure to hazards, as well as (3) enhance the safety and productivity of road maintenance personnel.	Institute of Transportation Engineers 2002 Annual Meeting, Mitretek Systems ITS Division
DATA INTEGRATION AND PLANNING FOR THE INSTALLATION OF AUTOMATIC BRIDGE ANTI-ICING SYSTEMS	This is the first of two papers focused on the issue of bridge prioritization for installation of automatic anti-icing systems. The objective of this paper is to illustrate the integration of data from various sources in a geographic information system (GIS) for the planning of automatic bridge anti-icing system installations. Database integration involved merging information on various criteria that were deemed important in the selection of bridges for anti-icing system installation. Data sources included: Nebraska Department of Roads (NDOR) bridge inventory, NDOR state accident data, NDOR maintenance yard data, archived weather data from the High Plains Regional Climate Center and the National Weather Service, and commercially available Nebraska streets, rivers, and streams data.	Transportation Research Board 82nd Annual Meeting, Search TRIS http://199.79.179.82/sundev/search.cfm
DECISION AID FOR PRIORITIZING BRIDGE DECK ANTI-ICING SYSTEM INSTALLATIONS	During winter conditions, moisture on bridge decks often freezes before the surrounding roadway surface. Automatic anti-icing systems spray chemicals that prevent or minimize ice bonding to the bridge deck. The Nebraska Department of Roads (NDOR) is interested in installing such systems on various bridges statewide. However, limited funding requires that bridges be prioritized for installation based on relevant criteria. The factors considered in the prioritization of installing automatic anti-icing systems include accident history, bridge alignment, weather, traffic, and bridge distance from maintenance yard, among others. Four different decision-aid methods; namely benefit-cost ratio, cost effectiveness, utility index, and composite programming; were considered. Given it's flexibility and advantages over other methods, composite programming appears to be the most suitable method for bridge prioritization.	Transportation Research Board 82nd Annual Meeting, Search TRIS http://199.79.179.82/sundev/search.cfm

TITLE	ABSTRACT	SOURCE
DECISION SUPPORT SYSTEM FOR WINTER MAINTENANCE: FEASIBILITY DEMONSTRATION	This project reports on existing work in developing decision support tools to select chemical applications appropriate to winter weather conditions, to describe in detail those which are at or near an operational state, and to assess the feasibility of implementation as part of a RWIS. A literature review identified four DSS: an expert system development project by the Swedish National Road Administration (SNRA), a table-based menu for anti-icing developed by FHWA, a computerized adaptation of the FHWA menu, and an expert system development by Swedish Road and Transport Research Institute.	Aurora Program, Ontario Ministry of Transportation
DESIGN GUIDELINES FOR THE CONTROL OF BLOWING AND DRIFTING SNOW	This report describes how to design effective and economical measures for controlling blowing and drifting snow. These measures include various snow fence designs to accommodate land use and right-of-way considerations; considerations for pavement design and appurtenances; proper siting of snow fence to compensate for terrain; and ways to use trees and plants as natural snow fences. The field research and sources of information are presented.	http://gulliver.trb.org/publications/shrp/SHRP-H-381.pdf
DEVELOPING A DESIGN POLICY TO IMPROVE PAVEMENT SURFACE CHARACTERISTICS	The Maryland State Highway Administration (MDSHA) routinely measures friction on State highways to assist with decision making associated with road maintenance management. The MDSHA uses the Friction Tester to monitor the micro-texture of the pavement aggregate during the service life of the pavement surface. Micro-texture is a measure of the degree of polishing of a road aggregate and is the main factor in determining the peak level of dry and wet friction provided by a pavement surface. The MDSHA is attempting to better understand surface frictional requirements at approach to pedestrian crossing, traffic lights, etc during wet weather and to establish minimum friction levels for different types of roadways based on accident data.	Transportation Research Board 82nd Annual Meeting, Search TRIS http://199.79.179.82/sundev/search.cfm
DEVELOPING THE FRAMEWORK OF A DYNAMIC TRAFFIC MANAGEMENT MODEL FOR HURRICANE EVACUATION: SUMMARY REPORT	Paper describes the development of a dynamic hurricane evacuation modeling framework, which can be used for planning and operational purposes. See also TRAFFIC MODELING FRAMEWORK FOR HURRICANE EVACUATION.	Transportation Research Board 79th Annual Meeting, Search TRIS http://199.79.179.82/sundev/search.cfm

TITLE	ABSTRACT	SOURCE
DEVELOPMENT AND TESTING OF VARIABLE SPEED LIMIT LOGICS AT WORK ZONES USING SIMULATION	Variable speed limits (VSL) have been primarily used to display reasonable speed limits to drivers based on real time road and weather conditions. They are also used to dynamically respond to traffic conditions especially at work zones or incidents. This paper presents the development of VSL control logic that can consider both safety and mobility measures at work zones. A surrogate measure of crash, minimum safe distance equation (MSDE), is proposed and a method of finding the optimum with respect to MSDE (the safety measure) and travel time (a mobility measure) has been elaborated.	Transportation Research Board 82nd Annual Meeting, Search TRIS http://199.79.179.82/sundev/search.cfm
DEVELOPMENT AND VALIDATION OF A MODEL TO PREDICT PAVEMENT TEMPERATURE PROFILE	To determine in-situ strength characteristics of flexible pavement, it is necessary to predict the temperature distribution within the hot-mix asphalt (HMA) layers. To determine the pavement temperature profile, the influence of ambient temperature and seasonal changes must be understood such that the effects of heating and cooling trends within the pavement structure can be quantified. It is possible to model daily pavement maxima and minima temperature by knowing the maximum or minimum ambient temperatures, the depth at which the pavement temperature is desired, and the day of year at a particular location. This paper extends that model to incorporate either the calculated daily solar radiation or latitude such that the model can be applied to any location.	Transportation Research Board 82nd Annual Meeting, Search TRIS http://199.79.179.82/sundev/search.cfm
DEVELOPMENT OF ANTI-ICING TECHNOLOGY	Nine state highway agencies conducted anti-icing experiments to determine when anti-icing is effective and how to conduct anti-icing efficiently. Anti-icing is effective and how to conduct anti-icing efficiently. Anti-icing treatment requires less chemicals than most deicing procedures and makes it easier to achieve bare pavement conditions. A limited cost-benefit analysis was performed, comparing anti-icing effectiveness with deicing operations. The findings of Scandinavian countries that use anti-icing are reviewed.	http://gulliver.trb.org/publications/shrp/SHRP-H-385.pdf
DEVELOPMENT OF HYBIRD MODEL FOR DYNAMIC TRAVEL TIME PREDICTION	This paper discusses a prediction model derived by integrating a path-based and link-based prediction models. Prediction results generated by the hybrid model and their accuracy are compared with those generated by the path-based and link-based models individually. The experimental results reveal that the predicted travel times with the path-based model are better than those predicted with the link-based model during peak-hours and vice versa. The hybrid model derives results from the best model at a given time, thus optimizing the performance.	Transportation Research Board 82nd Annual Meeting, Search TRIS http://199.79.179.82/sundev/search.cfm

TITLE	ABSTRACT	SOURCE
DEVELOPMENT OF ROAD SURFACE CONDITION SENSOR USING OPTICAL TEMPERATURE SENSOR AND WEATHER SENSOR	System is comprised of optical fiber embedded in the road and a temperature distribution measurement apparatus to measure longitudinal temperature distribution, ESS, and a judgment apparatus that classifies road conditions into five categories based on the various measurement data.	8th World Congress on ITS, Ministry of Land Infrastructure and Transport, Japan
DEVELOPMENT OF ROAD TEMPERATURE SENSING SYSTEM USING OPTICAL FIBER	Road surface temperature distribution sensing using optical fiber sensor embedded in roadway and ESS data. Tests on two kilometer section of National Route No. 18 in Nagano Prefecture, Japan.	7th World Congress on ITS, Ministry of Construction, Japan
DOCUMENTATION AND ASSESSMENT OF MN/DOT GATE OPERATIONS	Study conducted from March to August 1999 to assess new operational procedure prohibiting access to Interstates during unsafe driving conditions using mainline and ramp gates. Benefits and costs data.	www.dot.state.mn.us/guidestar/pdf/gatereport.pdf
DYNAMIC MESSAGING: A GUIDANCE DOCUMENT PROVIDING ADVISORY INFORMATION ON LOW-VISIBILITY WARNING SYSTEMS BASED ON RESEARCH AND ANALYSIS OF DEPLOYED SYSTEMS	The Enterprise program is multi-state pooled-fund study group with a focus on providing effective solutions for rural transportation applications. Enterprise, in cooperation with the Arizonia DOT, is researching solutions for problems motorists face in limited visibility situations. Identifies components of low-visibility warning systems and the techniques deployed by various states that best address improving safety by detecting low visibility events and disseminating advanced information to motorists as well further evaluating low-visibility detection technologies during these conditions.	Castle Rock Consultants
ECONOMIC EVALUATION OF ADVANCED WINTER HIGHWAY MAINTENANCE STRATEGIES	Estimated potential savings in labor and equipment costs of using pavement temperature data to customize material type and application rates.	http://www.itsdocs.fhwa.dot.gov/jpodocs/proceedn/4hy01!.pdf
EFFECT OF ENVIRONMENTAL FACTORS ON FREE-FLOW SPEED	Use of Idaho Storm Warning System project data to determine the effects of various weather factors on free-flow speed during 1997/1998 and 1998/1999 winter.	Proceedings of the Fourth International Symposium on Highway Capacity
EFFECTS OF VARIABLE SPEED LIMIT SIGNS ON DRIVER BEHAVIOR DURING INCLEMENT WEATHER	On a two-mile test roadway in Salt Lake Valley, Utah; speed limits are varied based on visibility and traffic conditions using a weighted average algorithm and display via DMS. Reduction in speed deviation, reduction in crash frequency, and increase in overall mean speed resulted.	Institute of Transportaion Engineers 2000 Annual Meeting, University of Utah

TITLE	ABSTRACT	SOURCE
EFFECTS OF VARIOUS DEICING CHEMICALS ON PAVEMENT CONCRETE DETERIORATION	Study investigating the effects of different deicers on concrete deterioration. Deicers produce characteristic effects on concrete samples by physically and chemically altering the aggregate, the aggregate-past interface, and the cement paste.	http://www.ctre.iastate.edu/pubs/midcon/Lee.pdf
EFFECTS OF WEATHER-CONTROLLED VARIABLE MESSAGE SIGNING ON DRIVER BEHAVIOUR	The purpose of the study was to investigate the effects of local and frequently updated information of adverse weather and road conditions on driver behavior. The information was transmitted by several DMS types including slippery road condition signs, minimum headway signs. Temperature displays and speed limits.	http://www.vti.se/nordic/1-02mapp/weather.htm
EFFICACY AND ECONOMIC EFFICIENCY FOR THAWING AGENTS SPRAY SYSTEMS - FINAL REPORT	With a length of 6 km, the thawing agents spray system used on the A45 (Sauerland line) is the longest installed in Germany. After the installation of this system, the number of crashes on the equipped road section and due to winter road conditions was reduced by more than 50 percent.	http://www.ops.fhwa.dot.gov/weather/Publications/GermanAnti-icingReport.pdf
ENHANCEMENTS TO THE VIRTUAL WEATHER STATION METHODOLOGY	Representative climatic conditions at any location can be estimated using data from nearby weather stations. The reasonableness of such estimates depends on the quality of weather data as well as method used in developing such estimates. This study investigates the possibility of improving the accuracy of climatic estimates. Four different methods of estimating the climatic parameters were studied and it was found that simple average of climatic parameters from nearby weather stations provides the most reasonable estimate. It was found that the elevation difference between the desired location and nearby weather stations significantly affects estimate bias. A relationship was developed to remove the bias due to elevation difference.	Transportation Research Board 81st Annual Meeting, Search TRIS http://199.79.179.82/sundev/search.cfm
ENVIRONMENTAL RESEARCH NEEDS CONFERENCE 2002 TRANSPORTATION ENVIRONMENTAL RESEARCH NEEDS STATEMENTS	Every five years the Transportation Research Board (TRB) conducts a Transportation Environmental Research Needs (ERN) Conference to select and draft top-priority statements of environmental research needs. These proceedings contain the top research needs identified at the conference, along with background papers. This report is published to assist those involved with government, university, and other research programs in selecting research projects that will have the greatest utility for the transportation environmental community.	http://gulliver.trb.org/publications/conf/reports/cp_28.pdf

TITLE	ABSTRACT	SOURCE
ENVIRONMENTAL SENSOR STATIONS (ESS) ITS STANDARDS ADVISORY: ADVISORY NO. 2	ITS Standards Advisories provide the transportation community with information and guidance on key activities related to ITS standards. Each Advisory focusing on a single ITS application and its corresponding standards. Standards Advisories highlight important, recent standards activities for the selected ITS application and provide links to more detailed information and resources. This advisory covers topics such as "The ESS Standard: What's New?", "Rolling Out ESS", "U.S. DOT Urges Use of ESS Standards", and "Standards Applicable to ESS Deployments".	http://www.its-standards.net/Documents/ess_advisory.pdf
ESTIMATING ADVERSE WEATHER IMPACTS ON MAJOR US HIGHWAY NETWORK	This paper presented a framework for estimating the impact, in terms of delay, of adverse weather events on travel in the United States. The Speed estimation methodology for travel in adverse weather was based on the Highway Capacity Manual. Using GIS and database tools, one can estimate travel delay and other relevant statistics at various resolutions including weather forecast zone, county, FHWA urbanized area, metropolitan area, state, and national levels. The estimation procedure employed NCDC's Storm Data and FHWA's HPMS and NHPN databases, which are all publicly accessible. The estimation procedure, which can be implemented repeatedly to assess the change from one year to the next, was used to estimate adverse weather impacts for the year of 1999.	Transportation Research Board 82nd Annual Meeting, Search TRIS http://199.79.179.82/sundev/search.cfm
EVALUATION OF A FIXED ANTI-ICING SPRAY TECHNOLOGY (FAST) SYSTEM	This paper describes the development of Fixed Anti-Icing Spray Technology (FAST) systems to apply less corrosive liquid chemical freezing-point depressants on portions of the Brooklyn Bridge. During the first phase of the project, several operational parameters were investigated, including spray pattern, spray angle and spray pressure. Phase II of this project describes the proposed extension of the FAST system and integration of a RWIS.	Transportation Research Board 81st Annual Meeting, New York City DOT
EVALUATION OF CALTRANS DISTRICT 10 AUTOMATED WARNING SYSTEM: YEAR TWO PROGRESS REPORT	The Caltrans Automated Warning System (CAWS) entered service in November 1996. The system includes 36 speed monitoring sites, 9 weather stations, 9 DMS and TMC computer systems. The independent evaluation was carried out by researchers at the University of California. The report bibliography includes summaries of all highway fog warning systems for which published information was available.	http://www.path.berkeley.edu/PATH/Publications/PDF/PRR/99/PRR-99-28.pdf
EVALUATION OF MOTORISTS WARNING SYSTEMS FOR FOG-RELATED INCIDENTS IN THE TAMPA BAY AREA	Investigation to determine extent of fog patterns and fog-related incidents in the Tampa Bay area, and suitable countermeasures to detect and warn motorists of fog conditions. Fog warning systems in Alabama, Arkansas, Georgia, New Mexico, Tennessee, Idaho, New Jersey, South Carolina, Louisiana, Oregon, Utah and California are discussed. Types of fog, conditions conducive to formation, and visibility detection technologies are also covered.	www.cutr.eng.usf.edu/research/fog.pdf

TITLE	ABSTRACT	SOURCE
EVALUATION OF SEASONAL EFFECTS ON SUBGRADE SOILS	This paper presents general expressions for the seasonal variations of average daily air temperature and variation of temperature and moisture in the fine-grained subgrade soil at the test site. An expression for the seasonal variation of resilient modulus was derived. Average monthly weighting factors that can be used for pavement design were computed. Other factors such as frost penetration, depth of water table and drainage conditions are discussed.	Transportation Research Board 82nd Annual Meeting, Search TRIS http://199.79.179.82/sundev/search.cfm
EVALUATION OF THE FORETELL CONSORTIUM OPERATIONAL TEST: WEATHER INFORMATION FOR SURFACE TRANSPORTATION	Defines strategy for conducing an independent evaluation of the FORETELL project, a regional road and weather forecasting/dissemination system in Iowa, Wisconsin, and Missouri.	http://www.itsdocs.fhwa.dot.gov/jpodocs/repts_te/7tr01!.pdf
EVALUATION OF THE OPERATION AND DEMONSTRATION TEST OF SHORT-RANGE WEATHER FORECASTING DECISION SUPPORT WITHIN AN ADVANCED RURAL TRAVELER INFORMATION SYSTEM	The Advanced Rural Traveler Information System (ARTIS) aims to provide en-route, operational decision support information including real-time and forecast weather conditions in rural areas. A three-year operational test was designed to measure user acceptance, use of the system for decision making, and use of weather-related data for maintenance operations.	www.itsdocs.fhwa.dot.gov/jpodocs/repts_te/@9301!.pdf
EVALUATION OF THE SEATTLE SMART TREK MODEL DEPLOYMENT INITIATIVE	Evaluation focused on institutional benefits, ATIS customer satisfaction, and ITS integration modeling. The impact of weather events was evident in the December 1998 web site usage levels.	Science Applications International Corporation (SAIC)
EVALUATION PROCEDURE FOR DEICING CHEMICALS AND IMPROVED SODIUM CHLORIDE	Encompasses a literature review of prior work, establishes criteria for characterizing chemical deicers, and identifies potential test methods for evaluating candidate deicing chemicals. Identifies 62 tests. Describes in detail 12 methods specifically developed for chemical deicers.	http://gulliver.trb.org/publications/shrp/SHRP-H-647.pdf
EVALUATION REPORT FOR THE EVACUATION TRAVEL DEMAND FORECASTING MODEL: DRAFT	The TDFM is a web-based software tool designed to predict congestion levels on major evacuation routes and predict state-to-state traffic volumes to aid in effective hurricane evacuation planning. Evaluation of the model was based on performance during a tabletop exercise.	Science Applications International Corporation (SAIC)

TITLE	ABSTRACT	SOURCE
EXTRACTION OF THE SLIPPERINESS COMPONENT FROM WEATHER AND TRAFFIC DATA FOR WINTER MAINTENANCE OPERATIONS	While traffic and weather information systems provide the current status of air and road surface temperatures, what many drivers really want to know is not the temperature but the degree of slipperiness. Although the friction coefficient is the best index for snow and ice maintenance operations, it is not so easy to manipulate. Some weather condition data are closely correlated with this friction coefficient. In this study, the substitutability of weather and traffic data is examined quantitatively through analysis of field data observed at an intersection.	Transportation Research Board 81st Annual Meeting, Search TRIS http://199.79.179.82/sundev/search.cfm
FEASIBILITY OF USING FRICTION INDICATORS TO IMPROVE WINTER MAINTENANCE OPERATIONS AND MOBILITY	NCHRP initiated Project 6-14 to evaluate the feasibility of using friction indications as tools for improving winter maintenance operations and mobility. This study has found that the use of friction measurements to improve winter maintenance operations and mobility is feasible (especially when deceleration devices are used), but devices with an extra wheel may not represent a practical solution to friction measurement. Therefore, direct friction measurements may not be a viable operational tool in winter maintenance (although they will and should be used as research tools). The study recommends a two-phase follow-up study to validate both scenarios and translate the findings into technology that improves the efficiency and effectiveness of snow and ice control operations, thereby reducing costs, increasing safety, and improving mobility of the driving public.	http://gulliver.trb.org/publications/nchrp/nchrp_w53.pdf
FIELD TESTS USING THE FREEZING POINT OF ROAD CHEMICALS IN WINTER MAINTENANCE OPERATIONS	The objective of this project was to field test a freezing point temperature sensor, as part of Phase IV of the Highway Maintenance Concept Vehicle Project. The project has performed field tests with a mobile monitoring system for freezing point temperature that detects the temperature at which materials on the road freeze.	2002 Joint Meeting of the CAATS and the RATTS, http://www.caats.org/Press%20Releases/CRCD.htm
FINAL REPORT ON SIGNAL AND IMAGE PROCESSING FOR ROAD CONDITIONS CLASSIFICATION	This paper evaluates two systems for classifying road conditions by using cameras and microphones respectively. One determines the road condition from an image of the road. Another uses a similar method to classify the road condition by analyzing the characteristic sound signals from passing cars on different road conditions. The systems have been operational during the winter season 2000/2001 in addition to manual observations of the road. The results from the evaluation are very satisfying especially for icy and wet road conditions.	AerotechTelub and Dalarna University
FLOOD WARNINGS ON-LINE	In Queensland, Australia; remote sensors are used to monitor creek and river water levels to warn motorists. The Queensland Department of Main Roads and the Royal Automobile Club of Queensland (RACQ) provide road condition information via web page (www.racq.com.au/journey) and toll-free telephone system with interactive voice response (IVR) technology.	ITS International, March/April 2001 Issue

TITLE	ABSTRACT	SOURCE
FREE AND OPEN EXCHANGE OF ENVIRONMENTAL DATA	The primary purpose of this Statement is to reassert the American Meteorological Society's commitment to a policy of free and open international exchange of environmental data, while at the same time endeavoring to draw critical distinctions among different types of environmental information.	http://www.ametsoc.org/AMS/policy/freeopenexch_final.html
FRICTION AS A TOOL FOR WINTER MAINTENANCE	Considers how friction measuring devices might be used operationally. They will likely be used as a measure of quality, as a source of traveler information, and as a means of controlling chemical application.	http://www.ctre.iastate.edu/pubs/crossroads/86friction.pdf
GETTING CLEAR ON FOG-RELATED CRASHES IN TAMPA BAY	Paper discusses a four-step process employed to evaluate advanced fog-detection technologies and suggest possible strategies to address fog-related incidents in the Tampa Bay Area. See also EVALUATION OF MOTORISTS WARNING SYSTEMS FOR FOG-RELATED INCIDENTS IN THE TAMPA BAY AREA.	www.path.berkeley.edu/~leap/itsdecision_resources/articles/S_ite_0200_fog_warning.pdf
HANDBOOK OF TEST METHODS FOR EVALUATING CHEMICAL DEICERS	Contains sixty-two test methods for the evaluation of chemical deicers in eight principal property performance areas, from physicochemical characteristics to health and safety aspects. Evaluations range from ice-melting tests to corrosion tests of reinforcement bar in concrete.	http://gulliver.trb.org/publications/shrp/SHRP-H-332.pdf
HAPPY MOTORING ON SAFER INTERSTATE HIGHWAY: HIGH-TECH FOG WARNING SYSTEM DEVELOPED AT GEORGIA TECH WILL ISSUE ADVISORIES TO MOTORISTS	An automated fog and smoke warning system will be deployed on 14 miles of Interstate 75 near Adel, Georgia. The system includes 19 fog sensors, ESS, speed detectors and CCTV. System software at GDOT's Atlanta TMC analyzes field data and decides which messages to display on four DMS and when to illuminate streetlights. A three-year evaluation is being planned.	http://gtresearchnews.gatech.edu/reshor/rh-ss01/fog.html
HIGHWAY DEICING: COMPARING SALT AND CALCIUM MAGNESIUM ACETATE (SPECIAL REPORT 235)	Deicing chemicals are important tools for highway snow and ice control. The National Research Council conducted a study to examine the full economic costs of using salt and CMA for highway deicing. The report defines the true cost of salt; estimates of monetary costs involved in mitigating environmental damage from road salt; summaries of the field performance, infrastructure and environmental impacts, production technologies and costs of CMA.	http://gulliver.trb.org/publications/sr/sr235.html
I-35W & MISSISSIPPI RIVER BRIDGE ANTI-ICING PROJECT: OPERATIONAL EVALUATION REPORT	A bridge that spans the Mississippi River on US Interstate 35W in Minneapolis, Minnesota has been fitted with a computerized system that sprays potassium acetate, an anti-icing chemical, on the bridge deck when data from environmental sensors indicate that hazardous winter driving conditions are imminent.	http://www.dot.state.mn.us/metro/maintenance/Anti-icing%20evaluation.pdf

TITLE	ABSTRACT	SOURCE
I-90 AUTOMATED GATE OPERATIONS SYSTEM	The Minnesota DOT is currently using 65 manually operated gates in three of eight Districts for directing traffic off rural interchanges and prohibiting access during unsafe driving conditions. The I-90 Automated Gate Operations system is comprised of four subsystems: traffic management, detection and sensor, communications (including wireless, landline, and internet access), and control and monitoring.	2002 Joint Meeting of the CAATS and the RATTS, http://www.caats.org/Press%20Releases/CRCD.htm
ICE-PAVEMENT BOND DISBONDING--FUNDAMENTAL STUDY	Illuminations the ice-pavement bond structure and the mechanics of its formation to provide a basis to develop techniques for destroying or disrupting the ice-pavement bond. The report characterizes the physical and chemical processes that cause deterioration in the bond formed between ice and asphalt and portland cement concretes.	http://gulliver.trb.org/publications/shrp/SHRP-H-643.pdf
ICE-PAVEMENT BOND DISBONDING--SURFACE MODIFICATION AND DISBONDING	Explores the research into new techniques for disbonding ice. Noncontact and contact methods are tested. Methods such as additives to alter surface texture; electromagnetic radiation; and abrasive air and liquid jets applied directly to ice pavement interface are discussed.	http://gulliver.trb.org/publications/shrp/SHRP-H-644.pdf
ICE-PAVEMENT BOND PREVENTION: FUNDAMENTAL STUDY	States the findings of an investigation of the freezing of water on portland cement concrete and asphalt concrete pavements. Surface analysis and mechanical testing techniques were used, as well as computer simulation of the crystallization process. Models, reference substrates, and actual pavements were used to isolate and control experimental variables. The ice-pavement system was studied as an adhesive joint in order to address the factors important to determining the ice adhesive strength.	http://gulliver.trb.org/publications/shrp/SHRP-92-606.pdf
IDAHO STORM WARNING SYSTEM OPERATIONAL TEST	Two phased test conducted on I-84 in southeastern Idaho between 1998 and 1993 to (1) determine accuracy of visibility sensors and (2) whether DMS reduce vehicle speed during low visibility conditions.	http://www.itsdocs.fhwa.dot.gov/jpodocs/repts_te/@cc01!.pdf
IDAHO'S ROAD WEATHER INFORMATION SYSTEM (RWIS) INTEGRATION PROJECT	The Idaho Transportation Department is spearheading a project to develop a web site that provides maintenance personnel with a "one-stop" access point for weather and road condition data in Idaho and within a 100 mile boundary of neighboring states. The project anticipates using existing data sources such as the NWS forecasts, Mesowest (University of Utah integrated weather system), and RWIS data from neighboring states. This paper details Idaho's approach to RWIS integration an the Challenges encountered.	2002 Joint Meeting of the CAATS and the RATTS, http://www.caats.org/Press%20Releases/CRCD.htm

TITLE	ABSTRACT	SOURCE
IDENTIFICATION AND DOCUMENTATION OF WEATHER AND ROAD CONDITION DISSEMINATION DEVICES AND DATA FORMATS	This project identifies means for improving consistency and usability of road and weather information presentation through identification of current and planned road and weather information dissemination systems and synthesis of various means for presenting information to end users.	www.aurora-program.org/pdf/standardinforpt.pdf
IDENTIFICATION OF TRIGGER WIND VELOCITIES TO CAUSE VEHICLE INSTABILITY	Study to determine the critical wind velocity and angle that would overturn different vehicles. A variety of road surface conditions, vehicle types and profiles, vehicle speeds, and vehicle loads are considered to identify the most critical condition.	Nevada DOT District II
IMPACT OF HIGHWAY ILLUMINATION ON TRAFFIC FATALITY IN VARIOUS ROADWAY AND ENVIRONMENTAL CONDITIONS	This paper investigates the impact of roadway illumination on traffic fatalities over a large geographic area. This research develops a systematic approach to assess the quality of service provided by the existing lighting system to traffic safety. Other factors, such as roadway design, traffic, and environmental conditions at the time of crash, can also be considered in the study.	Transportation Research Board 81nd Annual Meeting, Search TRIS http://199.79.179.82/sundev/search.cfm
IMPLEMENTATION GUIDELINES FOR LAUNCHING 511 SERVICES	The 511 Deployment Coalition has developed this document to assist implementers in their efforts to develop quality systems and to lay the foundation for ultimately establishing a consistent nationwide 511 service. These guidelines are designated as Version 1.1 and represent a thoughtful update of the original Implementation Guidelines published in November 2001. The Coalition plans to continue monitoring and reviewing the guidelines, producing updates as warranted. The Coalition intends to improve and expand these guidelines as implementers collectively march towards mature systems. The guidelines focus on two main areas: service content and service consistency.	http://www.its.dot.gov/511/511ver11.htm
IMPROVED VISIBILITY FOR SNOWPLOWING OPERATIONS	This digest describes several means, identified in NCHRP Project 6-12, that could improve visibility for snowplowing operations. The project included a review of existing and proposed approaches for improving visibility for snowplowing operations, the identification and development of potential means for improving these operations, and the conduct of limited field tests to evaluate the potential benefits of these means.	http://www.sicop.net/nchrp_rrd_250.pdf
IMPROVING PUBLIC RESPONSE TO HURRICANE FLOODING	Operational procedures include forecasts of the storm-total area average rainfall and its location in south Florida by the Miami Weather Forecast Office (WFO). If guidance from the Southeast River Forecast Center (RFC) indicates potential for flooding, a flood watch is issued. If flooding is imminent a flood warning is issued.	Proceedings of the American Meteorological Society (AMS) Symposium on Precipitation Extremes

TITLE	ABSTRACT	SOURCE
INFORMATION ON THE PLANNING, CONSTRUCTION AND OPERATION OF CHEMICAL THAWING AGENT SPRAYING INSTALLATIONS	Chemical thawing agent spraying systems are fixed equipment of the winter service. Road surface and weather condition detectors detect the ice formation of a road and trigger a thawing agent spraying system into operation. A spraying system allows the timely prevention of icing on hazardous places and assists a conventional (usually mechanical) winter service, by preventing the packing down of the snow layer.	http://www.ops.fhwa.dot.gov/weather/Publications/GermanAnti-icingGuidance.pdf
INTELLIGENT AND LOCALIZED WEATHER PREDICTION	Provides design details of a 24-hour weather prediction system for snow and ice control operations in road maintenance. The system accounts for detailed terrain effects. The system can produce weather maps at 6-hour intervals for meteorological users, or easy-to-read icons indicating rain, snow, temperature, and wind conditions laid on top of terrain and road network displays. Local weather observations can be incorporated into some forecasts.	http://gulliver.trb.org/publications/shrp/SHRP-H-333.pdf
INTELLIGENT VEHICLE INITIATIVE - SPECIALTY VEHICLE PLATFORM RESULTS FROM MINNESOTA'S FIELD OPERATIONAL TEST	In November 1999, the United States DOT FHWA awarded a major Intelligent Vehicle Initiative (IVI) grant to the Minnesota Department of Transportation. The intent of the project was to identify the safety and operational impacts of the technology, to guide future decisions regarding installation on specialized vehicles, and to encourage the development and appropriate deployment of such systems on all vehicle platforms. The technologies were tested in four snowplows, a State Patrol squad car, and an ambulance on a fifty-mile rural highway. This paper provides an overview of the project including technologies, evaluation, and findings.	Transportation Research Board 82nd Annual Meeting, Search TRIS http://199.79.179.82/sundev/search.cfm
INTERNET TECHNOLOGY-BASED ROAD INFORMATION SYSTEMS	A method of using eXtensible Markup Language (XML) technology, Road Web Markup Language (RWML) in the road information field is proposed.	http://rwml.its-win.gr.jp/papers-pdf/RWML-ITSWC1998Seoul.pdf
IOWA DOT WEATHER INFORMATION SYSTEM TO SUPPORT WINTER MAINTENANCE OPERATIONS	Understanding and interpreting weather information can be critical to the success of any winter snow and ice removal operation. Knowing when, where and what type of deicing material to use for a particular winter weather event can be a challenge. Knowing where to find the weather information needed to make decisions and what information to use can also be difficult. The Maintenance Division of the Iowa DOT has taken a number of steps to provide supervisors and operators with the weather information and training they need to make better operational decisions. A fifty-site RWIS coupled with a satellite delivered weather information system at nearly every maintenance garage have been sources for real-time weather information.	http://www.ctre.iastate.edu/pubs/midcon/Burk.pdf

TITLE	ABSTRACT	SOURCE
ITS APPLICATIONS FOR SNOW AND ICE CONTROL	Paper describes potential applications of ITS for winter maintenance and provides case studies.	7th World Congress on ITS (1026.pdf), Michigan State University
ITS INSTITUTIONAL ISSUES: A MAINTENANCE/OPERATIONS PERSPECTIVE	Details challenges of using advance technology to optimize resources. Personnel, training, and cost issues are discussed. The Aurora-sponsored project found that, particularly with RWIS, the proprietary nature of new technologies tends to hold public agencies to using equipment from a single vendor.	http://www.ctre.iastate.edu/pubs/midcon/Smithso2.pdf
LOSS OF LIFE IN THE UNITED STATES ASSOCIATED WITH RECENT ATLANTIC TROPICAL CYCLONES	Freshwater floods caused more than half of US deaths directly associated with tropical cyclones or their remnants during the 30-year period from 1970 to1999. Most fatalities occurred in inland counties. Statistical summary of casualties, reasons for losses, and review of efforts to mitigate threats.	http://ams.allenpress.com/amsonline/?request=get-pdf&file=i1520-0477-081-09-2065.pdf
MANAGEMENT OF ROADS IN WINTER USING CCTV CAMERA	A snowfall forecast system collecting and analyzing numerical data has been installed in Sapporo. A System for Managing Frozen Road Surface Using CCTV Camera enables real time monitoring of remote conditions. A system using CCTV images and ESS was developed to complement patrols and support efficient winter maintenance.	8th World Congress on ITS; Office Community Service Bureau, City of Sapporo, Japan
MANUAL OF PRACTICE FOR AN EFFECTIVE ANTI-ICING PROGRAM: A GUIDE FOR HIGHWAY WINTER MAINTENANCE PERSONNEL	Highway anti-icing is the snow and ice control practice of preventing the formation or development of bonded snow and ice by timely applications of a chemical freezing-point depressant. This manual provides information for successful implementation of an effective highway anti-icing program. It is written to guide the maintenance manager in developing a systematic and efficient practice for maintaining roads in the best conditions possible during a winter storm. It describes the significant factors that should be understood and must be addressed in an anti-icing program, with the recognition that the development of the program must be based on the specific needs of the site or region within its reach. The manual includes recommendations for anti-icing practices and guidance for conducting anti-icing operations during specific precipitation and weather events.	http://www.fhwa.dot.gov/reports/mopeap/eapcov.htm

TITLE	ABSTRACT	SOURCE
MEASUREMENT OF MOTORIST'S RELATIVE VISIBILITY INDEX (MRVI) THROUGH VIDEO IMAGES	This paper introduces a new road visibility index referred to as the motorists' relative visibility index (MRVI). This index represents the amount of visual information lost to the view of motorists due to atmospheric conditions in relation to the visual information available on an ideal clear day. MRVI is computed using readily available video images of roadways using relatively simple image processing techniques. MRVI is a road condition indicator and can be used for control of DMS, analysis of visibility effects on motorists, road closure decisions, and for fast identification of low visibility areas or time periods from a very large set of images collected from multiple video cameras.	Transportation Research Board 81st Annual Meeting, Search TRIS http://199.79.179.82/sundev/search.cfm
METEOROLOGICAL DATA AND XML	XML (eXtensible Markup Language) is a standard for communicating structured data. Use of XML is rapidly expanding, but the World Meteorological Organization (WMO) has not as yet taken a leading role in developing XML standards for meteorological information. This document analyzes the present use of XML in Meteorology and proposes options for WMO actions with a view to recommend a WMO standard for the exchange of data and metadata in XML.	http://www.wmo.ch/web/www/DPS/ET-DR-C-PRAGUE-02/Doc6(1).doc
MOBILITY AND SAFETY IMPACTS OF WINTER STORM EVENTS IN A FREEWAY ENVIRONMENT: FINAL REPORT	The main goal of the research project summarized in this report was the investigation of winter storm event impacts on the volume, safety and speed characteristics of interstate traffic flow. A literature review of weather related speed and trip choice factors, RWIS and traveler information dissemination was completed. . The models that resulted from this research can be applied in conjunction with each other to produce expected winter storm event volume and speed reductions (i.e., event travel and delay impacts), and crash increases (i.e., event safety impacts).	http://www.ctre.iastate.edu/pubs/midcon/Knapp1.pdf
MODEL OF HOUSEHOLD TRIP CHAIN SEQUENCING IN AN EMERGENCY EVACUATION	This paper presents an evacuation modeling framework that bridges the gap between observed household behavior and traditional evacuation models. The gap between observed behavior and theoretical models leads to longer-than-expected evacuation times. Through a series of two linear integer programs, this paper provides an expression for the household behavior in evacuation conditions. The first formulation determines the meeting location for the household members. The second formulation determines which drivers pick up each of the family members and the sequence of the collection. Tying these linear programs to traffic simulation software allows for a more complete evacuation simulation. Furthermore, information supply strategies may be incorporated into the simulation.	Transportation Research Board 82nd Annual Meeting, Search TRIS http://199.79.179.82/sundev/search.cfm
MODIFYING SIGNAL TIMING DURING INCLEMENT WEATHER	The largest decrease in vehicle performance occurs when snow and slush begins to accumulate on the road surface. Saturation flows (capacity) decrease by 20 percent, speeds decrease by 30 percent, and start-up lost times increase by 23 percent.	University of Utah, Transportation Research Board 80th Annual Meeting

TITLE	ABSTRACT	SOURCE
MULTI-FUNCTIONAL DEPLOYMENT OF AHS KEY TECHNOLOGY	Overview of state of development of key technologies for Advanced Cruise-Assist Highway System (AHS). Users services of AHS include support for road surface condition information. The functions required from road surface condition sensors are dry, wet, water film, new snow, packed snow, slush, packed snow ice sheet, and ice film. Laser radar sensors and millimeter wave radio meters are non-contact sensors able to detect road condition states.	Ministry of Construction, Japan
NATIONAL REVIEW OF HURRICANE EVACUATION PLANS AND POLICIES	This report includes information on the application of evacuation strategies and technologies, such as the use of reverse flow operations and intelligent transportation systems (ITS). It also summarizes current evacuation management policies, methods of information exchange, and decision-making criteria. The intent of this report is to provide a broad perspective on the current state of evacuation practices, while also presenting similarities and differences in individual state practices.	http://www.hurricane.lsu.edu/&EvacuationReview.pdf
NIGHTTIME VISIBILITY AND RETROREFLECTANCE OF PAVEMENT MARKINGS UNDER DRY, WET, AND RAINY CONDITIONS	The objective of this research was to determine the nighttime visibility of flat pavement marking tape, patterned pavement marking tape, and wet weather pavement markings tape under dry, wet (just after rainfall), and simulated rain conditions (ongoing one inch per hour rainfall). The measures of effectiveness were detection distances, eye fixation distributions, and the pavement marking retroreflectance.	Transportation Research Board 82nd Annual Meeting, Search TRIS http://199.79.179.82/sundev/search.cfm
OPERATOR INTERFACE DESIGN OF A LANE AWARENESS SYSTEM FOR SNOW REMOVAL OPERATIONS	Research conducted on a two-lane, rural state highway in Minnesota in low visibility conditions. Vehicle-mounted, magnetic, lane-tracking system displaying lane position through a prototype user interface with continuous visual reference to centerline or shoulder line, as well as peripheral modalities (i.e., directional seat vibration, peripheral visual displays in windshield corners, and an optional auditory warning). Could result in improved safety of operator and public, improved service levels (mobility) and reduced cost for snow removal operation operations and reduced economic impact on region. (productivity)	7th World Congress on ITS, University of Iowa
OPTIMAL CONTROL OF VARIABLE SPEED LIMITS AND ROAD LIGHTING BASED ON PREDICTED SHORT TERM SOCIO-ECONOMIC IMPACTS	In research conducted on a 6 km rural, two-lane road section in Finland during low visibility and winter weather conditions, information on traffic and weather conditions is input to a control system that executes the optimal decision (varying speed limits and roadway lighting intensity) on each road sections. The control system minimizes socio-economic costs (vehicle, time, environmental, lighting and crash costs), while maintaining an acceptable level of service.	7th World Congress on ITS; Helsinki Traffic Information Centre of FinnRA, Finland

TITLE	ABSTRACT	SOURCE
ORGANIZING FOR REGIONAL TRANSPORTATION OPERATIONS	Regional Operating Organizations (ROOs) are partnerships among transportation and public safety agencies to provide coordinated transportation operations on a regional basis. This Executive Guide provides an overview of the key features and critical elements impacting the development and longterm sustainability of ROOs. The guide is intended to serve as a resource for transportation management and operations leaders and decision makers. It highlights the findings and lessons learned from six case studies developed in conjunction with the National Dialogue on Transportation Operations. These six case studies are TRANSCOM in New York, New Jersey, and Connecticut; TransLink in Vancouver, British Columbia; the Metropolitan Transportation Commission (MTC) in the San Francisco Bay Area; the ITS Priority Corridor in Southern California; TranStar in Houston; and AZTech in Phoenix.	http://www.ite.org/library/ROOExecutiveGuide.pdf
PATTERNS OF CHLORIDE DEPOSITION NEXT TO A ROAD AS INFLUENCED BY SALTING OCCASIONS AND WINDS	Bulk deposition was collected in a field adjacent to highway E4 in SE Sweden in order to describe the deposition pattern of deicing salt. The result was related to wind characteristics and deicing activities on the road. Chloride was shown to be transported several hundreds of meters away from the road. The amount of air-borne chloride deposited in the roadside environment was well correlated to the road-salting intensity.	Transportation Research Board 82nd Annual Meeting, Search TRIS http://199.79.179.82/sundev/search.cfm
PERCOSTATION FOR REAL TIME MONITORING MOISTURE VARIATIONS, FROST DEPTH AND SPRING THAW WEAKENING	This paper presents the findings of the research and product development project, in which percostation (the road structure moisture, frost depth and spring law weakening monitoring station) was installed on a road in Rovaniemi, Finland. Percostation can be used to assist road officials in tracking real-time moisture levels, depth of the frost and especially the risk for the permanent deformations in the road structure during the spring thaw season. Based on the percostation measurement results, road officials can make decisions about measures to preserve the state of the road during critical conditions, for example by imposing weight restrictions during the worst thaw softening period.	Transportation Research Board 81st Annual Meeting, Search TRIS http://199.79.179.82/sundev/search.cfm
PERFORMANCE MEASURES FOR WINTER OPERATIONS	New winter maintenance vehicles are being equipped with DGPS receivers and numerous sensors that collect environmental data (e.g., pavement and air temperature), equipment status data (e.g., plow up / plow down), and material usage data (e.g., salt application rate). This paper describes a comprehensive set of performance measures for winter maintenance that can be computed from data collected by DGPS receivers and sensors on winter maintenance vehicles.	Transportation Research Board 82nd Annual Meeting, Search TRIS http://199.79.179.82/sundev/search.cfm

TITLE	ABSTRACT	SOURCE
PREDICTING WEATHER AND ROAD CONDITIONS: AN INTEGRATED DECISION SUPPORT TOOL FOR WINTER ROAD MAINTENANCE OPERATIONS	Winter road maintenance practitioners have expressed a strong interest in obtaining weather and road condition forecasts and treatment recommendations specific to winter road maintenance routes. These user needs led the Federal Highway Administration (FHWA) Office of Transportation Operations Road Weather Management Program to support the development of a prototype winter road Maintenance Decision Support System (MDSS). The system integrates weather and road data, weather and road condition model output, chemical concentration algorithms, and anti-icing and deicing rules of practice. This paper describes technical aspects of the MDSS (e.g., technologies, data fusion techniques, architecture) and how the ongoing consideration of stakeholder feedback has benefited the development effort.	Transportation Research Board 82nd Annual Meeting, Search TRIS http://199.79.179.82/sundev/search.cfm
PREDICTION OF DAILY TEMPERATURE PROFILE IN FLEXIBLE PAVEMENTS	The majority of previously published research on pavement temperature prediction has focused on predicting the annual maximum or minimum pavement temperature so as to recommend a suitable asphalt binder performance grade. However, modeling the pavement temperature on a daily or hourly basis has only been recently investigated. To determine the pavement temperature profile, the influence of ambient temperature and seasonal changes must be understood such that the effects of heating and cooling trends within the pavement structure can be quantified. In addition, the influence of different pavement structures on the temperature distribution within the pavement structure must be determined. This paper presents the temperature profile monitoring of flexible pavements on the Virginia Smart Road from March 2000 through May 2001. Developed models to predict the daily maximum and minimum temperature at depths to 0.188m within the pavement structure are presented.	Transportation Research Board 81st Annual Meeting, Search TRIS http://199.79.179.82/sundev/search.cfm
PROCEEDINGS FOR THE WEATHER INFORMATION FOR SURFACE TRANSPORTATION: DELIVERING IMPROVED SAFETY AND EFFICIENCY FOR TOMORROW	Symposium attended by a cross-section of transportation and weather professionals to establish national needs and requirements for weather information associated with decision-making actions involving surface transportation. See also WEATHER INFORMATION FOR SURFACE TRANSPORTATION (WIST): ESTABLISHING THE NATIONAL NEEDS AND REQUIREMENTS.	www.ofcm.gov/wist_proceedings/pdf/toc.pdf
PROCEEDINGS OF THE WORKSHOP ON STRATEGY FOR PROVIDING ATMOSPHERIC INFORMATION	The purpose of the workshop was to address issues identified in studies conducted by OFCM and the National Research Council (NRC). The workshop examined how the everincreasing inventory of atmospheric information could be accessed and used by those who need it. The issue was divided into two parts: getting the information to where it is needed, and insuring that users can read and understand that information.	http://www.ofcm.gov/sai/proceedings/pdf/00_opening.pdf

TITLE	ABSTRACT	SOURCE
REAL TIME FLOOD MODELING DUE TO THE SEVERE RAINFALL DURING A HURRICANE: THE WEST FORK OF THE CALCASIEU RIVER, CALCASIEU AND BEAUREGARD PARISHES, LOUISIANA	Flooding resulting from hurricanes is a major cause of loss of life and property. A new tool in understanding the nature and extent of flooding is now available to local emergency management and other personnel. This tool links hydrologic and hydraulic modeling programs, geographic information systems, and real time weather data. The tool provides local officials information to be used in selecting evacuation routes, buildings to be used as shelters, and areas to be impacted by rising flood waters. In addition, the technology provides local officials with information to mitigate flooding damage.	Louisiana State University
REAL TIME FORECASTING OF HURRICANE WINDS AND FLOODING	Forecasting system developed to support emergency preparedness, evacuation and sheltering decisions in Louisiana.	Louisiana State University
REDUCTIONS IN TRAFFIC SIGN RETROREFLECTIVITY CAUSED BY FROST AND DEW	A study of in-service traffic signs was undertaken to quantify the average effects of frost and dew on their retroreflective capabilities. Average reductions in retroreflectivity levels of 79 and 60 percent were found, respectively. Jurisdictions subject to frequent cycles of frost/dew should review usage guidelines governing the grade of sign materials used allowed for expected loss of retroreflectivity.	Transportation Research Board 82nd Annual Meeting, Search TRIS http://199.79.179.82/sundev/search.cfm
RELATIONSHIP BETWEEN WINTER ROAD SURFACE CONDITIONS AND VEHICULAR MOTIONS MEASURED BY GPS-EQUIPPED PROBE VEHICLES	Taxis, which move around ceaselessly over a wide area, have great potential as a sensor for detecting what the road surface conditions are like across a given area. In order to establish a method to estimate road conditions based on the vehicular motion of taxis, some field experiments were conducted using probe vehicles that fitted with vehicular motion sensors and a GPS device. The slip ratio, defined as the relative difference in speed between vehicle and tire wheel, was effective in indicating how slippery roads surfaces were. Some features of vehicular motion specific to slippery roads were identified and the discriminability of road conditions, whether icy or dry, without using wheel speed data, was also examined.	Transportation Research Board 82nd Annual Meeting, Search TRIS http://199.79.179.82/sundev/search.cfm
REMOTE SENSING AND EMERGENCY MANAGEMENT FOR COASTAL ENVIRONMENTAL DISASTERS	Natural coastal hazard include inundation events, erosion events, circulation and depositional processes, and biological hazards.	http://www.hurricane.lsu.edu/paper2A.htm

TITLE	ABSTRACT	SOURCE
REMOTE SENSING FOR TRANSPORTATION: REPORT OF A CONFERENCE	Proceedings summarize highlights from the conference held in December 2000. Sponsors include USDOT RSPA, NASA, AASHTO & National States Geographic Information Council. Themes of university consortia include Traffic Surveillance, Monitoring and Management; Environment Assessment, Integration and Streamlining; Transportation Infrastructure Management; and Disaster Assessment, Safety, and Hazards (DASH). The DASH theme includes flood, fog, snow, tornado and earthquake events.	http://gulliver.trb.org/publications/conf/reports/remote_sensing_1.pdf
REUNION ISLAND'S MERLIN PROJECT: AN ITS IMPLEMENTATION SUCCESS STORY	In response to rock falls triggered by torrential rains and high winds over a coastal road on Reunion Island (a French territory) in the Indian Ocean, traffic managers use automatic lane closure barriers on lanes near cliff and movable barriers to delineate travel lanes on remainder of road. From the TCC, they collect traffic and weather data and disseminate information via DMS. This technique increases safety by separating opposing traffic flows, reducing speed limits, and reducing incident response times.	7th World Congress on ITS, Direction Departementale de l'Equipement, France
REVIEW OF THE INSTITUTIONAL ISSUES RELATING TO ROAD WEATHER INFORMATION SYSTEMS (RWIS): FINAL REPORT	This project, funded by the Aurora Program, aimed to identify and document institutional issues relating to the implementation and development of Road Weather Information Systems (RWIS). The project comprised two main phases. The first phase involved performing a review of existing documentation of RWIS institutional issues, and summarizing these findings. The intent of the project was to explore the coordination and standardization issues of RWIS taking place within and between agencies, for example, rather than the technical aspects of RWIS. Using the literature review findings as background information, the second phase involved gathering information on the status of RWIS developments in a variety of agencies with responsibilities for RWIS, and also documenting first-hand experiences in implementing and deploying RWIS.	http://www.aurora-program.org/pdf/inst_issues.pdf
ROAD FLOOD WARNING SYSTEM	The Road Flood Warning System provides predictive road flooding information on Queensland (Australia) river crossings. The system obtains river height forecasts from the Bureau of Meteorology. It generates predictive information based on a set of pre-determined river height criteria of the concerned roads. The system improves the current road closure process by providing timely alerts for traffic managers to respond. At the locations that the Bureau does not monitor, regression and artificial neural network technology are used to correlate local condition with upstream river height stations. Predictive information is to be published in the Internet and used to activate roadside advisory devices as the additional elements to the existing traveler information service.	Queensland Department of Main Roads (Australia)

TITLE	ABSTRACT	SOURCE
ROAD WEATHER INFORMATION SYSTEM (RWIS): ENABLING PROACTIVE MAINTENANCE PRACTICES IN WASHINGTON STATE	Washington State DOT's "rWeather" program has integrated and expanded the capabilities of RWIS in the state, enabling proactive winter maintenance practices and better informed winter travel decisions. Report reviews potential benefits of a comprehensive, integrated RWIS; examines use and opinions of RWIS by maintenance personnel; identifies barriers to expanded use of RWIS technologies; and evaluates public response to the "rWeather" traveler information website.	http://www.wsdot.wa.gov/PPSC/Research/CompleteReports/WARD529_1RWISEval.pdf
ROAD WEATHER INFORMATION SYSTEMS (RWIS) DATA INTEGRATION GUIDELINES	The goal of the RWIS Data Sharing and Integration Guidelines is to provide agencies with a tool to fully utilize all of the road and weather data that is a available to them. This project, sponsored by the ENTERPRISE and Aurora consortium, was conducted in two phases. Phase one involved the composing of a survey for DOTs on their current RWIS practices and their thoughts on the benefits of and barriers to RWIS integration and data sharing. Phase two of this project utilized past research into RWIS practices and successfully integrated systems along with the survey results of phase one to present a discussion of the various issues involved in the deployment of a data integration project. This final report combines the two technical memoranda to present a comprehensive view of the state-to-practice for the deployment and integration of RWIS, and how an integrated system, capable of sharing information with other agencies, may be successfully established.	Castle Rock Consultants, Inc.
ROAD WEATHER INFORMATION SYSTEMS VOLUME 1: RESEARCH REPORT	Reviews current snow and ice control practices, communication of road weather information, and the potential uses of such information in roadway snow and ice control within highway agencies. Presents considerations regarding the location of road weather information systems and discusses possible cost-reduction ranges for implementation. Offers conclusions and recommendations for state and local highway maintenance agencies.	http://gulliver.trb.org/publications/shrp/SHRP-H-350.pdf
ROAD WEATHER INFORMATION SYSTEMS VOLUME 2: IMPLEMENTATION GUIDE	Supplements Volume 1. Describes the current technology, information sources, communication requirements, and proper siting of sensors. Includes sample requests for proposals for the necessary equipment and services.	http://gulliver.trb.org/publications/shrp/SHRP-H-351.pdf
ROAD WEATHER INFORMATION SYSTEMS: SOME FINDINGS ON HOW RWIS INFORMATION SHOULD BE DISSEMINATED TO THE TRAVELING PUBLIC	Survey of four potential user groups of RWIS information: commuters, recreational travelers, long distance travelers, and truckers. Results show that DMS, commercial radio and HAR are the most popular delivery methods. Road condition information (e.g., accumulating snow, fog, ice, wind and road closures) is preferred over information on alternate routes, travel times, or travel speeds. Preferred delivery times are one hour before departure and while en-route.	Transportation Research Board 80th Annual Meeting, Search TRIS http://199.79.179.82/sundev/search.cfm

TITLE	ABSTRACT	SOURCE
ROCKFALL HAZARD ASSESSMENT AND REMEDIATION AT HANO VILLAGE HOPI INDIAN RESERVATION, POLACCA, AZ	In November 2001, personnel from the Central Federal Lands Highway Division FHWA, began working with the Bureau of Indian Affairs (BIA) and Hopi tribe to mitigate pending rockfall hazards at First Mesa, AZ. This report describes the factors contributing to rockfall hazards at First Mesa, the various construction, environmental, and cultural limitations on remediation, alternative recommendations for hazard mitigation, and the expected results of the rock removal effort	Transportation Research Board 82nd Annual Meeting, Search TRIS http://199.79.179.82/sundev/search.cfm
RURAL FREEWAY MANAGEMENT DURING SNOW EVENTS - ITS APPLICATION	Based upon visibility, road surface conditions, and capacity of towns to accommodate motorists; the Minnesota DOT and law enforcement personnel activate warning sign, lower (or swing) gate arm, and activate gate lights to prohibit access to rural interstate freeways. Law enforcement personnel are positioned at gate location during closing and reopening. Systematic and well-coordinated plan for closing and reopening has reduced delay (mobility), accident frequency (safety), and lowered DOT costs to clear and reopen by 15 percent (productivity). Significant time savings result in less overtime pay. Future plans include the addition of fixed and portable VMS, CCTV cameras, and an electronic map.	7th World Congress on ITS, Minnesota DOT
RURAL ITS APPLICATIONS FOR SNOW MAINTENANCE AND WINTER HAZARD MITIGATION	Presents emerging ITS concepts and products for winter maintenance safety developed from the Ideas Deserving Exploratory Analysis (IDEA) program managed by Transportation Research Board. Includes fleet management, avalanche detection and gateway management system, fiber-optic-based visibility information system, and road condition sensor system concepts/products.	Transportation Research Board, Search TRIS http://199.79.179.82/sundev/search.cfm
SAFETY APPLICATIONS OF ITS IN RURAL AREAS	Report examines infrastructure-based technology applications aimed at reducing the frequency and/or severity of rural crashes. The main focus is on variable speed limit (VSL) systems and warning systems.	www.itsdocs.fhwa.dot.gov//JPODOCS/REPTS_TE//13609.htm
SIGNS OF RAIN	The New South Wales Roads and Traffic Authority has expanded DMS use to warn motorists during wet weather conditions.	8th World Congress on ITS

TITLE	ABSTRACT	SOURCE
SIMULATION OF A GEOTHERMAL BRIDGE DECK ANTI-ICING SYSTEM AND EXPERIMENTAL VALIDATION	The design of heated bridge deck anti-icing systems requires assessment of long-term performance under expected future weather conditions. A method of simulating the performance of such a system has been developed. The system studied in this work uses a bridge deck with embedded hydronic tubing and a ground-coupled heat pump system with vertical borehole heat exchangers as a heat source. The models of each component and their integration into the simulation of the whole system are described. Validation of the simulation method has been attempted by making use of operating data collected from an experimental heated bridge deck installation. The collection of data, estimation of the model parameters, and comparison of the simulation results with the measured data are discussed. Results indicate that the system simulation of the heated bridge deck is able to predict performance with reasonable accuracy under a range of weather and operating conditions.	Transportation Research Board 82nd Annual Meeting, Search TRIS http://199.79.179.82/sundev/search.cfm
SMART CONTROL OF A GEOTHERMALLY HEATED BRIDGE DECK	This manuscript describes the "smart" control system designed for a geothermal bridge deck heating system. The control system integrates concepts of model predictive control with a first-principles bridge deck model and hourly computerized National Weather Service (NWS) forecasts to prevent bridge icing without the use of salt or other chemical deicing materials. The proactive nature of the control system maximizes motorists safety and bridge life while minimizing system operating costs.	Transportation Research Board 82nd Annual Meeting, Search TRIS http://199.79.179.82/sundev/search.cfm
SNOW & ICE CONTROL OPERATIONS	Describes various aspects of Caltrans' methods of controlling snow/ice on mountainous highways, including chain controls, materials, environmental concerns, equipment, personnel management, communications, forecasting, enforcement, and avalanche control.	www.dot.ca.gov/hq/roadinfo/snwicecontrol.pdf
SNOW EMERGENCY VEHICLE ROUTING WITH ROUTE CONTINUITY CONSTRAINTS	This paper summarizes new results from continuing research dealing with development of a decision support system for assisting the Maryland State Highway Administration Office of Maintenance staff in designing snow emergency` routes for Calvert County. By taking into account some of the more realistic constraints, we try to solve two problems. One involves minimizing the total number of trucks and, the second one involves minimizing the total deadhead distance given the number of trucks. The two problems do not result in identical solutions in general. Some application results are also reported which indicate using such a system can achieve improvements in service and savings in operational costs.	Transportation Research Board 81st Annual Meeting, Search TRIS http://199.79.179.82/sundev/search.cfm
SNOW FENCE GUIDE	This guide provides construction plans and guidelines for placement of snow fence for maximum effectiveness and cost-efficiency. It also explains ways to work with landowners to obtain cooperation with a snow fence program, and it discusses considerations involved with use of trees and shrubs to block blowing snow.	http://gulliver.trb.org/publications/shrp/SHRP-H-320.pdf

TITLE	ABSTRACT	SOURCE
SOCIOECONOMIC IMPACTS OF HEAVY PRECIPITATION IN THE UNITED STATES	Flood losses rank just behind hurricane losses as the second greatest cause of economic losses from weather, and flood losses continue to grow. The number of lives lost due to flooding is decreasing but still ranks as the third highest cause of death ranking behind heat waves and lightning. Heavy rain in the Chicago metro area create rain-slick streets and highways causing three times the number of crashes than occur in light rain conditions. They also cause a 25 percent increase in the number of fatalities.	American Meteorological Society Conference Proceedings
SOUTHEAST MICHIGAN SNOW AND ICE MANAGEMENT (SEMSIM)	The Southeast Michigan Snow and Ice Management (SEMSIM) partnership includes the Detroit Department of Public Works, the Road Commission of Macomb County, the Road Commission for Oakland County, and Wayne County Department of Public Services. The purpose of the partnership is to develop an AVL (Automatic Vehicle Location) system that will allow the partners to fight a snowstorm in a cooperative effort. This report provides an evaluation of the first season, the winter of 1999-2000. The evaluation centered on determining if the system (1) provided the tracking and reporting tools that the SEMSIM partners wanted and (2) improved efficiency and impacted standard ITS measures in a positive way.	Road Commission for Oakland County
SOUTHEAST UNITED STATES HURRICANE EVACUATION TRAFFIC STUDY	Study to address problems during the Hurricane Floyd evacuation. The study documents behavioral analysis, Evacuation Travel Demand Forecast Model, reverse lane standards, and ITS strategies.	www.fhwaetis.com/etis
SPATIAL VARIABILITY OF THAW DEPTH	Statistical and spatial analyses were used to determine the variability of thaw using existing thaw depth datasets from various sites with a variety of climatic and terrain conditions. Results from the statistical and spatial analysis can be used to develop an approach to characterizing the spatial variability of thawing soil, to spatially distribute soil properties based on point data or one-dimensional models, or to populate sparse data sets with terrain properties. They are also useful for analyzing impact of thaw distribution on predictive models, such as for predicting vehicle mobility or surface runoff.	Transportation Research Board 82nd Annual Meeting, Search TRIS http://199.79.179.82/sundev/search.cfm
STATE OF THE PRACTICE AND REVIEW OF THE LITERATURE: SURVEY OF FOG COUNTERMEASURES PLANNED OR IN USE BY OTHER STATES	DOTs from 49 states (all but Virginia) were contacted in an effort to document the fog countermeasures that are currently in use or being planned by the other states. The results are presented in the report, along with the contact name and phone number or email address for each state.	Virginia Tech Research Council

TITLE	ABSTRACT	SOURCE
SURFACE TRANSPORTATION SAFETY AND OPERATIONS: THE IMPACTS OF WEATHER WITHIN THE CONTEXT OF CLIMATE CHANGE	This paper examines weather impacts on roadways, operational practices of transportation managers and road users, and the weather parameters with the greatest effects on roadways. Finally, a discussion of how possible climate change may affect these parameters during the next century is presented.	Mitretek Systems
SURFACE TRANSPORTATION WEATHER APPLICATIONS	Weather threatens surface transportation nationwide and impacts roadway mobility, safety, and productivity. There is a perception that traffic managers can do little about weather. However, three types of mitigation measures—control, treatment, and advisory strategies—may be employed in response to weather threats. Road weather data sharing, analysis, and integration are critical to the development of better road weather management strategies. Environmental information serves as decision support to traffic, maintenance, and emergency managers; and allows motorists to cope with weather effects through trip deferrals, route detours, or driving behavior.	Institute of Transportation Engineers 2002 Annual Meeting, Mitretek Systems ITS Division
SURFACE TRANSPORTATION WEATHER DECISION SUPPORT REQUIREMENTS	This series of documents presents the latest findings of the ongoing Surface Transportation Weather Decision Support Requirements (STWDSR) project. STWDSR Draft Version 1.0 documents the weather information requirements of all road users and operators. STWDSR Draft Version 2.0 focuses on the decision support requirements of a particular stakeholder group--winter road maintenance engineers. It also presents an operational concept for a Weather Information for Surface Transportation Decision Support System (WIST-DSS).	http://www.itsdocs.fhwa.dot.gov/jpodocs/repts_te/94f01!.pdf http://www.itsdocs.fhwa.dot.gov/jpodocs/repts_te/9dc01!.pdf http://www.itsdocs.fhwa.dot.gov/jpodocs/repts_te/9db01!.pdf http://www.itsdocs.fhwa.dot.gov/jpodocs/EDLBrow/401!.pdf http://www.itsdocs.fhwa.dot.gov/jpodocs/repts_te/@701!.pdf
SYNTHESIS OF BEST PRACTICES FOR INCREASING PROTECTION AND VISIBILITY OF HIGHWAY MAINTENANCE VEHICLES	The purpose of this research project is to study current practices in enhancing visibility and protection of highway maintenance vehicles involved in moving operations such as snow removal and shoulder operations, crack sealing, and pothole patching. This project report provides the most recent information on current moving operation practices throughout the country and the state of Iowa. It will enable the maintenance staff to adequately assess the applicability and impact of each strategy to their use and budget. The report's literature review chapter examines the use of maintenance vehicle warning lights, retroreflective tapes, shadow vehicles and truck-mounted attenuators (TMAs), and advanced vehicle control systems (AVCSs), as well as other practices to improve visibility for both snowplow operators and vehicles.	http://www.ctre.iastate.edu/reports/visibility.pdf

TITLE	ABSTRACT	SOURCE
SYNTHESIS OF ROAD WEATHER FORECASTING	Survey to document relationships between national surface transportation agencies and meteorological agencies. The countries of Canada, Denmark, Finland, Germany, Japan, New Zealand, Norway, Sweden and the United Kingdom were surveyed.	www.aurora-program.org/pdf/synthesis_weather.pdf
SYNTHESIS OF STUDIES ON SPEED AND SAFETY	Paper examines previous studies on the relationship between speed an safety and gives an overview of research interests. Weather affects safety through impaired visibility, decrease stability and reduced controllability. One study found that drivers appear to compensate for increased injury risks in that injuries are more frequent but less severe in adverse weather crashes. Another study found that speed variance is also impacted by weather. The standard deviation doubles during fog events and triples during snow. This study also found an average reduction of 0.7 mph for every mph that wind speed exceeds 25 mph. Another study estimated that wind speed above 30 mph reduced free flow speed by 5.6 mph.	Transportation Research Board 80th Annual Meeting, Search TRIS http://199.79.179.82/sundev/search.cfm
SYSTEM MONITORS FLOOD-PRONE CREEKS	The City of Palo Alto, California maintains a "Creek Level Monitor" website that displays water levels at five bridge locations. The system detects water levels with ultrasonic devices under bridges and transmits data to the communication system that controls storm pump stations. City residents receive advanced warning of flood conditions.	www.civic.com/civic/articles/2001/0122/web-flood-01-26-01.asp
TEMPERATURE AND HUMIDITY EFFECTS ON THE CO-EFFICIENT OF FRICTION VALUE AFTER APPLICATION OF LIQUID ANTI-ICING CHEMICALS	Experiment conducted in Canada to establish the reliance of various anti-icing chemicals based on temperature and humidity; specifically to determine what roll they play on road co-efficient of friction. Research showed that when most anti-icing chemicals transition from liquid to solid, and solid to liquid, a "slurry" phase is formed; producing relatively short-lived reductions in friction co-efficient.	http://www.wsdot.wa.gov/partners/pns/pdf/slicknessrpt.pdf
TESTING THE ADVERSE VISIBILITY INFORMATION SYSTEM EVALUATION (ADVISE) - SAFER DRIVING IN FOG	There are many advisory systems to warn drivers of fog. However, warning drivers that there is fog ahead does not instruct them on what to do. During the 1995-2000 winter seasons, a new technology known as the Adverse Visibility Information System Evaluation (ADVISE) was tested. ADVISE uses visibility sensors to determine current sight distance and corresponding safe speed for the prevailing conditions. DMS instruct drivers of safe speed. This research measures the effectiveness of the system in reducing the variability between speeds. ADVISE successfully reduced speed variability by an average 22 percent.	University of Utah, Transportation Research Board 81st Annual Meeting

TITLE	ABSTRACT	SOURCE
THE ADVANCED TRANSPORTATION WEATHER INFORMATION SYSTEM (ATWIS)	The Advanced Transportation Weather Information System (ATWIS) project was designed to provide a current road and forecasted weather report to the traveling public and commercial vehicles within North and South Dakota. This prototype project was to investigate how to merge information and current technologies from both state and private industry to provide in-vehicle decision support data for the traveler. The ATWIS was conceived and designed to provide information specifically for ground transportation, its users and maintainers. This paper examines the development and operational history of the multi-state ATIS.	http://www.ctre.iastate.edu/pubs/midcon/Owens.pdf
THE EFFECT OF VARIABLE MESSAGE SIGNS ON THE RELATIONSHIP BETWEEN MEAN SPEEDS AND SPEED DEVIATIONS	This research studies the effect of DMS on the relationship between hourly cross-sectional mean speeds and speed deviations. This section of I-90 in the vicinity of Snoqualmie pass, Washington is a rural freeway location subject to adverse weather conditions, and experiences over seventy-five reported vehicle crashes annually. DMS were installed to reduce crash potential by effective speed and traffic flow management. Aggregate results on vehicle speeds and vehicle speed deviations at the hourly level show that there is a significant decrease in mean speed when the DMS are on, along with a significant increase in speed deviation.	Transportation Research Board 81st Annual Meeting, Search TRIS http://199.79.179.82/sundev/search.cfm
THE EFFECT OF WEATHER ON FREE FLOW SPEED	Free flow speed is affected by pavement conditions, visibility and wind speeds. The effects of poor weather should be considered in such cases as part of capacity and level-of-service analyses.	Transportation Research Board 80th Annual Meeting, University of Idaho
THE MEASUREMENT AND THEORY OF TIRE FRICTION ON CONTAMINATED SURFACES	Summarizes results of various studies related to friction characteristics of wet, snowy and icy pavement. Preliminary project showed that modeling constants can be used to differentiate contaminates (water, snow, ice), and that friction levels can be monitored for salting control.	http://www.ctre.iastate.edu/pubs/crossroads/94measurement.pdf
THE ROLE OF GROUND-BASED GPS METEOROLOGICAL OBSERVATIONS IN NUMERICAL WEATHER PREDICTION	A significant effort has been expended to develop new or improved remote sensing systems to observe moisture fields (including water vapor and clouds). One such system uses ground-based GPS receivers to make accurate all-weather estimates of atmospheric refractivity. The first and most mature use of GPS for this purpose is in the estimation of integrated (total column) precipitable water vapor. NOAA/FSL has shown that GPS integrated water vapor data can be used effectively in objective and subjective weather forecasting.	http://www-frd.fsl.noaa.gov/pub/papers/Gutman2001a/p.pdf

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THE ROLE OF NEW DATA COLLECTION TECHNOLOGY IN PERFORMANCE SPECIFIED MAINTENANCE CONTRACTS	This paper shall describe the form of contract and the role that technology developments have played in allowing clients to specify performance and contractors the ability to manage to them. The paper shall refer to long-term road maintenance contracts that have been in operation in Australia for the past seven years and New Zealand for four years and developments seen in the latest generation of contract documents.	Transportation Research Board 82nd Annual Meeting, Search TRIS http://199.79.179.82/sundev/search.cfm
THE USE OF ABRASIVES IN WINTER MAINTENANCE: FINAL REPORT OF PROJECT TR 434	Report reviews the state of the practice of abrasive usage in Iowa counties and classifies usage according to effectiveness.	www.sicop.net/Abrasives%20report.pdf
THE USE OF MOBILE VIDEO DATA COLLECTION EQUIPMENT TO INVESTIGATE WINTER WEATHER VEHICLE SPEEDS	Research involves traffic and weather data (i.e., visibility, roadway snow cover, volume, speed, and headway/gap data) collected by a trailer-mounted video data collection/monitoring system. Collected data used to predict vehicle speed and speed variability. Results indicate that average winter weather speed was 16 percent lower than that in speed under dry conditions. In winter weather, speed variation was 307 percent higher than variation during dry conditions. The resulting model predicted that off-peak winter weather speeds would decrease by 3.9 mph when visibility fell below one-quarter mile, and decrease by 7.3 mph when snow began to cover roadway lanes.	Transportation Research Board 79th Annual Meeting, Search TRIS http://199.79.179.82/sundev/search.cfm
THE USE OF SELECTED DEICING MATERIALS ON MICHICAN ROADS: ENVIRONMENTAL AND ECONOMIC IMPACTS	This report analyzes the performance, environmental effects and economic costs of seven deicing materials including sodium chloride (road salt), calcium magnesium acetate (CMA), a potassium chloride product (CMS-B) patented by Motech, a patented corrosion-inhibiting salt (CG-90 Surface Saver), calcium chloride, a patented concrete road surface containing calcium chloride pellets (Verglimit), and sand.	http://www.michigan.gov/mdot/0,1607,7-151-9622_11045_21847---,00.html
THERMAL ASPECT OF FROST-THAW PAVEMENT DIMENSIONING: IN SITU MEASUREMENT AND NUMERICAL MODELING	The thermal behavior of pavements in winter has a major influence on their dimensioning. The Paris-based Laboratories Central Des Ponts et Chauss'ees (LCPC) and the ministe're des Transports du Quebec (MTQ) have models to forecast the propagation of frost, frost heave and thaw phenomena. They have developed a collaborative project to validate these models on an experimental pavement. This pavement was constructed in Quebec in 1998 and its thermal behavior was monitored for three years. This paper presents the assessments of the thermal models. It describes the models, site and the temperature conditions of the three winters, pavement structures and their physical properties, instrumentation set up, and the analysis and comparison of the results of the models among themselves and in relation to the observations conducted on the pavements.	Transportation Research Board 82nd Annual Meeting, Search TRIS http://199.79.179.82/sundev/search.cfm

TITLE	ABSTRACT	SOURCE
TRAFFIC MODELING FRAMEWORK FOR HURRICANE EVACUATION	Development of computer-based incident management decision aid system (IMDAS).	Transportation Research Board 80th Annual Meeting, Search TRIS http://199.79.179.82/sundev/search.cfm
TRAVELAID	Report discusses effectiveness of DMS and in-vehicle traffic advisory systems (IVUs) on a mountainous pass for changing driver behavior. DMS and VSL signs were installed on I-90 to provide speed limit, weather, and roadway information to motorists in order to reduce the number and severity of crashes. Report includes analysis of mean speeds and speed deviation based upon a driving simulator study.	www.itsdocs.fhwa.dot.gov//jpodocs/repts_te//13610.html
TRUCKING INDUSTRY PREFERENCES FOR DRIVER TRAVELER INFORMATION USING WIRELESS INTERNET-ENABLED DEVICES	If truck drivers could use Internet-enabled wireless devices to access traveler information, what type of information would they most want to have? We analyzed preferences for traveler information from managers of 700 trucking companies to determine how they valued information. Using a factor-analytic model with regressor variables, we found clear differences in preferences across types of trucking operations. "Locations of freeway incidents and lane closures," "weather information," and "travel times on alternative routes" were evaluated as important by the greatest number of carriers.	Transportation Research Board 82nd Annual Meeting, Search TRIS http://199.79.179.82/sundev/search.cfm
USE OF EXPERT SYSTEMS FOR ROADWAY WEATHER MAINTENANCE DECISIONS	Automated systems for forecasting frost and fog on roads and bridges using expert systems were deployed in Iowa.	http://www.ctre.iastate.edu/pubs/semisesq/session5/takle/
USE OF PAVEMENT TEMPERATURE MEASUREMENTS FOR WINTER MAINTENANCE DECISIONS	Analyzed pavement temperature data from urban and rural sites on bridges and roads to evaluate nighttime trends and differences of temperature at different locations under different weather conditions. Using RWIS pavement temperature data and cloud cover data from Jan. 1997, temperature differences, cooling rates, and lag times between urban and rural sites were computed.	http://www.ctre.iastate.edu/pubs/crossroads/33use.pdf

TITLE	ABSTRACT	SOURCE
UTILIZING ROAD WEATHER INFORMATION SYSTEM (RWIS) DATA TO IMPROVE RESPONSE TO ADVERSE WEATHER CONDITIONS	The advent and expanded use of Road Weather Information Systems (RWIS) shows potential for improving the identification of weather-related factors contributing to low levels of safety and for improving guidance provided to response personnel during or preceding times of adverse weather. This investigation revealed several significant issues associated with the use of RWIS data for improving adverse weather-related crash prediction and response: (1) the categorical nature of some RWIS-reported data elements limits its usefulness in guiding response actions, (2) RWIS data is limited in historical timeline and ease of accessibility, and (3) RWIS data are highly localized spatially (i.e., reporting the pavement surface status only at the location of the in-road sensor) which results in substantial discrepancies between officer-reported and RWIS-reported crash data.	Kimley-Horn and Associates
VARIABLE SPEED CONTROL: TECHNOLOGIES AND PRACTICE	Static speed limit signs fail to provide accurate information on speed selection when traffic and environmental conditions are less than ideal. Paper documents findings from a state-of-the-practice review on VSL systems. Paper reviews and compares characteristics of VSL systems, and discusses potential benefits and limitations associated with their deployment.	ITS America 11th Annual Meeting Proceedings, Michigan State University
VIDEO CAMERAS FOCUS ON VISIBILITY	A researcher has developed a technique for automatically measuring visibility with video cameras. The camera is aligned to detect contrasting portions of targets in order to generate a signal indicative of contrast levels. A processor uses the signal to compute visibility. The prototype system was installed on northbound Highway 35 near Duluth, Minnesota.	www.its.umn.edu/news/visibility.html
WASHINGTON STATE DEPARTMENT OF TRANSPORTATIONS MAINTENANCE ACCOUNTABILITY PROCESS: AN ONGOING EXPERIMENT IN PERFORMANCE MEASUREMENT	The Washington State Department of Transportation (WSDOT) has utilized its current system of highway maintenance performance measures since 1996. This system is called the Maintenance Accountability Process (MAP) and has generally been successful since its inception. The MAP has provided WSDOT maintenance the tools to clearly communicate to legislators and policymakers the outcomes of investments in the maintenance program. This paper describes the performance measure lessons we have learned while using the MAP and some associated improvements in performance measure processes; some implemented and other being considered for future implementation.	Transportation Research Board 82nd Annual Meeting, Search TRIS http://199.79.179.82/sundev/search.cfm

TITLE	ABSTRACT	SOURCE
WEATHER BASED TRAFFIC MANAGEMENT APPLICATIONS IN NEVADA	Maintenance operations dealing with inclement weather occur at almost all levels of government across the United States. Several operational strategies and technologies have been developed to assist in the forecasting and detection of roadway conditions associated with inclement weather. RWIS technologies have become a cornerstone to several traffic management applications in northern Nevada. Detection of road and weather conditions allow for the development of detection and warning systems to alert motorists of potential driving difficulties of intermittent hazards.	Institute of Transportation Engineers 2002, Nevada DOT
WEATHER IMPACTS ON ARTERIAL TRAFFIC FLOW	This paper synthesizes literature regarding weather effects on traffic flow along signalized arterial roadways. Generally, weather impacts traffic by reducing visibility, decreasing pavement friction, as well as impacting driver behavior and vehicle performance (e.g., traction, stability, maneuverability). Weather effects on roads and traffic are presented, relevant literature is reviewed, and findings from the literature are summarized in the conclusion.	Mitretek Systems
WEATHER IN THE INFO-STRUCTURE	This paper addresses the Weather Response component of the Infostructure. It's primary purpose is to discuss the fundamental data needs of the weather infostructure component, and to estimate an aggregate cost for national deployment of road weather data collection systems. It does this by first documenting a methodology for determining the number of Road Weather Information System (RWIS) sensors (or ESS) needed across the country to support basic road weather needs, and then documenting a methodology for determining the cost.	Cambridge Systematics, Inc.
WEATHER INFORMATION FOR SURFACE TRANSPORTATION (WIST I): ESTABLISHING THE NATIONAL NEEDS AND REQUIREMENTS	OFCM and FHWA initiated a project, within the federal meteorological community, to identify the nation weather needs and requirements for all surface transportation modes. Establishing initiatives, the Joint Action Group for WIST, database records, and plans for 2000 WIST Symposium are discussed.	http://www.ofcm.gov/wist_proceedings/proceedings.htm
WEATHER INFORMATION FOR SURFACE TRANSPORTATION (WIST II): ESTABLISHING THE NATIONAL NEEDS AND REQUIREMENTS	OFCM and FHWA initiated a project, within the federal meteorological community, to identify the national weather needs and requirements for all surface transportation modes. In this venue, surface transportation consists of roadways, rail, waterways, and pipelines. Noted shortcomings were the absence of definitive information on the spatial and temporal scales required for decision processes, and the lack of any specific threshold for identified weather elements.	http://www.ofcm.gov/wist2/proceedings2000/wist2startup.htm

TITLE	ABSTRACT	SOURCE
WEATHER INFORMATION FOR SURFACE TRANSPORTATION (WIST): NATIONAL NEEDS ASSESSMENT REPORT	This report provides a complication of weather information needs across the six surface transportation sectors--roadway, railway, transit, marine transportation, pipeline systems, and airport ground operations--and an analysis of these needs. The findings in the report provide a framework for actions to substantially improve surface transportation operations in the future.	http://www.ofcm.gov/wist_report/wist-report.htm
WEATHER: A RESEARCH AGENDA FOR SURFACE TRANSPORTATION OPERATIONS	Weather crosscuts almost every goal, use, and operation of highways, and yet, meteorology, from a transportation perspective, is focused mostly on the flight operations. To make weather issues an important part of highway programs, people who manage highway operations must seek new techniques and ITS that complement the amazing system of weather-information collection, analysis, and forecasting that exists in the US.	http://www.tfhrc.gov/pubrds/02mar/05.htm
WEATHER: MAKING IT A NATIONAL PRIORITY IN SURFACE TRANSPORTATION	Includes "A National Program for Surface Transportation Weather Applications" by Pisano & Nelson; " An Advanced Winter Road Decision Support System" by Mahoney; "Research Needs in Weather Information for Surface Transportation--The Perspective of the User Community" by Nixon; "Utilizing FAA-Developed Automated Weather Algorithms for Improving Surface Transportation Operations in Adverse Weather" by Hallowell; "Foretell--Some Findings and their Research Implications" by Davies, Choudhry & Canales; "Future Growth of Surface Transportation Weather: An Academic Question" by Osborne; and "Private Sector Meteorology and ITS" by Smith.	www.ops.fhwa.dot.gov/weather/publications/its_america.pdf
WEATHER-RESPONSIVE TRAFFIC MANAGEMENT CONCEPT OF OPERATIONS: DRAFT	The purpose of this paper is to provide a concise summary of a concept of operation and associated research needs pertaining to weather-responsive transportation management. The primary focus of this paper is on the needs and activities of freeway and arterial transportation managers, and how these needs change or differ during Adverse weather. However, the concept of operations also involves transportation-related activities or others including public transportation managers, public safety personnel, highway maintenance personnel, and emergency response personnel.	Cambridge Systematics, Inc.
WHITE PAPER: AN INTEGRATED NETWORK OF TRANSPORTATION INFORMATION	The integrated network is the "infostructure" that facilitates monitoring, management, and operation of the entire transportation network. The integrated network will enable Road Weather Information and offer the opportunity (1) to detect and respond to regional crises, (2) for fewer and less severe crashes, (3) for better operator and user information, and (4) to reduce energy consumption and negative environmental impacts.	www.itsa.org/ITSNEWS.NSF/4e0650bef6193b3e852562350056a3a7/927cd5cae21c0ff085256b190049bd4e?OpenDocument

TITLE	ABSTRACT	SOURCE
WINTER MAINTENANCE IN THOMPSON FALLS (MEMORANDUM)	A winter storm event, beginning 12/14/00 in the Thompson Falls area, resulted in numerous complaints regarding driving conditions on MT 200 (P-6) between the Plains section (Missoula Division) and the Thompson Falls section (Kalispell Division). The Plains section had bare road while the Thompson Falls section had snow and ice pack when the storm had passed. At the request of the Kalispell Area Maintenance Engineer, Maintenance Review was assigned the task of finding out why this happened. The Review team went to the area on a fact-finding tour and documented different treatment strategies and resulting roadway outcomes.	Montana DOT
WINTER OPERATIONS WEATHER FORECASTS: DO THEY WORK FOR THE MAINTENANCE SHED SUPERVISOR?	An evaluation of Utah DOT's RWIS included validation of NWS forecasts and Northwest Weathernet forecasts for specific interstate corridors, and satisfaction surveys completed by maintenance supervisors.	Transportation Research Board 80th Annual Meeting, Search TRIS http://199.79.179.82/sundev/search.cfm
WINTER STORM EVENT VOLUME IMPACT ANALYSIS USING MULTIPLE SOURCE ARCHIVED MONITORING DATA	Paper discusses how data from several information management systems in Iowa were used to analyze the volume impacts of winter storms. Analysis indicated that winter storms decrease traffic volumes by 29 percent on average (range from 16 percent to 47 percent). Analysis revealed a relationship between percent volume reduction and total snowfall, minimum average wind speed and the square of maximum wind gust speed.	Transportation Research Board 79th Annual Meeting, Search TRIS http://199.79.179.82/sundev/search.cfm

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