Best Practices for Road Weather Management
Version 2.0

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 the figure. 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).


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 the table. TMC operators also have the capability to manually override messages selected by the system.

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.

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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

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 the figure, 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.

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 the following table, 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.

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

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 the table below.

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.

Contact(s):
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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

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 the figure, 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.

Utah DOT Maintenance Vehicle with Fog Dispersal Equipment

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.

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

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. 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.

**Idaho DOT
Maintenance Vehicles**

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.

**Idaho DOT
Chemical Storage Tanks**

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 the table.

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.

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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

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

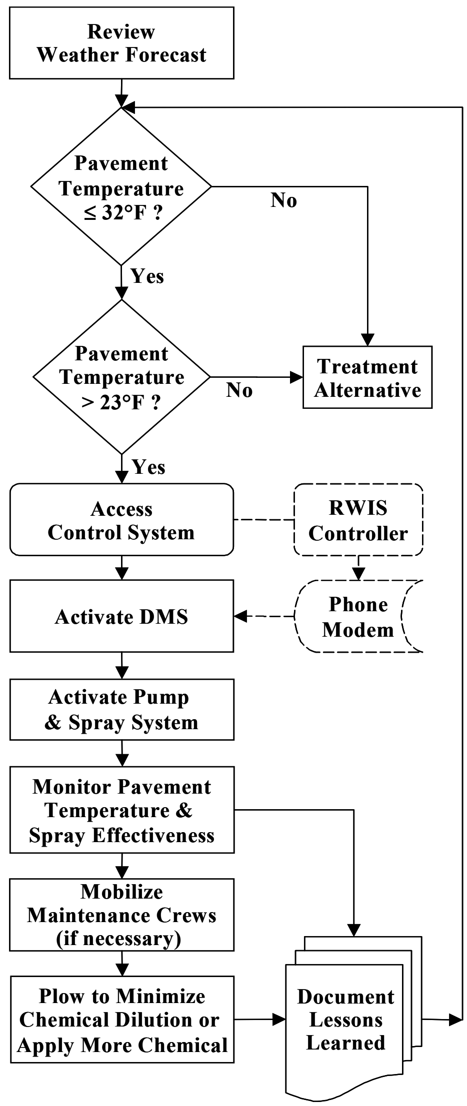
The New York City Department of Transportation (DOT) developed a fixed anti-icing system prototype for a portion of the Brooklyn Bridge. The system sprays an anti-icing chemical on the bridge deck when adverse weather conditions are observed. Anti-icing reduces the need to spread road salt, which has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



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 in the figures below.

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.

**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.

**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):

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Reference(s):

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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

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 the figure, 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.

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):

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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

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 the figure, has automated application controls. Computerized salt spreaders automatically adjust the application rate based upon the speed of the snowplow.

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 the figure, 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.

**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 the following table, 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.

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

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 the figure. Traffic managers may also broadcast pre-recorded messages via three Highway Advisory Radio transmitters in the area.

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 the table 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.

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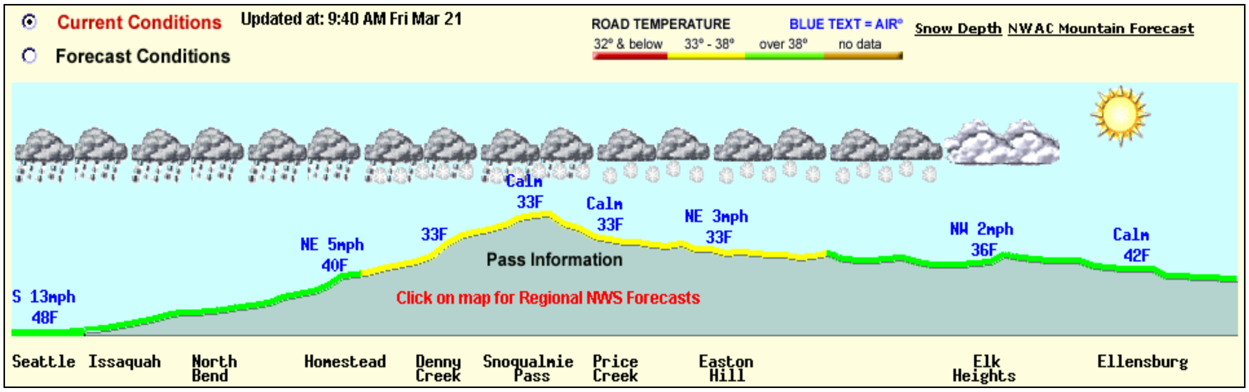
Keywords: wind, high-profile vehicles, high wind warning system, freeway management, traffic management, control strategy, access control, advisory strategy, traveler information, internet/web site, environmental sensor station (ESS), dynamic message signs (DMS), highway advisory radio (HAR), safety

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.



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 the figures, 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*).

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.

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