Surface Transportation Weather Applications

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Abstract. 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. The Road Weather Management Program of the Federal Highway Administration (FHWA) promotes and facilitates deployment of integrated road weather systems, decision support applications, and effective management practices.

INTRODUCTION

Surface transportation is the dominant carrier of people and commerce in the United States. Surface transportation services require usable infrastructure and effective systems. Dependence on timeliness means that road users demand a highway system that is not susceptible to service disruptions, including those due to weather. Primary highway operational goals—safety, mobility and productivity—are affected by environmental conditions near or on the ground. This paper describes weather threats to surface transportation and management practices to cope with adverse conditions. (19)

WEATHER THREATS TO SURFACE TRANSPORTATION

Weather is a ubiquitous threat to surface transportation nationwide. Weather acts through visibility impairments, precipitation, high winds, temperature extremes, and lightning to affect driver capabilities, vehicle maneuverability, pavement friction, and roadway infrastructure. Table 1 lists various impacts of weather and related events on the roadway environment and surface transportation systems.

Weather Events	*Roadway Environment Impacts*	*Transportation System Impacts*
Rain, Snow, Sleet, Hail & Flooding	• Reduced visibility • Reduced pavement friction • Lane obstruction & submersion • Reduced vehicle stability & maneuverability • Increased chemical and abrasive use for snow and ice control • Infrastructure damage	• Reduced roadway capacity • Reduced speeds & increased delay • Increased speed variability • Increased accident risk • Road/bridge restrictions & closures • Loss of communications/power services • Increased maintenance & operations costs

Weather Events	*Roadway Environment Impacts*	*Transportation System Impacts*
High Winds	• Reduced visibility due to blowing snow or dust • Lane obstruction due to wind-blown debris & drifting snow • Reduced vehicle stability & maneuverability	• Increased delay • Reduced traffic speeds • Road/bridge restrictions & closures
Fog, Smog, Smoke & Glare	• Reduced visibility	• Reduced speeds & increased delay • Increased speed variability • Increased accident risk • Road/bridge restrictions & closures
Extreme Temperatures & Lightning	• Increased wild fire risk • Infrastructure damage	• Traffic control device failure • Loss of communications & power services • Increased maintenance & operations costs

Table 1 – Weather Impacts on Roadway Environments and Transportation Systems

Weather Impacts on Mobility

Weather impacts roadway mobility by increasing delay (i.e., variability in travel time), reducing traffic volume and speed, increasing speed variance (a measure of travel speed uniformity), and decreasing capacity (i.e., maximum rate at which vehicles can travel on a roadway segment). To determine weather effects on traffic delay, surface weather observation data were combined with reported travel time data in the Washington, D.C. metropolitan area. An analysis of the data found that aggregate weather effects accounted for roughly 12% of travel time delay. An estimation of average delay in the Seattle, Washington metropolitan area, using a different analysis methodology, found that average delay increases by 21% on days with adverse weather. The studies also demonstrated that all weather-related delay occurs on 13% to 19% of days in these metropolitan areas. (15, 20, 28)

Delay effects may be partially balanced by reduced traffic volumes in adverse weather. The Iowa State University investigated 64 winter storm events at seven interstate locations in the state. The study found that traffic volumes decreased by 29% on average when compared to volumes under clear conditions. Results also indicated that on weekday afternoons traffic volumes increased in the early hours of a winter storm. Another Iowa State University study analyzed traffic flow in adverse weather on Interstate 35 in Polk County. It was determined that average winter weather speeds were approximately 16% lower than speeds during normal weather with dry pavement. Winter weather speed variance was over 300% higher than variation during dry conditions. (7, 8)

Drivers tend not to defer trips in mild conditions such as rain. Consequently, as traffic congestion increases, the capacity reducing effects of weather have a greater impact on transportation system operation. Many urban transportation networks will operate at or near capacity as traffic volumes increase over time. Figure 1 depicts national traffic volume trends applied to a typical freeway segment. If weather reduces freeway capacity by 10%, traffic congestion can result, as shown in the figure. Under congested conditions, small changes in effective capacity or traffic volume can have significant delay effects. The Oak Ridge National Laboratory has estimated that capacity of U.S. freeways and principle arterials was reduced by more than 11% due to fog, snow and ice in 1999. The lab also projected that nearly 544 million vehicle-hours of delay or 23% of total delay was caused by these weather events, with snow accounting for 90% of delay. Icy conditions and fog accounted for seven and three percent of estimated delay, respectively. Taking the effects of rain into account would show that the overall impact of weather is even greater. (1)

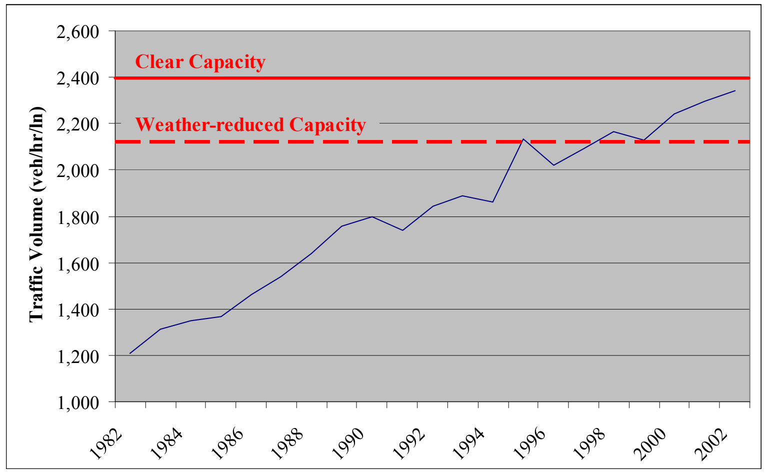

Figure 1 – Capacity Reduction due to Weather

Weather Impacts on Safety

Weather affects roadway safety through increased crash risk and frequency, as well as exposure to weather-related hazards. Each year over 10% of all passenger vehicle crashes occur in rain, snow, or sleet. Eighteen percent of fatal passenger vehicle crashes (over 6,600) and 22% of injury crashes (over 470,000) occur under poor weather or pavement conditions annually. In 1999, 13% of large truck crashes happened in rain, snow, sleet, hail, or fog; and 16% occurred on wet, snow-covered, slushy, or icy pavement. Reported conditions may contribute to traffic accidents, but do not necessarily imply causation. (13, 25)

Much of the population is exposed to weather-related hazards. Sixty-nine percent of U.S. residents (198 million people) live in snowy regions (with more than five inches of annual snowfall). As shown in Figure 2, 74% (or nearly 3 million miles) of the nation's roads are located in these snowy areas. Over 50% of the U.S. population (over 143 million people) have a five percent or greater chance of being affected by a named hurricane during a season, which begins on June 1st and ends on November 30th. Most hurricane fatalities result from inland

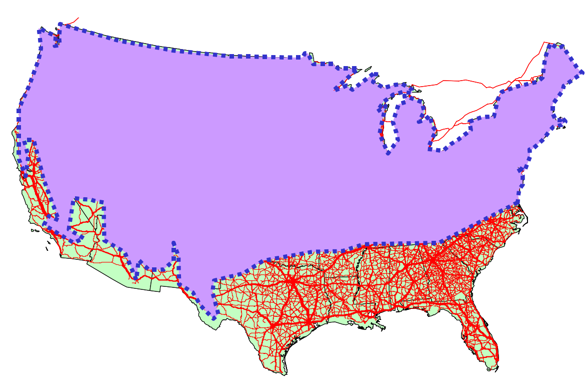
Figure 2 – Snowy Areas of the U.S.

flooding after landfall of a tropical cyclone. Nearly 60% of deaths related to Hurricane Floyd were associated with drowning (i.e., flooding) and vehicles. Evacuation from coasts to inland areas is only one management strategy to cope with hurricane threats. Post-landfall effects on infrastructure and reentry traffic control after the storm also present significant management problems. These problems will be compounded as more people settle in coastal areas threatened by hurricanes.

Weather Impacts on Productivity

Weather events influence transportation system productivity by disrupting access to these systems, and increasing operating and maintenance costs. Winter road maintenance accounts for 24% of road operating costs. Each year, state and local agencies spend over two billion dollars on snow and ice control operations and over five billion dollars to repair roadway infrastructure damaged by snow and ice. In 1999, state Departments of Transportation (DOTs) spent an average of $2,800 per route mile (or $1,100 per lane mile) on winter road maintenance.

MANAGEMENT STRATEGIES TO MITIGATE WEATHER IMPACTS

There is a perception that traffic managers can do little about weather. However, environmental effects on traffic operations and roadway facilities can be mitigated. There are three basic types of mitigation measures: control, treatment, and advisory strategies. 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. Advisory strategies provide information on predicted and prevailing conditions to both managers and motorists. Advisory information serves as decision support to managers, and allows drivers to cope with weather effects through trip deferrals, route detours or changes in driving behavior. Road weather and traffic prediction models can also be used to assess and address weather impacts.

Management strategies require relevant, accurate, and timely environmental data to effectively mitigate weather effects. Managers need observations and predictions of road weather conditions to make operational decisions. For example, a route-specific pavement condition forecast provided for a six to 24-hour time frame is more useful for winter road maintenance than a general five-day weather forecast. Weather information must correspond to the appropriate time horizon or decision scale, as specific types and sequences of management decisions are made at each scale. The coordinated scales from planning to warning represent a control hierarchy from managers, to dispatch and operations staff, to remote devices controlled by operators to warn motorists or regulate road usage. General weather and transportation decision scale relationships are shown in Table 2.

Weather Scales	*Decision Scales*	*Time Horizon* *Functions*	*Transportation Decision Examples*
Climatic	Planning	Months to Years • Design facilities • Procure resources	• Deploy infrastructure/systems • Procure equipment/materials • Coordinate evacuation planning with adjacent states
Synoptic /Meso	Operational	Hours to Days • Manage resource deployment • Manage system operation	• Mobilize and treat snow/ice • Mobilize and disperse fog • Modify speed limits • Close threatened roads/bridges
Micro	Warning	Seconds to Minutes • Operate control systems • Monitor automatic advisory systems	• Advise of reduced visibility • Notify drivers of high water

Table 2 – Weather and Transportation Decision Scales

Arterial Management

Weather-related arterial management utilizes control strategies—primarily traffic signal control—to improve roadway safety and mobility. Advisory strategies, such as tracking and monitoring of thunderstorms, can enhance productivity by minimizing the down time of traffic signal controllers damaged by lightning. Traffic managers in the City of Charlotte, North Carolina operate a system with nearly 600 traffic signals. For 139 downtown signals, specialized timing plans have been developed for heavy rain, snow or icy conditions. A central traffic signal control system implements these timing plans to slow the progression of traffic when pavement conditions are poor.

The Utah DOT regulates traffic flow in adverse conditions by implementing weather-related signal timing plans on some arterials in the Salt Lake Valley. Signal timing plan cycle lengths remain constant while offsets, splits, and clearance intervals are modified for inclement conditions. These timing plans typically increase all-red time by one second, increase amber time by 10% to 15% based upon intersection size, decrease "dry condition" speeds by 30%, increase start-up lost time by 23%, and decrease "dry condition" saturation flow rates by 20%. Traffic managers consider storm duration, affected corridor length, pavement conditions and traffic conditions when executing weather-related timing plans. (18)

Freeway Management

Most traffic management strategies focus on freeways where the investment in surveillance and warning devices is greatest, and where high traffic volumes and speeds make weather threats most hazardous. Several management strategies can be employed to improve highway safety and mobility in adverse weather. Truck-mounted carbon dioxide dispensers can be used to disperse fog on some highways. When visibility is below 300 feet (91 meters) and the temperature is below freezing, Utah DOT maintenance staff spread cold carbon dioxide gas along roads to encourage precipitation of fog particles. This treatment strategy includes the application of anti-icing chemicals as fog is dispersed to prevent pavement freezing. (3)

Various control strategies can be employed for precipitation events, when pavement is slippery, and when visibility is reduced. In Northern Virginia, weather-related incident detection algorithms have been developed and implemented on Interstates 66, 395 and 495. Based upon road and weather conditions observed via closed circuit television (CCTV) cameras, traffic managers select databases for “sunny,” “rainy,” or “snowy” conditions. An advanced traffic management system (ATMS) on Interstate 4 in Orlando, Florida switches from a “dry pavement” detection database to a “wet pavement” database when wet pavement is detected.

Alabama DOT traffic managers operate an intelligent transportation system (ITS) that detects fog on the Bay Bridge and other segments of I-10, automatically alters speed limits with variable speed limit (VSL) signs and modifies lane configuration via lane control signs. Traffic and emergency managers can coordinate to guide vehicles on road segments obscured by fog or wind blown dust. When visibility is less than 500 feet on highways from Kern County to San Joaquin County, California Highway Patrol vehicles are used to group traffic into platoons, which are led through affected areas at a safe pace. On the Lake Pontchartrain Bridge in Louisiana, traffic is restricted to the right lane during heavy fog conditions and law enforcement personnel escort vehicle platoons from the front, the middle and the rear. (24, 26)

Control strategies are often combined with advisory techniques to notify drivers of traffic regulations. When sustained wind speeds are between 30 and 39 mph (48 and 63 kph), a “wind warning” message is displayed on dynamic message signs (DMS) deployed near Maryland Transportation Authority bridges. “Wind restriction” messages prohibit high-profile vehicles from crossing bridges when wind speeds exceed 39 mph. During the evacuation prior to arrival of Hurricane Floyd in 1999, traffic was severely congested on highways in Florida, Georgia, North Carolina and South Carolina. By reversing traffic flow (i.e., contraflow) on Interstate 26 during reentry operations after the hurricane, managers in South Carolina expanded roadway capacity and increased the maximum evacuation volume (i.e., 1,400 vehicles per hour per lane) by 49%. To alert drivers of contraflow operations, portable DMS & highway advisory radio (HAR) transmitters were positioned along the interstate. (23)

A survey of 21 traffic management centers (TMCs) found that some weather information was received in nearly 90% of the centers. More than 60% of TMCs used information tailored to specific needs, as opposed to general weather forecasts. However, only 25% integrated weather information into central software. Traffic managers can improve highway operations by integrating road weather data into TMCs and establishing thresholds to alert managers of inclement or hazardous conditions. When notified, managers can take proactive measures such as positioning snowplows at vulnerable locations before a predicted storm or disseminating warnings to motorists via DMS.

Traveler Information

An ITS allows traffic managers to disseminate advisory and regulatory traveler information to motorists directly from a TMC. These systems also facilitate sharing of road weather data among managers in multiple agencies and neighboring jurisdictions. To improve traffic operations under adverse environmental conditions, traveler information may be furnished through roadside warning systems, web-based applications, and interactive telephone systems.

Flooding is an example of a condition warranting driver notification. Flood warning systems have been developed to meet this need. The City of Dallas, Texas monitors water levels at over 60 stream locations near roads. The flood warning system consists of float switch sensors that report stream levels to a central computer system every twenty minutes and electromechanical message signs at each monitoring site, as shown in Figure 3. When water reaches the roadway edge, a sensor activates flashing red lights and changes the sign message from “High Water When Flashing” to “Do Not Enter High Water”. The system automatically posts warnings on the City’s Flooded Roadway Warning System website and alerts maintenance staff who erect barricades on threatened roads. (2, 10)

Figure 3 – City of Dallas Flood Warning System

Many state DOTs provide textual and graphical road weather information on Internet websites. The most advanced is the Washington State DOT traffic and weather information website that collects data from a variety of sources, and displays current and forecasted pavement and weather condition data on a color-coded, statewide map. The DOT accesses real time data from meteorological observing networks, a CCTV surveillance system, mountain pass reports, as well as various satellite and radar images. (27)

The Advanced Transportation Weather Information System (ATWIS) uses interactive voice response technology to provide route-specific road condition reports and six-hour weather forecasts to drivers on Minnesota, Montana, North Dakota, and South Dakota highways. Cellular telephone users dial #7233 (or #SAFE™) to access weather and pavement forecasts extending roughly 60 miles (or one hour) in their direction of travel. The ATWIS is also the basis for road weather data in the 511 traveler information service for the region. 511 is the national traveler information telephone number that was allocated by the Federal Communications Commission in 2001. (16, 21)

Modeling Strategies to Address Weather Impacts

The Road Weather Management Program focuses on three user groups—maintenance managers, traffic managers, and emergency managers. The documentation of high-level weather information requirements for these decision-makers led to the prototyping of the Maintenance Decision Support System (MDSS) for winter maintenance managers. A decision support tool for emergency managers—the Evacuation Traffic Information System (ETIS)—has also been developed based upon their data needs. The FHWA hopes to demonstrate the value of such models by deploying and evaluating them in operational environments. Central to all management strategies is that efficient response to weather threats requires accurate road weather information and the integration of that information with transportation data. (12)

Traffic prediction models exist for a wide rage of surface transportation systems including traffic signals, arterial corridors, and regional highway networks. In cooperation with the Federal Emergency Management Agency and the U.S. Army Corps of Engineers, the FHWA has sponsored development of the ETIS to promote coordinated, multi-state, multi-agency planning and operations for hurricane evacuations. The ETIS is a web-based application with the capability to monitor, predict and display state-to-state traffic flows for coastal states from Texas to Virginia. The system is also able to ingest traffic data from state DOT traffic management systems for comparison of predicted and actual traffic volumes. (11, 23)

Researchers at the Georgia Institute of Technology are developing a traffic prediction model that ingests data from Georgia DOT vehicle detection systems to compute a "traffic congestion index". Traffic flow data is synthesized by the model to compute historical and current delay measures or congestion indices. The congestion index model will be tested in Atlanta, and may be integrated with air quality and weather forecasts in the future. The Smart Travel Laboratory at the University of Virginia is developing traffic simulation models that predict traffic volumes and travel times using real-time and historical data from vehicle detection systems in Virginia DOT's Smart Traffic Center in Virginia Beach. More research is needed to calibrate traffic prediction models for appropriate sensitivity to weather and to validate modeling tools with surveillance data. (4, 22)

ROAD WEATHER DATA IN TRAFFIC MANAGEMENT ENVIRONMENTS

All management strategies described above clearly demonstrate the need for relevant road weather data and the integration of this information with traffic monitoring and control resources (e.g., display software in a TMC). Road weather data must be tailored to decision scales and incorporated into traffic control systems. To make operational decisions on resource deployment and system operation; observations of atmospheric, pavement, and water level conditions through environmental sensor stations (ESS) as well as road weather predictions must be integrated with ATMS, advance traveler information systems (ATIS) and other systems, as generalized in Figure 4.

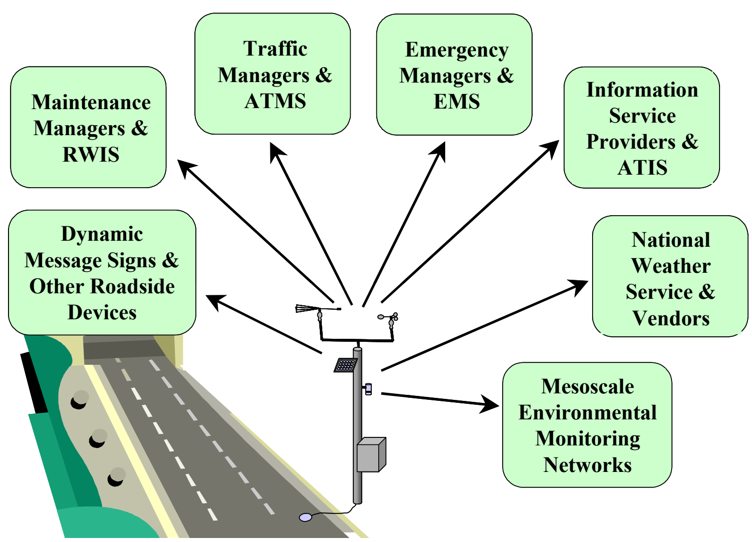

Figure 4 - Environmental Sensor Station (ESS) Operational Applications

A mesoscale environmental monitoring network (or mesonet) integrates data from surface observing stations over a given region. Mesonet data may be used to monitor conditions and to aid in forecasting of the progression of mesoscale weather features (i.e., predicting weather conditions over small areas on the order of roughly 40 square miles or 100 square kilometers). An example is the MesoWest mesonet, which collects weather observations from roughly 350 stations in the National Weather Service (NWS) surface aviation network and 2,100 other stations in the western United States. Observation data is made available to state DOT agencies in Montana, Nevada, Utah, and Wyoming through cooperative agreements between local NWS offices and the states. National integration of such regional and specialized mesonets would be very beneficial to road weather management. Enhancing relationships with the NWS, the Office of the Federal Coordinator for Meteorology (OFCM), the Department of Defense (DOD), the Federal Aviation Administration (FAA), and other agencies will facilitate national environmental data integration efforts.

CONCLUSIONS

Weather has dynamic affects on surface transportation systems. Better management strategies require integrated road weather observation data and predictions as well as data sharing and analysis capabilities. The proliferation of ITS enables road weather management gaps to be addressed. In order to reap significant operational benefits, innovative road weather management practices must be documented and disseminated to encourage implementation of effective management strategies. Additionally, investments must be made to furnish the appropriate road weather information to transportation decision makers.

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