A POLICY FORUM: WEATHER AND HIGHWAYS

developed by the

ATMOSPHERIC POLICY PROGRAM
AMERICAN METEOROLOGICAL SOCIETY

in coordination with the

Federal Highway Administration (FHWA)

with additional support from the

National Science Foundation (NSF)

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Panel 2

Public (Federal, State, Local) And Industrial Development Of Strategies And Plans To Effectively Respond To Weather Information

POSITION PAPERS

Public and industrial development of strategies and plans to effectively respond to weather and climate information.

Mahlon G. "Lon" Anderson
AAA Mid-Atlantic

At AAA, we represent some 46 million-member motorists—we are the end users of your product. And for some of us, as your white paper noted, weather can be a life and death matter. We are in the travel information business—and that includes helping members deal with weather. At AAA Mid-Atlantic, my club, with members from Virginia to New Jersey, we use your information regularly on TV, radio and in the press. When you do a great job, you help us look great--When you blow it, sometimes our advice misses the mark as well.

Weather has always played an integral in transportation. Think back to D-Day, June 6, 1944. It was moved to that date because of weather: when conditions would likely allow us to move the tens of thousands of troops from ship to shore, and air to ground. The war analogy is an important one. There is a war going on on our highways. Last year that war cost us nearly 43,000 lives on American soil, and another 3 million in injuries. Interestingly, the numbers were about the same as those from the front in World War II. Daily we now lose about 118 lives, with about 8,000 injuries—about the same as we did in that war. I spoke to 500 servicemen and women at Patuxtent Naval Air Station recently. I thanked them for their service, talked about 9/11 and then told them that in my war, the war on our highways, we had suffered more than 80,000 dead on American soil since 9-11.

Highway crashes are a crafty foe—they attack every community without regard to race, creed, age. An equal opportunity killer. Perhaps the worst part is this crafty foe has got us convinced that crashes are inevitable. Perhaps some are but the deaths and injuries are not and most can be prevented.

The role of Weather in this war

Just as You played a key role on D-Day, so too you play a key role here, every day in the war on the highways. You provided critical intelligence then--You provide critical intelligence now to highway users and travelers every day. Critical intelligence—or any intelligence behind the wheel-- often seems wanting on our highways. By FHWA numbers, in the U.S. alone some 7,000 highway deaths and 800,000 injuries appear to be weather related -- and that is just annually. You—the providers of weather information and thus likely road conditions, you are one of the resources that those of us in traffic safety turn to regularly. We get your information and then try to provide a simple "for drivers this means..." Actually your role in the road war actually provides some of the most spectacular battles—on the losing side.

Here are some examples:

a) Last Memorial day, you told us it was likely going to be overcast and rainy. We warned motorists—driving could be more dangerous, challenging. But the folks don't always hear your message and ours: 70+ car collision in fog on I-68 near Cumberland, MD. (Unlike D-day, unfortunately, we can't move holiday dates, even when the weather appears to be less than ideal—or worse. So around holidays, weather is an even bigger issue.)

b) Two years ago, you gave us headline news on I-95 between DC and Richmond when over 100 vehicles in two sections of 1-95 experienced the meteorological phenomenon of drizzle freezing on the road in a couple of low dips in the highway. The destruction was complete and pretty unbelievable. Tractor trailers, cars and buses strewn every which way.

c) Back in the 80's you gave us one of the worst commuter days DC had ever seen. A driving snow storm hit mid-afternoon. Result, a plane crashed into the 14th street bridge, and Metro had its first crash inside the subway with loss of life. And for those of just trying to get home, my express bus (45 minute trip) lasted five hours. Infinite number of crashes/fender-benders that day.

These examples are just in my AAA territory.

Your role in this war is to provide good information – i.e.,critical intelligence. What is that exactly? What's acceptable is changing. It used to be a weather forecast for the East Cost today – then, in the Washington Metro area this morning. Now, we can get forecasts for Bethesda at 7 a.m., at noon, and at 5 p.m., complete with live Doppler radar pictures that show us exactly where the storm is and going—minute by minute.

Precision is being demanded more and more—Metro –our mass transit system in Washington—made the decision to close its system at 11 a.m. the day Hurricane Isabel—you remember "Izzie"—arrived based upon weather forecasters' predictions of when winds would be a steady 40 mph. Since AAA was telling folks not to drive that day, and now the subway and bus system was shutting down, it forced the Federal government to close, and our city was essentially shuttered as of 11 a.m.

I wish I had had an 11:30 tee time. Beautiful day. By 4, we were getting a breeze and some clouds and then it went down hill fast. Ok—so you blew it. But the impact on 4 million plus folks just in this region is the important issue here. Yet in many ways that was a victory-- we may have battened down the hatches a little early, but we certainly were ready and injuries and loss of life were minimized.

We expect you to give us the truth, the whole truth and nothing but the truth. And be within 15 minutes on your hurricane predictions. 15 minutes, one way or the other. Doesn't matter which way. We're not picky. But also give that to us 24 hours in advance. We have decisions to make, places to go, people to see.

Things appear to have changed in the weather industry since Isaac's Storm – the hurricane that hit Galveston, unannounced back in September 1900 when over 8,000 died. Further, as we get more enshrouded in our protective cocoon of modern life, we have less tolerance for making changes that are weather related.

So as we demand more precision of you, the challenge also falls to others to figure out what to do with the more accurate information. We can expect better use of resources—scheduling of road clearing equipment and crews—that's obvious. Less obvious applications include proliferation of electronic message boards up and down our highways. You know the ones that say "Test Test Test" or "Test ABC Test123". I have a better idea. Use these to relay real data. Caution—"33 degrees. Likely icing ahead, slow down" or in Cumberland. "Likely fog ahead—slow down you idiots!" In that way drivers can have real time, accurate information.
We can see this occasionally now, but as such signage, and more specific localized data – air and road surface info become available, the requirement to use this data constructively becomes even more urgent. These signs are expensive, and collecting this level of data is expensive, but the lives we save in this highway war, may be our own. And think of the expense to us and our society of 43,000 killed, 3 million-plus wounded.

Summary

Economic costs of our crashes in 2002 was put at $243 billion. That's the economic damage from our war in one year. Yet, your policy white paper on weather and highways states "one of the biggest challenges may be educating and convincing the U.S. DOT that a road weather initiative is needed given their large investment in aviation weather services. In the average year, we lose 112 lives in commercial aviation crashes, admittedly a low number, largely because of your excellent work. On the average day in America, we lose 118 lives, and by your estimates, 7,000 or 16% are weather related—that's 19 lives a day. How many billions have we spent on anthrax with five lives lost? Yet your paper says, we have a potentially tough job convincing the federal government to put a highway weather program in place?

You folks hold one of the keys to helping America win its most deadly, if undeclared, war. The war on American's highways.

Public and industrial development of strategies and plans to effectively respond to weather and climate information

Lisa Ballard, PE
Research Engineer
Western Transportation Institute, Montana State University, Bozeman

INTRODUCTION

As a research organization focused on rural transportation in a cold-weather state, Western Transportation Institute at Montana State University (WTI), has a strong interest in weather and winter mobility. WTI's experience in this area has been in weather-related ITS applications, assessing the needs of the end users, and developing a surface temperature model.

The discussion of strategies and plans for responding to weather and climate information can be started by breaking the subject into four areas. The end user accesses both the weather/climate information as well as the road conditions. Each of these are measured, modeled, or observed. Then this information is packaged, and sometimes interpreted, before it gets to the end user. To limit "stove-piping", where a user has to access different applications to do his or her job, this weather and road condition information is sometimes packaged with other transportation-related information before the end user sees it. For example, in a 511 traveler information phone system, the weather and road conditions can be packaged with construction or incident information. For an advanced transportation management system, road weather information system data can be displayed in the same application as the traffic data and the dynamic message signs. Policy implications should be considered in each of these four areas: weather information road conditions, packaging of data, and the end user.

How do highway system managers and users apply weather information?

Before answering how weather information is used, it is important to identify who the users are. Within Montana and California, and probably across the country, the primary user is winter maintenance. The second major user is the traveler. But other users include the operator in the traffic management center, incident responders and dispatchers in agencies outside of the department of transportation, and uses for planning, engineering, and research. In the west, weather information is used primarily for snow and ice control, high winds, and low visibility.

When users are trying to get weather information, they are using every source they can access. They are just as likely to use publicly available resources as they are to use the products designed for highway weather information. A 2001 survey of Caltrans weather information users asked, "How often do you use these methods to obtain weather information for making weather-related decisions in your job?" The highest used sources were non-Caltrans Internet websites and televised weather reports. The RWIS computer application ranked slightly better than commercial radio weather reports.[1] A survey of travelers on Fredonyer Summit in northern California provides further insight into the use of weather information. This survey was conducted prior to the implementation of a system that would detect snow or ice presence on the roadway and activate a message, "Icy Curves Ahead" only when relevant. Eighty-eight percent of potential drivers indicated that the system would

[1] Ballard, Lisa, et.al. 2002. *Handbook and Summary Report: Assess Caltrans Road Weather Information Systems Devices and Related Sensors.* Western Transportation Institute, Montana State University, Bozeman: Developed for Caltrans New Technology and Research Program.

provide useful information, 88% agreed that the system would make them more likely to slow down, and 77% would fell safer knowing the system was in place.

Despite the potential of weather information in making our roadways safer, it is not clear how much the local maintenance decision makers use even the most basic observations, such as using the RWIS. The use appears to be somewhat individual preference, but is also related to training, the perceived accuracy of the data, and the influence of senior staff. In many cases, a maintenance decision maker simply reads the current situation from the plow truck instead of reviewing forecasts.

Users recognize the limited usefulness of the point source data provided by RWIS. Maintenance users will tell stories of how one RWIS is placed to detect the location that ices first while another RWIS is placed to represent the average conditions at a site. Others will say a certain location does not report pavement temperatures anymore because the puck has been paved over. While proper placement and maintenance increases the usefulness of the sensor, it is still impossible for sensors to economically estimate pavement temperatures through complex terrain.

Finally, in discussing how weather information is used, national decision makers should recognize the importance of road and weather information to travelers. In a rural, cold-region environment, this information is more important to travelers than construction information, traffic conditions, travel times, public transit information, or incident information. The 2003 Montana Traveler Information Survey indicated more than 90% felt is was very important to have winter conditions on a phone-based traveler information system. The Fredonyer Summit survey identified the desirability of road condition information. The 1997 Rural Traveler Survey indicated that adverse weather conditions rated just behind best route and road conditions when identifying the importance of traveler information pre-trip. Call volumes on the Montana 511 traveler information system clearly indicate a correlation between winter driving conditions and number of calls.

HOW IS THE NATIONS' HIGHWAY SYSTEM CHANGING, AND HOW WILL THIS AFFECT THE DEVELOPMENT OF APPLICATIONS?

We see a change in the highway environment and in the users of the highway. Even in the most rural environments, the transportation departments are moving towards more operations and management and less building or expanding facilities. Also, the prevalence of technology and information in the society is impacting the highway environment. The computer comfort and confidence level among the blue-collar maintenance workers should continue to increase. Meanwhile, the travelers will expect higher quality of service, either through better traveler information or better road conditions. Also, we can expect to see more unfamiliar drivers, especially on the rural roads. As the population ages and continues to sprawl out of the urban areas, we can expect. Finally, for the next ten years, we can expect to continue to have parts of the rural road system, especially in the mountainous and spread-out west, without any land-based communications infrastructure. Often the locations without communications are also the most dangerous stretches of roads. Without a creative solution, this will limit the ability to monitor conditions and provide en-route traveler information.

WHAT ARE THE OPPORTUNITIES FOR AND BARRIERS TO EFFECTIVE APPLICATION OF WEATHER INFORMATION TO HIGHWAY SAFETY AND OPERATIONS?

There is a paradox that the end users encounter both too much information and too little. With accessibility to RWIS data, road-weather forecasts, governmental forecast agencies, private meteorological conditions, and research or experimental applications, via television, radio, web, telephone, page, or subscription satellite service, it is no wonder that the maintenance or traffic management user does not know what to do with all that information. Designers of the Fredonyer Icy Curve system suggested a page to a maintenance supervisor when ice was detected and the system was active, but the supervisor responded that he would have staff on the road in trucks anyhow, so this page would have no affect on their response. Despite the current availability of excess information, the quality is not good enough for the most proactive and innovative responses. Montana Department of Transportation is moving away from anti-icing and towards just-in-time icing partially because inaccurate forecasts have led to placing liquid chemicals when no storm occurs, or vice versa. This provides the opportunity to develop better methods of interpreting and quality of data. Some of the methods of interpretation are computer-based decision support tools, yet on the institutional side, a state weather information coordinator and/or meteorologist can greatly assist in improving the interpretation of information.

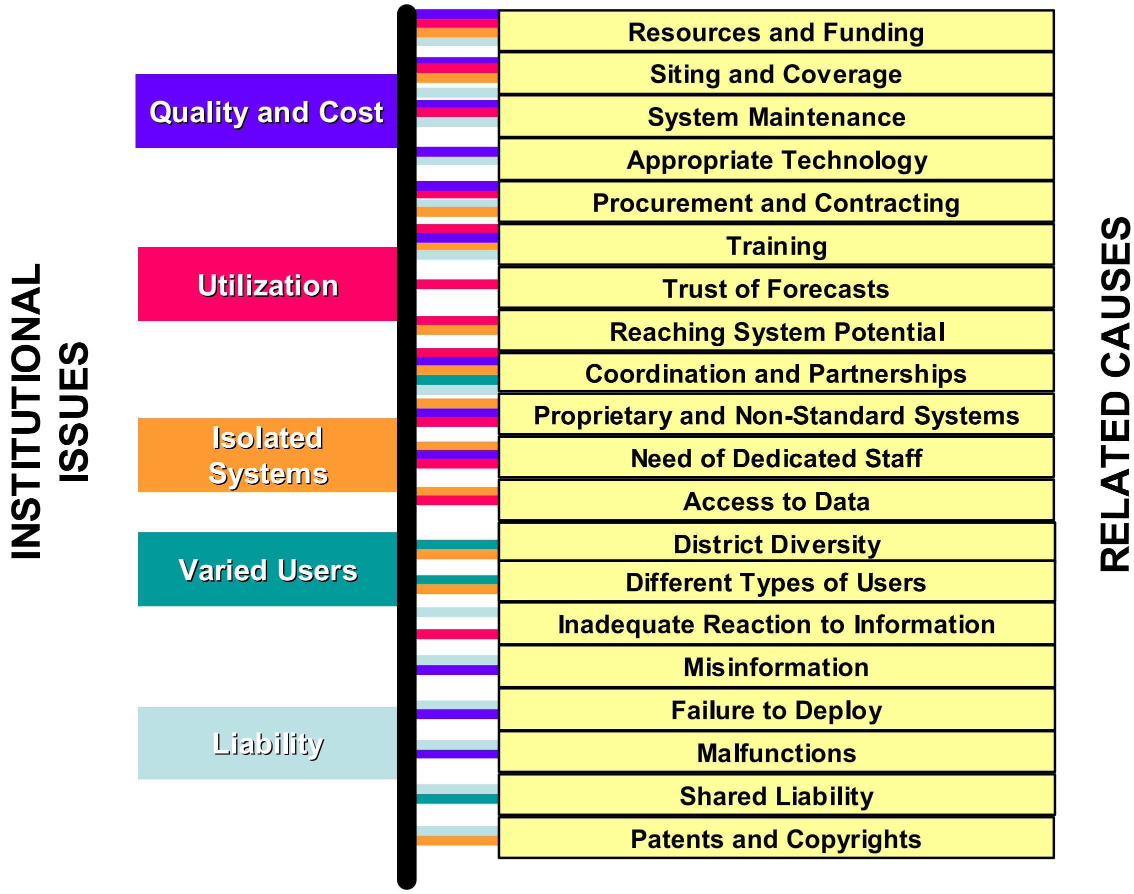
Another opportunity is to work with other interested parties. Incident response agencies, such as fire, highway patrol, and emergency medical services, must travel in all weather conditions and have their own sets of needs that should be incorporated into a national policy. The trucking industry and transporters of hazardous materials can also contribute.

Many of the institutional issues and barriers facing us on the national level are the same as those that face Caltrans when reviewing their use of Road Weather Information Systems. A 2001-2002 study assessing the use of RWIS in Caltrans RWIS those institutional issues into quality and cost, utilization, isolated systems, varied users, and liability. Each of these institutional issues have multiple related causes. For example, limited resources and funding was seen as a cause for all five issues. These institutional issues and related causes are depicted in the following figure. Many of these causes have potential solutions, which, if implemented, would decrease some of the current institutional issues. Similarly, any policies or programs on the national level would also help improve the use of currently available weather information.

On the technology side, we see good promise in providing modeled road conditions in complex terrain to maintenance users. When running in a forecast mode, this type of model can provide maintenance users with information on if, when, and where to treat the roads.

At this point, there are a number of institutional and technological questions yet to be addressed. Meteorological and surface temperature forecasts continue to advance, but how do you include human actions into a model? For example, how can a model forecast a pavement temperature or the formation of ice when the model does not know when or if plowing or anti-icing occurs? How does a model incorporate the impact of traffic on the formation of snow? These are questions yet to be researched.

These and other research areas should ultimately improve the application of weather information in managing the highway system. The outcomes of the research will be incorporated into products provided by the private enterprise, yet it is the academic institutes and government that is best suited for research. The barrier to studying and deploying methods to improve safe travel during adverse weather conditions is money. Yet theses applications should be saving lives.


INSTITUTIONAL ISSUES
Quality and Cost
Utilization
Isolated Systems
Varied Users
Liability
Resources and Funding
Siting and Coverage
System Maintenance
Appropriate Technology
Procurement and Contracting
Training
Trust of Forecasts
Reaching System Potential
Coordination and Partnerships
Proprietary and Non-Standard Systems
Need of Dedicated Staff
Access to Data
District Diversity
Different Types of Users
Inadequate Reaction to Information
Misinformation
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RELATED CAUSES

Public and industrial development of strategies and plans to effectively respond to weather and climate information

Richard J. Nelson. P.E.
Nevada Department of Transportation

1. How do highway managers apply weather information?

Highway managers face many challenges from the weather throughout the year. In some cases the general population isn't even aware. Many construction activities are weather dependent. For example: concrete paving can be adversely affected if the temperature is too hot or below freezing or if the winds are too strong. Routine maintenance activities can be weather sensitive as well. In one case a pavement seal coat was planned during a week when no rain was forecast. The day after it went down rain showers caused a very slick condition that resulted in four fatalities and several millions of dollars in legal settlements.

Winter operations represent the most extensive application of weather information in highway operations.

Winter operations

Keeping the highways passable and maintaining a consistent pavement condition are goals during the winter. While major storms have the greatest overall impact on mobility, the most horrific crashes tend to occur when motorists transition from good to poor road conditions with little or no warning; the patch of frost or ice on a shady curve, a pocket of dense fog or a flooded dip section. If accurate forecasts are available with sufficient time to act and highway managers believe them, the agency might be able to take preventative action instead of reacting after the condition materializes.

A variety of weather products are utilized for strategic and tactical planning.

Long Range Forecasts

Long-range outlooks are utilized for strategic planning. Seasonal outlooks provided by the National Weather Service are useful in determining what deviations from "normal" may be expected. The NWS Forecast Office in Reno, NV, presents a winter briefing to the emergency responders to discuss climatology and what the effects of global weather phenomenon like El Nino, Southern Oscillation (ENSO) may present. Other discussions available from the Climate Prediction Center are also helpful in making estimations and broad preparations for the acquisition of materials (abrasives, chemicals and sand bags) and potential staffing requirements.

A 30-day outlook is also useful to assess the risk associated with initiating equipment repairs, refining manpower needs and estimates of future material use.

Short-Range Forecast

Short-range forecasts on the order of three to five days are utilized to develop tactical plans associated with employee shift schedules, material usage and the potential reallocation of resources. Each Monday and Thursday maintenance managers at NDOT conduct a weather discussion by teleconference to assess the upcoming planning horizon.

Maintenance managers have their favorite source for weather forecasts. The discussions provide the opportunity to evaluate and reconcile the various forecasts and the impact on the region to develop consensus and agree on the “plan of attack” for the next three-day period.

"Now-casts"

Many state highway agencies utilize value added meteorological services to provide twice daily forecasts. These forecasts are designed to meet the special needs of highway maintenance crews.

The service provided to Nevada has a general discussion for the region and individual forecasts zoned for each crew’s roads. An assessment of potential (ranked 1 to 5) for snow, ice and frost is also given. These forecasts are delivered by e-mail with notification by pager/cell phone in the event circumstances dictate an update. The meteorologist is also on call to discuss the forecast or how the forecast is playing out.

The key to the successful utilization of the variety of forecasts lies in the relationship between the meteorologist and maintenance crews. If a relationship exists between the meteorologist and the maintenance crews, the crews can understand the constraints of the meteorologist and the meteorologist understands the unique needs of crew. This relationship builds trust in the meteorologist and their forecasts.

ROAD WEATHER INFORMATION SYSTEMS

It used to be that the only source of meteorological data was at the airport. This may or may not have any relationship to what was happening on the highway network. To fill this need for data, highway agencies developed their own network of sensor stations and created road weather information systems (RWIS). These systems consist of environmental sensor stations (ESS) placed near the roadway to gather traditional atmospheric data with sensors imbedded in the pavement to gather pavement condition data. These systems provide near real time data (usually polled every 15 to 30 minutes) to the highway manager. This information on atmospheric and pavement condition and the related forecast products help highway managers make tactical decisions before, during and after storms to optimize their response.

a. Pavement temperature forecasting

One product common to most RWIS is pavement temperature forecasting. Initialized by pavement temperature and with inputs from traditional atmospheric forecasting models, a 24-hour pavement temperature forecast is generated.

The pavement temperature forecast used in conjunction with other forecast atmospheric parameters indicates what locations may be subject to the development of frost, snow or icepack development on the road. This allows for tailored treatments to match specific forecast conditions.

b. Thermal mapping

Thermal mapping is the process of determining the relative difference in minimum pavement temperature from one section of pavement to another during the winter under various atmospheric conditions. With this data, the pavement temperature forecast generated for one specific location (at the RWIS ESS) can be interpolated between the forecast sites to identify problem areas across the network.

When this pavement temperature profile is coupled with the atmospheric forecast maintenance managers can see where there may be specific areas of snow, ice or frost concerns for the forecast period allowing for specialized treatment strategies.

2. How is the nation's highway system changing?

With the completion of the Interstate Highway System there has not been a substantial increase in the number of miles of new highways. Projects to rehabilitate and add extra capacity have been undertaken, but not to the extent necessary to address the 81% increase in vehicle miles traveled since 1980. Just-in-time delivery has turned the nations highways into warehouses and opened up opportunities for the supply of goods and services to located someplace other than the demand. This is evidenced by an increase in combination truck travel of 97% since 1980.

In addition to the increased use of the highway system, there have been increases in environmental awareness and concerns regarding growth in government that compound the highway manager's challenge in dealing with inclement weather.

Advancements in vehicle design and safety help address safety and mobility. For example, the development of traction control systems and advanced breaking systems have made significant contributions to motorist safety and mobility in inclement weather. The down side to this, however, is that there are more motorists on the highways during inclement weather.

Drivers education programs do not adequately address winter driving skills.

3. What are opportunities and barriers to effective application of weather information and applications that could enhance safety and operations of the nation's highway system?

One of the major barriers is the disconnect between the state agencies that are responsible for the operations of the highway system and the agencies that have the expertise to develop advanced weather applications. Projects such as these are competing for limited funds. Some initiatives have been undertaken by pooling funds from several agencies; however, the applications have been operationally oriented. To reach this state, there are needs for basic research into specific problem areas such as advancements in mesoscale forecasting and in the understanding of conditions at the boundary layer that exists at pavement level. Some limited attempts at this basic research have been attempted through the AURORA consortium, COMET projects and through the work being conducted as part of the MDSS project. The majority of work is occurring overseas.

Some specific opportunities are:

- Continue to develop decision support systems and weather forecasting tools to provide improved planning and tactical response to weather events. As this program matures, I believe we will see the need to establish focused research groups to investigate specific weather concerns with respect to surface transportation. These groups will perform the initial work necessary to create the foundation of knowledge that future applications can be created from.
- Develop forecasting tools to predict localized weather events that will create hazardous driving conditions at spot locations. This will involve a better understanding of the pavement – atmosphere boundary.
- Involving meteorologists and maintenance managers in the design of highway projects to identify opportunities to mitigate winter weather hazards can make a direct contribution to mobility. For example, consideration of winter solar exposure and the potential for blowing and drifting snow can make direct improvements to mobility.

- Establish and implement guidance for the construction (particularly site location and ESS configuration) and operation of RWIS so it can be better utilized by meteorologists for climatologic studies and inclusion into the met database.
- Emphasize the use of pavement temperature forecasting as a tool to develop mobility forecasts for motorists with sufficient time so modifications to travel plans can be made.

Public and industrial development of strategies and plans to effectively respond to weather and climate information

Jeffrey F. Paniati
Federal Highway Administration

Introduction

The Federal Highway Administration (FHWA) is pleased to be a co-sponsor of this forum, and we appreciate all the efforts of the American Meteorological Society to make it happen. The topics of this forum, weather and highways, touch most people that commute or travel on a daily basis. We've all had those miserable experiences of driving when the weather turns bad. And while we tend to think of these concerns on an individual basis, collectively the impacts to the nation from an economic, mobility or safety viewpoint are significant.

The national highway system is experiencing growing congestion as traffic demand increases at a pace that significantly exceeds the construction of new roads. From 1995 to 2001, total roadway miles increased by 36,371 miles or less than one percent. However, vehicle miles traveled rose over 358 billion miles or 13 percent during the same time period.

The Texas Transportation Institute's 2003 Urban Mobility Study looked at 75 of the nation's largest metropolitan areas and found the following trends:

The cost of congestion continues to climb. 5.7 billion gallons of wasted fuel and 3.5 billion hours of lost productivity resulted from traffic congestion in 2001 costing the nation $69.5 billion, $4.5 billion more than the previous year. The extra time needed for rush hour travel has tripled over the last two decades. Congestion has become a major quality-of-life issue for many, a significant economic concern for industry, and an increasingly hot political topic.

Adding different weather phenomena to the congestion mix can make a routine traffic delay quickly deteriorate from bad to worse. A seemingly benign rain shower can turn an afternoon commute into an hour's long struggle. The freight community experiences an estimated $3.4 billion annually in weather-related delay in metropolitan areas.

The impact to safety on the nation's roadways from adverse weather is just as staggering as it is to mobility and the economy. For example, in 2001:

- 1,408,496 weather related crashes occurred. This is 22.3 percent of total crashes
- 6,918 people lost their lives in weather-related crashes. This is over 16 percent of the total number of people killed in crashes
- 615,429 people were injured in weather-related crashes. This is 20 percent of total injuries.

Are weather forecasts of today sufficient in detail and accuracy to provide for a safer roadway environment? Can research and advances in numerical weather prediction that have benefited other segments of our society (e.g., the aviation industry) be applied to the road surface? Do we know enough about the behavior of drivers and vehicles under varying weather conditions to enhance system operations?

As we explore how well the weather and surface transportation communities have come together to work on these problems, we need to consider the ways in which policies have helped or hindered those efforts, and to consider what changes need to be made to enable us to go farther. The following sections provide insight, from the Federal Highway Administration perspective, to questions posed by this policy forum associated with strategies and plans to effectively respond to weather and climate information.

1. How do the highway system managers and users apply weather information?

This question has multiple answers because highway system managers cannot be categorized into one group. The highway is a very dynamic environment, and the management of the system requires many areas of specialization. Highway managers can specialize in areas ranging from construction to maintenance, from engineering and safety to traffic management. In 2000, the FHWA Road Weather Management Program documented the weather information needs of 44 types of highway system managers in order to make 423 kinds of decisions.

That said, highway managers generally use three types of strategies to mitigate weather impacts on roads: advisory, control and treatment strategies. Advisory strategies provide information on prevailing and predicted conditions to both managers and motorists to influence decisions. Control strategies alter the state of roadway devices (such as traffic signals and ramp gates) to regulate roadway capacity and permit or restrict traffic flow. Treatment strategies supply resources to roads (such as plowing or applying sand or salt) to minimize or eliminate weather impacts. Highway managers utilize these strategies in different situations ranging from snow and ice control to coordinating evacuations during natural events (such as a hurricanes or wild fires). Such differing missions and requirements translate into little homogeneity across the specializations with respect to the application of weather information for highway managers. The degree to which weather varies across the country also adds a level of complexity.

Transportation managers obtain road weather information from observing systems and private meteorological service providers. Some state agencies deploy Environmental Sensor Stations (ESS), which are the field components of Road Weather Information Systems (RWIS). An ESS is a fixed roadway location with one or more sensors measuring atmospheric, pavement and/or water level conditions. 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 manager. Environmental information from state-owned ESS may also be used to enhance National Weather Service (NWS) forecasts and supplement mesoscale environmental monitoring networks (i.e., mesonets). Some agencies are deploying and testing environmental sensors on their maintenance vehicles. These mobile sensors can be utilized to sense atmospheric conditions and pavement conditions (e.g., temperature, friction), which are transmitted to central locations via Global Positioning System (GPS) technologies.

Traffic managers may use road weather information to alter traffic signal timing to accommodate slower travel speeds on slippery roads. Speed limits can be reduced on freeways based upon safe travel speeds for prevailing visibility, pavement, and traffic conditions. When travel conditions are unsafe due to low visibility, excessive snow accumulation or flooding, traffic managers may restrict access to specified lanes or bridges, entire road segments, vehicles without required equipment (e.g., tire chains), or designated vehicle types (e.g., tractor-trailers). Weather information can help maintenance managers make decisions about staffing levels, plan the most efficient treatment routes, select chemicals and road treatment strategies (e.g., anti-icing, plowing, fog dispersal), and determine the timing of maintenance activities (e.g., crack sealing operations in summer months). In response to flooding, tornadoes, hurricanes, or wild fires emergency managers use weather information—primarily from the NWS, the U.S. Geological Survey and the National Hurricane Center—to identify threatened areas and evacuate vulnerable residents.

Highway managers disseminate road weather information to different types of road users or travelers (e.g., commuters, tourists, commercial vehicle operators) with varying information needs. Road weather information allows travelers to make decisions about travel mode, route selection, vehicle type and equipment, departure time and driving behavior (e.g., speed). Managers may furnish road weather information through roadside warning systems (e.g., highway advisory radio), interactive telephone systems (e.g., 511), and state agency web sites.

Small segments of the highway management community have been experimenting with both intelligent transportation systems (ITS) and intelligent weather systems (IWS). For example, some in the winter maintenance community subscribe to private sector providers for detailed forecasts of wintry precipitation and pavement temperatures. There are federal and state-sponsored pooled-fund projects associated with the development of sophisticated decision support systems, which combine numerical weather prediction with computerized rules of practice for winter road maintenance. Still, there is a significant component of the winter maintenance community that only utilizes weather information from the media or only takes action when neighboring (upstream) jurisdictions report problems.

In many cases, highway managers are not aware of the types of products that exist to help their programs. Sometimes, tailored support for a specific activity just does not exist. Even if the support does exist, many road managers may not find the information useable (e.g., not in the right format or too much weather jargon) or they may not have a strategy in place to use the information. There are very few highway managers that have access to staff trained in meteorology or the skills to interpret and use the data provided. By integrating accurate, timely, route-specific weather data into decision-making processes, highway managers can effectively counter weather-related congestion and delay, reduce weather-related crashes, and disseminate relevant, credible information to travelers.

2. How is the nation's highway system changing, and how will this affect the development of applications?

The management of the nation's highway system is undergoing a fundamental paradigm shift and the FHWA is leading the way to reshape the way that highways are operated. The history of highway transportation, until most recently, was focused on building the road network. Federal agencies "grew up" around the need to build roads, beginning with the farm-to-market roads of the 1930s and into the Interstate System construction era of the 1950s, 60s and 70s. As better operations becomes a strategy more fully applied to transportation, it will require rethinking agency organizations and how services are delivered to those who depend on the transportation system. Effectively addressing problems such as congestion and safety will hinge on the ability to reshape traditional transportation organizations into "21st century operations agencies using 21st century technologies". The FHWA has focused on six characteristics that can transform an organization into a 21st century operations agency.

Customer Focused

A transportation agency that exhibits 21st century operations maintains focus on its customers' – the travelers' – needs. The agency understands who its customers are (residents, tourists, workers, businesses, and freight) and their needs. These agencies recognize that travelers care about the quality and reliability of their trip from end-to-end regardless of who "owns" the roadway. Agencies obtain feedback from their customers and are responsive to their travel needs. They make sure that information about the performance of the transportation system is readily available, timely, and targeted to the needs of the customer.

Performance Driven

Performance of the transportation system will become a key metric. Today, we largely measure performance in terms of condition of the physical infrastructure. Increasingly, performance measures such as reliability and delay will be important determinants of how well the system is meeting customers' needs. The FHWA is documenting benefits of intelligent transportation systems in six performance measure areas including road capacity, cost savings, customer satisfaction, delay, energy and environment, as well as safety.

Systems Approach

Operations require a regional and integrated approach to managing the performance of the transportation system. This means having a regional view that transcends city/county/state boundaries and system ownership. The result is a higher-level concern for the operation of the entire roadway network regardless of agency ownership. A systems approach also refers to the integration of technical systems such as intelligent transportation systems within and across agencies. The performance of the transportation system is largely determined by the ability of agencies to work cooperatively together by sharing data and coordinating responsibility.

Real-Time Management

Key to virtually every congestion mitigation strategy is real-time, or near real-time, information about what is happening on roadways, including information on weather, pavement conditions, incidents, traffic flow (e.g., speed, volume), maintenance activities and construction plans. This information can be shared with the public and with multiple agencies for effective coordination and faster responses. Improved information is also an asset to the freight community. Information on the location of freight shipments helps carriers manage their fleets, helps manufacturers control their inventory systems, and provides advance information to Federal agencies concerned with trade facilitation and national security.

24/7 Operations

Historically, highway agencies develop and administer road construction projects and operate roads. This work is largely accomplished during "typical" work hours – eight hours a day, five days a week. However, the transportation system functions 24 hours a day, seven days a week. Delay can happen any time, any place, and for many reasons. To be responsive to their customers, operations agencies must develop the capability to conduct some functions on a 24/7 basis. This requires different staff approaches and a change in philosophy.

Proactive Management

Highway agencies focused on better operations are proactive in anticipating and managing transportation events. Planning for special events including signal-timing changes, use of dynamic message signs and traveler information are routine. Monitoring weather observations and forecasts and anticipating their impact on transportation allows for use of proactive strategies, such as anti-icing. Advanced planning for traffic impacts from work zones ensures minimal disruptions to travelers and businesses. Operations agencies fully plan for the disruptions to traffic in advance of the event.

Improved road weather management resources can be developed by focusing on these characteristics. Managers will be able to better serve their customers with tailored, route-specific, real-time environmental data that is integrated with their control systems. Empirical studies of the impacts on weather and pavement conditions on roadway safety and mobility, agency productivity and environmental quality will lead to innovative strategies that improve transportation system performance. An integrated approach to transportation management can be achieved through institutional coordination among traffic, maintenance and emergency managers as well as data sharing across jurisdictional boundaries. With high-resolution near-term forecasts and nowcasts, highway managers can develop and implement proactive strategies, such as anti-icing, that more efficiently achieve their operational objectives.

Another aspect of how the FHWA is taking a proactive role in advancing the state of the highway system is through specific programs that bring the weather and surface transportation communities together. For example, the Road Weather Management Program of the FHWA Office of Operations has a dual mission of making the meteorological community aware of specific road weather information needs while educating the highway management community to new tools and techniques to support their mission. The Maintenance Decision Support System (MDSS) project is just one program that has brought significant visibility to the underserved surface transportation weather market. The MDSS project is using state-of-the-art weather forecasting technologies and computerized maintenance rules of practice to create an automated system that generates an optimized set of recommendations for winter road maintenance. Through interactions between the research and academic communities, private sector weather providers and state and federal agencies, the level of service and expectations for better techniques and methodologies has already been raised, even before its conclusion. The goal of the Road Weather Management Program is to eventually have a system in place to provide "Anytime, Anywhere, Road Weather Information" for both the users of the highway system and the agencies that maintain them.

3. What are the opportunities for and barriers to effective application of weather information to highway safety and operations? What improvements in weather information and applications could enhance the safety and operations of the nation's highway system?

There are many opportunities to merge intelligent transportation and intelligent weather systems to improve safety and operations of the highway system. However, before major strides can be made, there must be a fundamental realization that weather information for the roadway surface is as valuable and as important as for other modes of transportation. Significant resources have been utilized to make the aviation industry safer. The results have been dramatic over the last two decades leading to very few weather-related aviation incidents. The same kind of resources and energy that went into mitigating aviation-related weather problems (such as wind shear and microbursts) can be brought to bear to help reduce crashes, injuries and fatalities on the nation's roadways. We as a nation must recognize the value in all of the associated research, which will ultimately increase mobility and make the roads safer.

Weather Research

More research is needed to accurately observe, model and predict conditions close to the ground. To do this, the meteorological research community needs to better understand boundary layer interactions. Much of the rapid advances in meteorological science have come from the modeling of the middle atmosphere. Ground and near-surface fluxes, heat transfer and turbulence are all complex issues that must be tackled with applied research. Higher resolution models will be required to capture the physics of the boundary and to produce route-specific forecasts in meters and feet rather than kilometers and miles.

Highway Research

The surface transportation community has only begun to estimate how much lost roadway capacity can be "bought back" by employing road weather management strategies when inclement conditions occur. Through simulation, we have shown that employing a weather mitigation strategy on a road (such as weather-responsive signal timing) will increase roadway capacity. We've demonstrated improvements in traffic flow, but the extent of change is unclear. There is a need to conduct more extensive research in this area.

Barriers Standing in the Way

There are additional barriers that stand in the way of making progress in the use of weather information for highway operations. Some highway managers have described one barrier as "information overload". Often times, highway managers are inundated with weather products and jargon that have no direct bearing on their mission. These managers must sift through products to find pertinent details. Part of the time, managers give up and move on with their operations without the benefit of the latest weather information. Others find important weather information but don't have it presented in a way that is useable to them or in a format that can be handled by their systems. A national road weather observing system that promotes open data sharing, analysis, and integration will be critical to support transportation operations during adverse weather.

In addition, the highway manager isn't looking for just "more forecasts". They seek weather information that is ***tailored to their mission***, presented in a way that can be readily understood, and formatted in a way that can be easily processed. More accurate observations and forecasts are important, but so are the parameters that are important to their mission. These can be accurate measurements and predictions of precipitation start and stop times, precipitation type and accumulation. Observations and predictions of air and road surface temperatures as well as driver-level winds and visibility are essential.

In Conclusion - Moving Forward Together

There are many opportunities to improve the highway system through an inclusive approach, taking into account the strengths of the research community, the private sector and the state and federal practitioners. As a first step, the weather community must better understand the mission and expectations of the highway manager and the highway manager must be able to understand the limitations and near term improvements of the weather community.

The challenge ahead is formidable. However, the cost in lives, property, and economic impact dictate that we meet this challenge. Together we can shape and provide direction for a safer and more efficient 21st Century surface transportation system.