Chapter 1
Introduction and Background

1.0 Introduction

This report provides a compilation of users' needs for weather information—needs that have been validated with user communities in six surface transportation sectors. Based on an analysis of these needs, the report identifies strategic thrust areas for improving and expanding the weather information currently available. It suggests next steps in these areas that will enhance the value of weather information to the safety, efficiency, and effectiveness of the nation's surface transportation systems.

For this report, ***needs*** are defined as weather data that provide important elements of information for the decision-making processes used by travelers, operators, or managers involved in any surface transportation activity (the ***users***). A weather information need is characterized by a ***weather element***, the transportation ***activity*** that requires the information, the ***threshold*** at which the activity needs information about that element, and the ***lead time*** required for effective planning or action.


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The nation's surface transportation sectors include (from upper left) rural and urban transit systems, long-haul railroads, the Marine Transportation System, pipeline systems, and airport ground operations.

This chapter highlights some of the important impacts of weather on the nation's surface transportation systems and summarizes some of the existing and emerging capabilities for providing ***weather information for surface transportation*** (WIST) to users. Chapter 2 describes the process by which users' needs for WIST were identified and validated by developing a set of WIST Needs Templates. The final version of these templates is included as Appendix B. Chapter 3 summarizes the interests in WIST of the federal, state, and local organizations that participated in developing and validating the templates. Each template covers one of the six transportation sectors: roadways, long-haul railways, the Marine Transportation System (MTS), pipeline systems, rural and urban transit, and airport ground operations (see textbox below).

Chapter 4 provides a high-level view of the data in the WIST Needs Templates, along with background information—gathered from the user communities during development of the templates—that helps in interpreting the template data. Users throughout the surface transportation communities surveyed for this study need accurate weather information beyond what is currently available. From highway maintenance managers concerned about freezing precipitation to pipeline operators worried about hurricane-induced tidal surge to river barge captains concerned about reduced visibility in fog, users, decision makers, and regulators across the spectrum of transportation activities ***confirmed the value of weather information in improving safety and enhancing the efficiency and effectiveness of their activities.***

The economic impact of weather on transportation systems, its toll on the safety and health of the public using these systems, and the increasing demands that will stress system capacity, environmental quality, and social equity dictate that actions be taken to resolve the myriad weather-related transportation issues facing our nation. These factors are reflected in the conclusions from the WIST needs analysis, presented in Chapter 4. Chapter 5 suggests the next steps to be taken in six strategic thrust areas for continuing the coordination of research and development (R&D) programs and for translating research results and new technology into products and services to meet WIST users' needs. Chapter 5 also presents a summary vision of future weather information systems for surface transportation, if users' WIST needs are recognized and met.

Transportation Sectors Versus Modes

For this report, the term ***mode*** best describes a narrower, more specific form of transportation, such as automobile, bus, truck, ferry or subway train. The term ***sector*** is broader in scope and encompasses multiple modes that share a major characteristic, such as the medium in which they operate (on water, on roads, on railways, in the air, etc.) or operation under one management (e.g., transit authorities). This report covers six transportation sectors:

Roadway—state and federal highways, roads, and streets

Long-Haul Railway—rail lines providing intercity freight and passenger service, with their yards, stations, and depots

Marine Transportation System (MTS)—coastal and inland waterways, ports and harbors, and the intermodal terminals serving them

Rural and Urban Transit—bus and van service on streets and roadways, rail lines for metropolitan subway and surface "light rail" systems

Pipeline Systems—Above and below ground pipelines for commodities such as crude oil, refined petroleum products, and natural gas, plus the storage, transfer, and pumping facilities for pipelines

Airport Ground Operations—All ground movement of vehicles, work crews, and passengers.

1.1 Why Should We Be Concerned?

The nation's surface transportation systems touch our lives many times each day. They connect consumers with resources and enable us to travel where we need or desire to go. Nearly every citizen uses or relies on these systems daily—including the 3.9 million miles of public roads, 2 million miles of oil and natural gas pipelines, 120,000 miles of major railroads, and over 25,000 miles of commercially navigable waterways. Transportation services are provided at 5,400 airports, throughout the 6,200 miles of urban rail transit, and at 3,750 waterport terminals (FHWA 1998, p. 17; DOT 1999; TRB 2001). The total value of the national transportation infrastructure is $1.5 trillion, and 11 percent of the national gross domestic product (GDP), or about $8 trillion, is related to transportation (TRB 2001, FHWA 2002a). Weather influences virtually every type of operation or activity involved in these transportation systems and facilities.

The scale of use of surface transportation systems in the United States is impressive. More than 200 million cars and light trucks use our highways. Commuters number about 115 million, and 34 million of them travel more than 45 minutes each way. Of the more than 9 million recreation vehicles, 1.1 million are on the road at any given time. Of the more than 3 million truckers, about 1.1 million are long-distance haulers. Rental cars number about 1.6 million (TRB 2001, FHWA 2002a). On the nation's waterways, ferryboats carry about 134 million passengers each year, while about 78 million people annually engage in recreational boating. In addition, cruise ships provide service to 5 million passengers every year (DOT 1999).

Parts of our surface transportation system function at or near their maximum capacity much of the time, and capacity utilization is increasing. All surface transportation modes have congestion at critical bottlenecks. Weather reduces the capacity throughout the system, creating new bottlenecks and exacerbating existing ones. Actions that mitigate these weather effects improve transportation system safety and efficiency.

1.1.1 Adverse Weather and the Nation's Streets and Highways

In the United States about 41,000 people die on highway systems each year. These deaths result from six million crashes that also cause more than 3 million injuries annually. According to the National Highway Traffic Safety Administration (NHTSA), each year, on average, about 1.7 million of these vehicle crashes occur in adverse weather or weather-related adverse road conditions.[1]

Road Weather Bottom Line:
7,000 fatalities
800,000 injured
$42 billion in economic costs
—each year

Source: NHTSA estimate (Lombardo 2000).

One estimate from NHTSA is that adverse weather and adverse road conditions related to weather are directly or indirectly a factor in approximately ***800,000 injuries*** **and** ***7,000 fatalities*** resulting from vehicular crashes. That represents about 28 percent of the total crashes and 19

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[1] Uniform statistics on weather conditions as a *factor* in accidents are difficult to collect. NHTSA is working on gathering reliable data on this important factor from state and local public safety authorities, but results were not available for this report. The numbers cited here for weather-related injuries, fatalities, and costs are estimates presented by a NHTSA official at the WIST II symposium.

percent of the total fatalities. The estimated annual economic cost from these weather-related crashes (deaths, injuries, and property) amounts to nearly ***$42 billion*** (Lombardo 2000)**.**

Table 1-1 shows the weather condition present when vehicle crashes caused injuries or death. Table 1-2 compares, by vehicle type, the deaths during adverse weather with total roadway deaths. Note that neither of these tables includes weather-related adverse road conditions, which may persist after the weather clears. Nor does the presence of adverse weather at the time of a crash imply that weather was a causal factor.

Winter weather causes a pile-up on Interstate 95 in Virginia. Image Courtesy of WRC-TV, copyright 2002.

Safety and the economic consequences of accidents are certainly critical reasons for being concerned about ***road weather***—the impact on road and highway conditions of weather and related phenomena. But they are not the only reasons. Rain, ice, snow, fog, and other adverse weather conditions can directly reduce the effective capacity of roads and highways (Chin et al. 2002). Because of safety concerns and the consequences when an accident occurs, state and local authorities may impose lower speed limits and partial or complete closures of streets, roads, and highways. Or they may restrict the vehicles allowed to travel on them. Many effects of weather on road conditions—for example, standing water after heavy downpours, roadbed weakening from prolonged excessive soil moisture, potholes after the winter freeze-thaw season, fallen trees and debris after strong storm winds—can continue to slow or halt normal traffic for hours, days, and even weeks after the weather itself has turned fair.

Table 1-1 Weather Condition at Time of Vehicle Crashes (1999 Data)

Number of Crashes (percent total)		Weather	Injuries	Deaths
5,281,000	84%	Normal	2,757,000 (85%)	37,107 (89%)
679,000	11%	Rain	364,000 (11%)	3,086 (7%)
199,000	3%	Snow/Sleet	63,000 (2%)	680 (2%)
47,000	<1%	Fog	18,000 (0.5%)	569 (1%)
72,000	1%	Other	34,000 (1%)	275 (<1%)
6,279,000	100%	All conditions	3,236,000 (100%)	41,717 (100%)

Source: Lombardo 2001.

Table 1-2 Adverse Weather and Deaths by Vehicle Type (1989–1999 Totals)

Vehicle	Total Deaths	Adverse Weather Present	Percent of Total
Passenger Cars	312,620	42,585	13.6
Light Trucks	190,271	26,221	13.8
Large Trucks	56,278	9,346	16.6
Motorcycles	28,537	969	3.4
Buses	3,617	622	17.2

Source: Lombardo 2001.

In one year (1999), an estimated 544 million vehicle hours of delay occurred on freeways and principal arterial roads, just from fog, snow, and icy conditions (Chin et al. 2002). State, city, and county highway maintenance agencies spend $2.1 billion per year to treat snow and ice on roadways—a third of which is spent just for treatment chemicals (FHWA 1998, p. 16; Davies et al. 2001). The information gathered from transportation system decision makers for this study suggests that these measurable costs represent merely the tip of an iceberg of total direct and indirect economic costs incurred each year because of road weather.

1.1.2 Adverse Weather and Other Surface Transportation Sectors

Other surface transportation sectors are also affected by the weather, although the significant weather conditions and consequences may differ from the more familiar effects on roads and highways. For most of us, the MTS and the nation's pipeline systems operate behind the scenes of our everyday lives. Our road and rail systems are familiar sights, but most of us are unaware of the extent to which daily commerce depends on waterways and pipelines, as well as on trucks and trains. Figure 1-1 shows major ports and waterways of the MTS; Figure 1-2 shows just one of the nationwide pipeline systems in the pipelines sector.

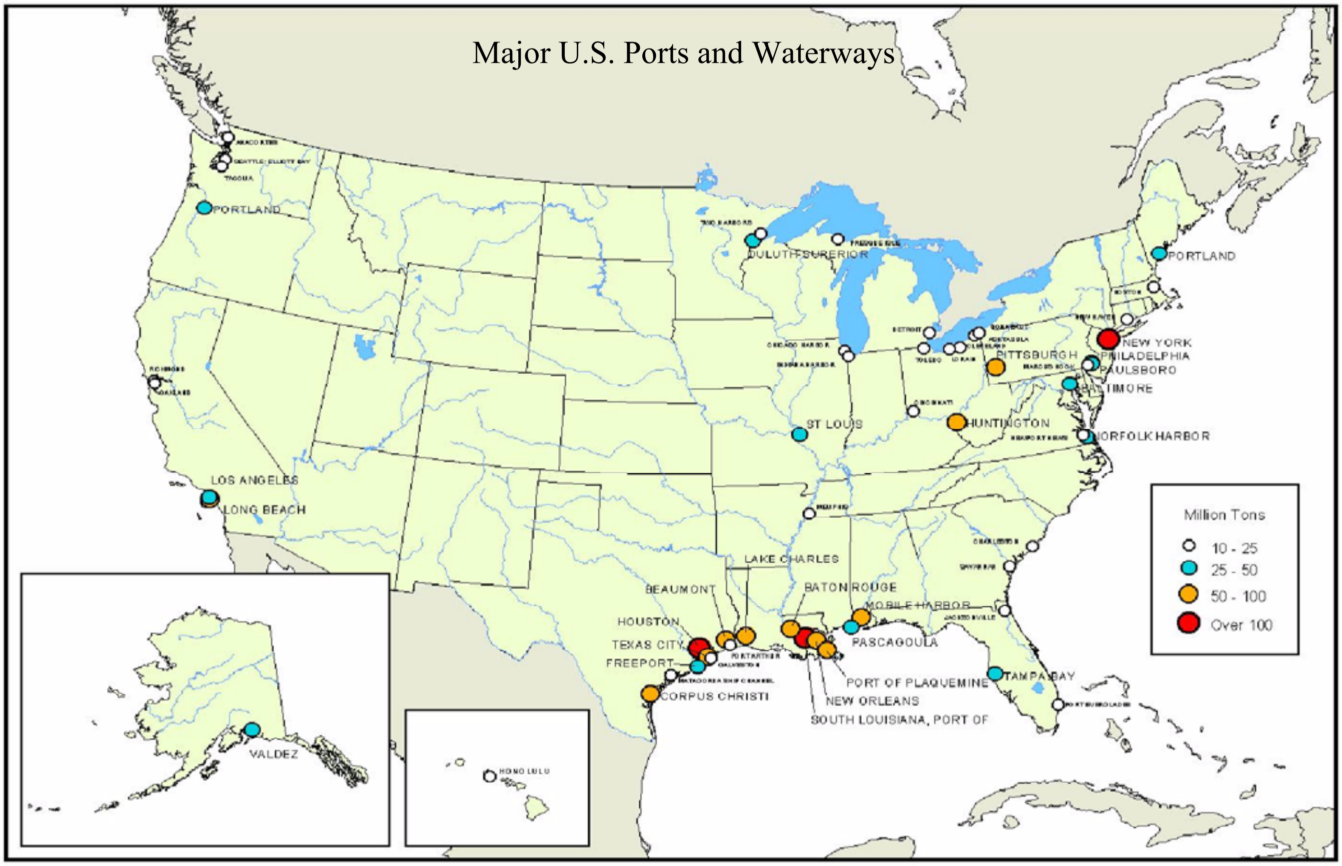


Figure 1-1 Major U.S. ports and waterways. Source: U.S. Army Corps of Engineers

We are even less aware of the diverse ways that weather affects these essential transportation sectors. Although these sectors—railroads, waterways and ports, airport ground operations, and pipelines systems—have far fewer injuries and deaths than occur on roads and highways, weather still affects safety and economic efficiency. The U.S. Coast Guard lists weather as the cause of 7 percent of recreational boating accidents (DOT 1999, p. 41). Weather impacts in one region have consequences that ripple through interconnected transportation networks, causing bottlenecks, delays in delivery, and imbalances in supply and demand that lead to higher costs for consumers.

Figure 1-2 Major refined petroleum product pipelines of the United States. See Section 4.6 for additional maps of U.S. pipelines. Source: AOPL 2002.

The freight community views these transportation assets and infrastructure as an end-to-end system. This systems viewpoint begins with the goods as they arrive at a port in the United States aboard a ship; are transferred to truck, rail, or plane assets; and move to distribution centers or retail centers. To be efficient, this intermodal system requires significant coordination among many producers and shippers. As the practice of just-in-time delivery (the dependable delivery of raw materials or goods so that a factory or retailer does not have to maintain a large inventory) spreads through U.S. industry, shippers must plan for and cope with weather of all types and severity.

Reduced visibility from fog slows traffic on the MTS.
Photo courtesy NOAA Photo Library.

The MTS offers a telling illustration of how these essential transportation systems can be affected by weather. This system comprises the nation's navigable waterways, ports, and harbors, as well as the connections to railroad, roadway, and pipeline systems. It enabled the United States to become the world's leading maritime trading nation; over 95 percent of U.S. foreign trade tonnage is shipped by sea (DOT 1999), and more than 38 percent of intercity freight is carried on inland waterways and pipelines (Coyle et al. 2000). On February 27, 2001, fog closed the Houston ship channel to inbound traffic, causing long delays for vessels using this waterway. Similar conditions caused a backlog of almost 80 ships earlier in the month. Houston and neighboring ports are home to the nation's largest oil and petrochemical plants. Fog along the Gulf Coast was cited as the main reason for a huge, 12 billion barrel decline in the output of U.S. refineries that week. (Reuters 2001).

In October 1994, a major flood on the San Jacinto River near Houston undermined numerous pipelines. Eight pipelines ruptured, igniting petroleum spills into the river. More than 500 people suffered burn injuries. Effects of weather phenomena are the second-most frequent contributor to pipeline damage or failure.

Source: NTSB 1996

Another incident, this one involving an Amtrak passenger train derailment, illustrates how weather conditions can cause problems specific to a transportation system's infrastructure and operations. July 29, 2002, was an excessively hot day in the Mid-Atlantic region. As the Capitol Limited sped through Kensington, Maryland, the engineer applied the train's emergency brakes after spotting an area of misshapen track ahead. The multiple car derailment 45 seconds later left bleeding passengers crawling out the windows of overturned cars. A total of 101 passengers were injured, with one still in serious condition the next day. Experts considered the most likely cause of the 30-inch misalignment of the welded track to be buckling due to the hot weather. A heat order issued that day had reduced the posted speed for freight trains from 55 to 45 miles per hour (mph), but not the 70 mph speed limit for passenger trains. The line remained closed to all traffic until the derailed cars could be removed and the damaged track replaced. Although the number of derailments due to heat buckling of rails has declined, there were 44 accidents attributed to this weather-related condition in 2001 (Manning 2002).

1.2 Exposures, Threats, and Risks are Increasing

The economic and safety impacts of adverse weather and weather-related road conditions on highway carrying capacity will multiply as traffic approaches the effective carrying capacity of the system (Figure 1-3). Since 1982, while the U.S. population grew just 20 percent, the time Americans spend in traffic jumped an amazing 236 percent (U.S. News and World Report 2001).

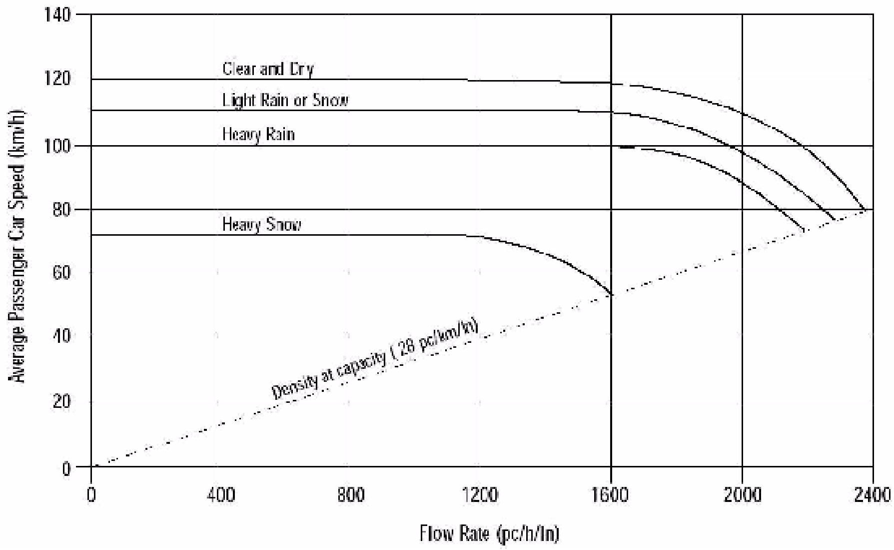


FIGURE 1-3 Speed-flow curves for different weather conditions, assuming a free-flow speed of 120 km/h. As traffic density (flow rate) increases, adverse weather has a greater impact on average vehicle speed. Pc = passenger car, ln = lane.

In major American cities, the length of the combined morning–evening rush hours doubled, from under three hours in 1982 to almost six hours today. The average driver now spends the equivalent of nearly a full workweek each year stuck in traffic. Congestion costs Americans $78 billion a year in wasted fuel and lost time—up 39 percent since 1990. In Houston, traffic jams cost commuters on the Southwest Freeway and West Loop 610 an average of $954 a year in wasted fuel and time. In New Jersey's Somerset County, congestion costs the average licensed driver $2,110 a year (U.S News and World Report 2001).

The Federal Highway Administration projects that, over the next 10 years, the number of vehicle-miles traveled is estimated to increase by 24 percent. In 20 years, it is expected to increase by 53 percent (FHWA 2002a). As more people and more freight travel more miles on the same streets and highways, adverse weather and weather-related road conditions will increase the strain on the roadway system.

Travelers are certainly aware of the risks associated with road weather. In March 2002, the Gallup Organization reported the results of a public opinion survey on the information most important to potential users of "511" traveler advisory services. Reports on weather-related and road surface conditions were most frequently identified as the most critical component for a 511 service, ahead of accident and road incident reports, construction updates, and even congestion levels on freeways. Forty percent of the respondents identified weather and road conditions as most critical (ITSA, 2002b).

Call "511" for Road Weather!

40% of potential users of 511 travel advisory services identify road weather and surface conditions as the "most critical" component of this growing transportation information service.

To the extent that capacity-reducing weather variations can be anticipated and communicated, and more precise mitigation measures can be implemented, system efficiency can be improved while operating costs and the number of crashes can be reduced. A recent literature review found no comprehensive studies of costs and benefits for an implemented road weather information system (RWIS) in North America (Boon and Cluett 2002, p. 39). However, there are numerous case studies of how limited RWIS deployments, combined with an anti-icing program, have decreased costs and improved efficiencies for both road maintenance management and travelers.

The costs and benefits of forecast-activated anti-icing pretreatment have been studied on a 29-mile stretch of U.S. Highway 12 in Idaho. This study showed a 62 percent reduction in road maintenance labor hours, an 83 percent reduction in use of abrasives to improve traction, and an 83 percent decrease in accidents (Breene 2001). Case studies prepared for the FHWA's RoadSavers program include the following results reported by state and local highway agencies using an RWIS (FHWA 2002c):

- In the first winter of using an RWIS in decisions on deploying crews for de-icing, the Massachusetts Highway Department saved over $53,000, one-fourth from lower labor costs and the rest from reduced use of equipment, salt, and sand.
- The West Virginia Parkways Authority installed four RWIS units along a 153-km stretch of the West Virginia Parkway in 1989. The savings in salt use were estimated at $6,500 per storm, with labor savings of an additional $2,300 per storm.
- The Dallas, Lubbock, and Amarillo districts of the Texas Department of Transportation installed RWIS stations beginning in 1990. Maintenance managers reported cost savings in materials, equipment, and labor that paid for the installations after the first two or three storms. The RWIS stations have also proved useful in scheduling construction work in fair weather. The RWIS sensors are being evaluated for use in flash-flood warnings during the summer thunderstorm season.
- The New Jersey Department of Transportation began installing RWIS stations in the 1980s and plans to build up to a system of 50 to 60 stations providing statewide coverage. Savings in chemicals, labor, and equipment costs are estimated to reduce expenses for snow and ice control by 10 to 20 percent or more, statewide.

A road weather service system in Finland for both road maintenance personnel and road users has an estimated cost–benefit ratio of approximately 1 to 5 for snow and ice control (DOT 2002).

Richard Raczynski, Chief Engineer for the New Jersey Turnpike, with one of the RWIS stations installed along that state's highways. Copyright AP Wide World Photos.

A 1 to 5 ratio of costs to benefits has also been estimated for full implementation of RWIS and related operational efficiencies in Washington State (Boon and Cluett 2002, p. 39). Thus, a well-informed "weather response" has a high economic payoff, as well as decreasing the risks to persons, goods in transit, and transportation assets.

Risks from exposure to adverse weather conditions are increasing in other ways as well. Certain elements of the population, such as those who are elderly, disabled, or have a low income, are more severely affected by weather impacts on their modes of transportation than the average citizen may be. In the 2000 census, persons 65 and older were 12.6 percent of the population. The Census Bureau expects this fraction to rise to 20 percent by 2030 (Kinsella and Velkoff 2001, pp. 133-134). Many of the elderly rely on rural and urban transit systems, which are subject to delays and cancellations in adverse weather. As a second example, the Census Bureau reports that one fifth of all Americans and nearly half of all senior citizens over age 65 have some level of disability (McNeil 1997). The routine of scheduled, accessible transit operations is a key factor in enabling people with disabilities to find and accept employment and to participate in other daily life activities. Because the number of people with disabilities is likely to increase as the population ages, the total risk from adverse weather impacts on their modes of transportation will increase.

A third example of increasing risks is the shipment of hazardous materials. Hazardous materials are shipped via many modes of transportation in the roadway, rail, MTS, and airport ground operations sectors covered in this study. If a release of hazardous materials occurs, atmospheric transport and diffusion of hazardous substances becomes an immediate concern of the public safety and emergency response teams involved. Major arteries may be closed, and populated areas at risk of exposure may need to be evacuated quickly. The weather may or may not play a role in causing a hazardous release. However, emergency response managers always need to know how the weather will affect the dispersion of materials and their plans for containing the damage and recovering.

1.3 MEETING WIST Needs—The Time is Right!

We cannot control the weather or its effects on vital transportation systems. What we can do is *use information about the weather and weather-related conditions* to manage the operations of our transportation systems more effectively, in preparing for and responding to whatever the weather may bring. Fortunately, the immense advances made in meteorological and environmental sciences, coupled with the twin technological revolutions in computing and digital-based communications, provide us with powerful new tools for delivering weather information to potential users across the surface transportation sectors.

However, the answer lies not simply in providing more and more data. The information conveyed by the data must be useful. It must be timely and accurate enough for decision makers to rely on it when their decisions can be costly in terms of both safety and economic consequences. Just as important, the information must be readily assimilated into the decision processes and procedures that potential WIST users already rely upon—or will use in the future—to make their decisions, implement them operationally, and reassess those operations for continuing correction and improvement. Two *key challenges* should be kept in mind when assessing current and emerging capabilities for delivering WIST to users:

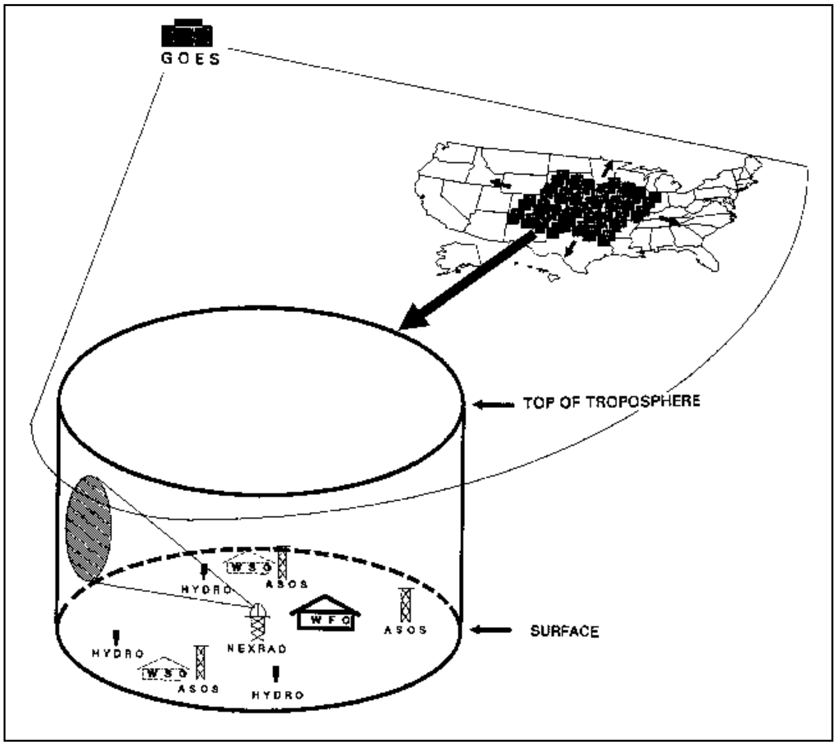
- **WIST is for Decision Support**. Transportation system managers, infrastructure operators and maintenance personnel, vehicle operators, shippers, and travelers—the entire gamut of potential WIST users—need WIST as one factor in often complex decisions about their actions. Meeting those needs requires understanding how the information could affect the user's decision process: What information does the user need? When is it needed? How accurate does it need to be to make a difference?
- **WIST Users have Diverse Needs.** Because the kinds of transportation-related decisions made by WIST users differ, as do the circumstances in which decisions must be made, the information content and its attributes vary from user to user. This report recognizes the diversity of information needs by referring to multiple "user communities" even within a transportation sector. At a general level, a weather map in the newspaper or the weather report on the evening television news provide some useful information to many of these communities. But the *potential benefits* of our scientific knowledge and technological capabilities can only be realized by tailoring WIST at a much more detailed level, across a broader spectrum of diverse user communities, than has ever before been done.

Section 1.3.1 highlights some of the most promising tools to meet this challenge. Section 1.3.2 describes future opportunities that further research and development can provide. In Section 1.3.3, the current situation in coordinating technology implementation for WIST—with the R&D to support it—is compared with the progress made in aviation weather during the past decade.

1.3.1 The Potential for Existing and Emerging Technology to Meet WIST Needs

Collecting Observations and Preparing Forecasts

Many of our existing national science and technology assets can be applied to the challenges of meeting WIST user needs. The National Weather Service (NWS) within the National Oceanic and Atmospheric Administration (NOAA) is the main federal provider of weather information. The recently completed NWS modernization of observing and information systems has already greatly improved high-resolution weather information through more and better weather observations, improved weather analysis and forecast models, a wider range of forecast information, and broader dissemination of products and services. In addition to providing weather data and services to the nation around the clock, every day of the year, the NWS also partners with other federal programs, academia, and the private sector in research and operational areas.



The suite of observing systems used by the modernized NWS includes weather satellites in geostationary orbit (GOES), Doppler weather radars (NEXRAD), automated surface observing systems (ASOS), and automated rain gauge and stream gauge networks (HYDRO). Courtesy NWS.

A recent initiative growing out of the NWS modernization is the National Digital Forecast Database (NDFD). The mission of NDFD is to increase the benefits of government weather forecasts, primarily through providing digital weather information to “drive” custom applications developed by partners in the weather information provider community. The database is intended to be a “seamless mosaic of NWS digital forecasts” including weather, water, and climate forecasts from Weather Forecast Offices, River Forecast Centers, and the National Centers for Environmental Prediction. It will begin with 5-km spatial grids prior to 2003, with the aim of improving resolution to 2.5 km nationally after that. Temporal resolution will be 6 hours for days 1 to 3 prior to 2003, migrating to 3 hours for days 1 to 3. Temporal resolution for days 4 through

7 will be 12 hours. NDFD will be available to all users and partners in the public and private sectors (Ruth 2002).

Supplementing the suite of NWS data and services, the private sector provides specialized or value-added weather information to a wide range of WIST users. Commercial providers already provide specialized processing of observational data from the NWS systems, mesonets, and specialized observing systems, as well as preparing special-purpose analyses and forecasts (many of which are developed for surface transportation or aviation users). A key role for the private sector in the WIST delivery systems of the future will be information technology applications for specialized weather services, including value-added graphics and data dissemination formats suitable as input for specific users' display or decision support systems (Smith 2001).

> "The provision of weather information in the United States is essentially a partnership between the public sector and the private sector."
>
> Jimmie Smith
> Chair, AMS Board of
> Private Sector Meteorology
>
> Source: Smith 2001, p. 76.

Intelligent Transportation Systems (ITS) and WIST

The ITS concept has been defined as "the application of computers, communications, and sensor technology to surface transportation." An intelligent transportation system can be viewed as a physical transportation infrastructure supported by a communication and information network. An objective of ITS is to provide highway and transit systems with communication capabilities that are already part of air and maritime transportation. These capabilities include controlling elements of the physical infrastructure, dispatching resources, and informing users (ITSA 2002).

ITS as a guiding concept for surface transportation traces back to research authorized under the 1991 Intermodal Surface Transportation and Efficiency Act (ISTEA). The Department of Transportation administers the resulting research and subsequent deployment programs through the ITS Joint Program Office, but ITS programs are overseen by various agencies with responsibilities for surface transportation. Academic and private-sector organizations are involved in much of the work. In practice, ITS programs have to date primarily covered the highway and transit transportation sectors, with little application yet to other sectors of surface transportation.

The connection between ITS and WIST, in essence, is that ITS provides a means to communicate WIST to anyone connected to an intelligent transportation system's communications network. The National ITS Program has established a functional standard for ITS communication networks called the national ITS architecture.[2] This architecture, based on the concept of open systems, currently defines 32 user services and the interfaces between them. WIST information would be one of the information types flowing into some of these user services, for example the Maintenance and Construction Operations service. User-oriented information tools—such as graphical display systems or decision support systems—that are connected to an ITS-compliant system can be designed to make use of WIST data available on

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[2] The national ITS architecture can be accessed in full at <http://itsarch.iteris.com/itsarch/>.

that system. Thus, the ITS architecture provides a technical foundation for delivering WIST in a form relevant to the diverse needs of users.

Smart Road Research

The control room overlooking the Smart Road where Virginia Tech researchers analyze data – near Blacksburg, VA

Courtesy Intelligent Transportation Society of America.

An ITS communications architecture can also aid in gathering WIST observation data. For instance, the Environmental Sensor Station interface standard in the national ITS architecture can be used to pick up observations from environmental sensor stations along roadsides or railbeds.

WIST and Surface Transportation Decision Support Systems

A ***decision support system***, as this term is typically used, means a computer-based information processing and display system (hardware and software) that incorporates a variety of data inputs and processes them into an information product (e.g., a graphical display, an audio message, or a printed report) useful to a subsequent decision process. This decision process may occur in the thinking of a system manager or operator, or it could be automated as another computer-based application. Typically, though, current decision support systems are designed to aid human decision makers by giving them highly pertinent information in a form the user can understand quickly.

Decision support systems that incorporate WIST input data can be as simple as roadside traffic advisory signs or a 511 telephone number service for recorded traffic advisory information. Advanced traveler information systems (ATISs) have proven successful in giving travelers alternative routes to avoid congestion and incidents. Studies of recent ATIS deployments have found that they: (1) help drivers make better-informed choices; (2) assist drivers in avoiding congestion and unexpected delays; and (3) reduce the time spent driving (Lappin 2000). These systems show that reliable and timely information about current and future weather conditions enables people to make better decisions about their particular activities and contributes to their safety, as well as increasing the efficiency of those activities. Three examples of current decision support systems that incorporate WIST are described below.

ATWIS. One example of current technology for providing in-vehicle information on road conditions and weather forecasts is the Advanced Transportation Weather Information System (ATWIS). ATWIS began as a means of providing route-specific road condition reports and nowcasts (forecasts from the current time through the next six hours) by cellular telephone to rural travelers in the northern Great Plains. The weather forecasts, which are updated hourly, provide information from a traveler's present location (specified by saying the interstate highway mile marker and direction of travel) to approximately 60 miles down the traveler's route. Road weather observations, including road surface conditions, are acquired through coordination with the state departments of transportation (Owens 2000).

By 2000, ATWIS had expanded to three states (North and South Dakota and Minnesota), covering 96,000 miles of highway. Surveys conducted by an independent evaluator found that 94.3 percent of travelers who knew of the service believed it would benefit their safety in the future. The system also provides departments of transportation in the three states with a simple text message and 48-hour forecast tailored to each transportation district. The surveys found that nearly all maintenance crew supervisors read the reports daily. Ninety-five percent said that the daily forecasts were helpful in their planning, and 75 percent altered plans or assignments as a result of the forecasts. A commercial partner has now joined the project (Owens 2000). During 2002, the commercial deployment of this system was enhanced and expanded to include 511 service available to both land lines and cellular telephones in South Dakota and Montana. Extension of the 511 service is planned for additional states. Additional service options are being added on a state by state basis (Osborne 2002b).

FORETELL. FORETELL is a multi-state initiative covering the Upper Mississippi Valley region and funded in part by the Federal Highway Administration (FHWA). The goal of the FORETELL program is a RWIS integrated with a wider set of ITS services to enhance safety and facilitate travel. FORETELL provides detailed weather forecasts, generated four times per day for the next 24 hours, with hourly updates, available to users via the public Internet. Spatial resolution is on a 10-km grid, and the forecasts are mapped to interstates and highways to predict pavement conditions. It also collects atmospheric and road condition observations from roadside sensors and mobile platforms, processing them into "plain English" descriptions for users. A field operational test of the RWIS has been completed in Missouri, Iowa, and Wisconsin (FHWA 2002b). A final report is forthcoming.

FORETELL forecasts include precipitation, temperature, cloud cover, wind direction and speed, weather radar imagery, atmospheric pressure, pavement temperatures, and 24-hour precipitation accumulation. They also predict ice conditions and provide information on drifting snow and roadway temperature. The FORETELL display can provide users with route-by-route information about the specific weather parameters required to conduct their operations. For example, it can be configured to flag sections of roads that are affected by frost, drifting snow, ice, or snow accumulation (Sheffield 2000).

MDSS and the STWDSR Initiative. The FHWA's Office of Transportation Operations is sponsoring a multi-year, multiphase initiative to develop Surface Transportation Weather Decision Support Requirements (STWDSR) as part of the Road Weather Management Program. Early documents produced under STWDSR developed a needs analysis for decision support to winter road maintenance managers, as a first step toward a conceptual WIST Decision Support System (WIST-DSS). A prototype system aimed at winter road maintenance, called the Maintenance Decision Support System (MDSS), has been developed for the FHWA by a team of national research centers (NCAR 2002):

- Massachusetts Institute of Technology–Lincoln Laboratory and the National Center for Atmospheric Research, representing the university research community
- The Forecast Systems Laboratory, and National Severe Storms Laboratory of NOAA (Department of Commerce)
- The Cold Regions Research and Engineering Laboratory of the U.S. Army Corps of Engineers

In the future, snow removal operations will be guided by road weather data from maintenance decision support systems. Photo courtesy Ohio Department of Transportation.

The MDSS work is guided by an Operational Concept Description, which is the high-level specification for the WIST-DSS (Nelson 2001, p. 7). The MDSS project goal is to develop a prototype capability that:

1. Capitalizes on existing road and weather data sources,
2. Augments data sources where they are weak or where improved accuracy could significantly improve the decision-making task,
3. Fuses data to make an open, integrated and understandable presentation of current environmental and road conditions,
4. Processes data to generate diagnostic and prognostic maps of road conditions along road corridors, with emphasis on the 1- to 48-hour horizon,
5. Provides a display capability on the state of the roadway,
6. Provides a decision support tool, which provides recommendations on road maintenance courses of action, and
7. Provides all of the above on a single platform, and does so in a readily comprehensible display of results and recommended courses of action, together with anticipated consequences of action or inaction.

(Mahoney 2001).

The priorities of the MDSS include developing capabilities for improving diagnostic and prognostic weather information, supporting operational-scale road treatment decisions, and tailoring the interface for use by winter road maintenance managers (NCAR 2002). Release 1 of an MDSS functional prototype was made available to the public in September 2002. This functional prototype is designed to be a template for future operational capabilities in winter road maintenance decision support. The design is modular, so that components can be modified and improved by organizations responsible for winter maintenance operations. The developers anticipate that the private sector and transportation departments at the state and local level will jointly develop operational versions of the system (Mahoney 2002).

1.3.2 Expanding the Fundamental Knowledge Base for New Capabilities

As the preceding section illustrates, a great deal is being done with the current state of knowledge in atmospheric and environmental sciences, as well as the state of the art in technologies for observing systems, information analysis, modeling and forecasting, and information visualization and communication. However, there are areas in which our fundamental knowledge of weather phenomena is too limited to provide all the information WIST users need, when they need it. If these needs are to be met, fundamental research must be done to fill the gaps in what we know. The goal of such research should be to expand the understanding of the causal factors responsible for weather elements that affect surface transportation systems.

Weather and related information of interest to surface transportation includes conditions throughout the boundary layer (to about 1 km altitude, higher for some weather radar applications). But the consequences that affect the first 2 meters vertically are particularly relevant to surface transportation. These effects include the interaction of weather with structures above ground level and ground-surface-subsurface geophysical conditions related to weather. In each of these domains, there are issues of the temporal and spatial resolution required to reflect climatic and physiographic variations at the scales relevant to different transportation activities.

To provide this information, atmospheric science must be extended through better physiographic characterization, more complete observation of the weather and weather-related elements of interest at relevant spatial and temporal scales, and improved modeling to predict future states of these elements. Appendix E contains a detailed list of the needed research, gathered during the WIST needs identification process described in Chapter 2.

The observational issue is partly a matter of integrating diffuse capabilities (e.g., the variety of nontraditional surface/subsurface observing systems) and extending other environmental observing capabilities (e.g., higher resolution remote sensing at ground level) and new space-based remote sensing techniques. Heat balance modeling for road temperature is a good example of how weather modeling concepts can be applied, but further extension of current geophysical modeling capabilities is needed before the potential benefits of this and other modeling concepts can be reaped through technological applications.

Many environmental prediction techniques are related in their common use of observations, the sequential processing of environmental information, or the fusion of parallel kinds of information. Integrating these techniques to meet WIST user needs will require an open system of environmental information (incorporating observational data and short-term extrapolations from observations, as well as forecasts based on model outputs) that can also disseminate information products to end users in user-friendly formats.

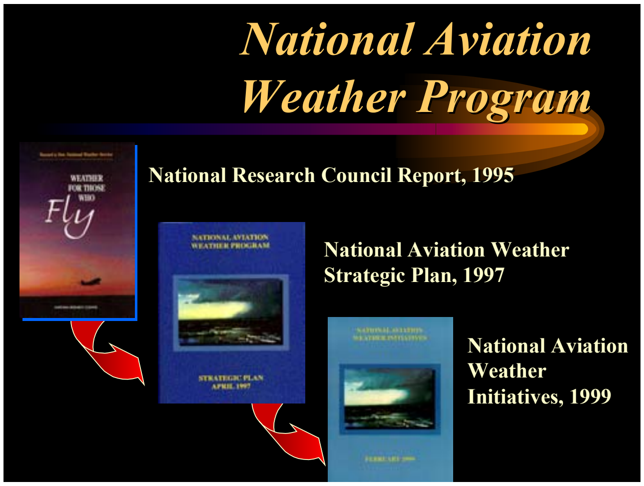
WIST-related research must include more than environmental sensing stations and meteorological modeling. There must also be investigations into new remote-sensing technologies, such as using differential Global Positioning System data to provide water vapor information. Also needed is work in cognitive structures and knowledge representation, to guide development of information structures that communicate *useful* information more effectively and quickly to transportation system managers and crews, vehicle/vessel operators, and other transportation decision makers. Finally, research is needed on what motivates users to pay attention to weather information and incorporate it in the decisions that guide their daily actions.

1.3.3 Aviation Weather and Surface Transportation Weather

The situation for WIST now is reminiscent of the situation for aviation weather a decade ago. A 1994 report from a National Research Council study committee, *Weather For Those Who Fly,* described the significant impacts that weather has on safety and efficiency in different aviation sectors (air carriers, commuters and air taxis, general aviation). It presented a vision of how technology could marry recent advances in weather observation and prediction with information communication and visualization to provide diverse communities of aviation weather users with information that would be far more useful and relevant to their operational decisions (NRC 1994).

A year later, a second study committee of the National Research Council shook up the status quo. It called on the Federal Aviation Administration (FAA) to "provide leadership, establish priorities, and ensure the funding needed to improve weather services for aviation weather users and to strengthen related research" (NRC 1995, pg. 1). This report, *Aviation Weather Services: A Call For Federal Leadership and Action,* decried the fragmentation of federal R&D programs for aviation weather and recommended a coordinated federal effort to seize the opportunities that science and technology were offering.

Reports from the National Research Council spurred a federal interagency strategic plan for aviation weather, leading to initiatives that are now producing operational results.



National Aviation Weather Program

National Research Council Report, 1995

National Aviation Weather Strategic Plan, 1997

National Aviation Weather Initiatives, 1999

In the years after these reports were published, the FAA, NOAA/NWS, the aviation weather services in the Department of Defense, and other agencies did embark on a much more vigorous initiative to improve aviation weather. They clarified roles and responsibilities of key players, including the private sector, in providing aviation weather services. The information providers worked with the academic research community and user communities in the aviation sectors to find a pragmatic balance between technology push and (user) requirements pull. User needs were validated, and the federal partners defined and adopted a coordinated set of requirements, to be addressed by programs within and among the partners. These efforts not only coordinated R&D programs but also implemented projects to transfer research results and innovative technology into aviation operations. The fruits of this initiative are now improving the safety and cost-effectiveness of day-to-day operations. Thus, the series of steps taken to improve aviation weather provides a useful case study for the effort required to address WIST needs.

In some respects, however, the situation for WIST is even more challenging than it was for aviation weather a decade ago. By 1994, the importance of aviation weather to the aviation industry and the nation had already been recognized for fifty years, dating back to the importance of weather services during World War II and every military action since. The vulnerability of the first commercial services to adverse weather made aviation weather a priority for both the air carriers (cargo and passenger) and the National Weather Service. Many Weather Service Forecast Offices were co-located with an airport. By contrast, at a June 2001 meeting on the future of intelligent transportation systems, surface transportation weather was described as "a niche industry for the past thirty years that has received little attention from the meteorological community" (Osborne 2001).

Compared with the more mature status of aviation weather, WIST-related R&D is still in its early, tentative phase, as is federal agency support for implementing WIST in operational systems. This difference is reflected in federal budget outlays (Table 1-3). Within the Department of Transportation, weather-related operations in fiscal year 2003 totals $456 million and is supported by $30.8 million in R&D programs. However, nearly all (97 percent) of the operations are in aviation weather, as is 94 percent of the supporting research. The $2 million R&D budget in the FHWA represents just 6.5 percent of the total DOT budget for weather research.

Table 1-3 Federal Budget for Meteorology, Fiscal Year 2003

Annual Budget	Weather Operations	Supporting Research
Total DOT: $59.3 billion	$456 million	$30.8 million
Aviation	$443 million	$28.8 million
FHWA	$0	$2 million
All Federal Entities: $2.84 billion for meteorology	$2.46 billion	$384 million

Source: OFCM 2003

Of course, much of the federal presence in weather-related operations and in R&D for atmospheric sciences is in other departments and agencies, particularly in NOAA/NWS, as indicated by the bottom line in Table 1-3. A coordinated effort to develop WIST-related applications of existing and emerging science and technology can be leveraged from this large investment in general meteorological services and the R&D to support it. Given the significant role that surface transportation plays in the nation's economy and public safety, a similar table for the federal budget in 2012 could show significant growth not just in WIST-related R&D but also in WIST operations—but only if a coordinated WIST effort can follow the trail blazed by aviation weather.

1.4 Roles and Responsibilities of Information Users and Providers

The primary roles in providing weather information for surface transportation are shared among a diverse array of partners in the public and private sectors. In the public sector are federal entities and a large number of state and local government activities. In the private sector, commercial entities sell value-added meteorological services and products (often referred to as VAMS). There is an even larger (in numbers and in market presence) set of commercial entities that provide general information and communication products or services, in which WIST is now or could be incorporated. (Broadcast and cable television news, commercial radio, newspapers, and Internet service providers are just a few examples in this second category.) Participating in both the public and private sector provider activities are the academic research community and a growing number of "public-private" entities, often established with public support at the state level.

Federal entities generate most of the general weather information and services for public use, as well as providing regulatory guidance for both providers and users of WIST. Federal entities are also major WIST users in their roles as regulators of, or service providers to, the surface transportation communities. State and local entities augment federal WIST services with local or specific types of observations and transportation-oriented weather decision aids. These entities also constitute major WIST user communities, particularly those with direct responsibility for maintaining infrastructure or operating transportation systems (state departments of transportation, city and county street/highway departments, regional transit and airport authorities, school districts, and more). The private sector includes substantial WIST user communities, including any commercial entity involved with transporting goods or people in any of the surface transportation sectors, as well as the VAMS and general information disseminators on the provider side.

Partnerships and alliances are critical in this environment where thousands of entities have roles in developing, maintaining, and operating the nation's transportation system. The framework for successful partnering, particularly where the federal agencies are involved, is shifting toward more inclusive participation. There is greater consideration of multiple goals, as well as recognition of the diverse priorities present in local, regional, national and international activities, plans, and markets. Leadership will be essential to facilitate the changes required, but the leaders must be willing and able to listen to and work with their partners. Building constructive relationships will go a long way toward overcoming the obstacles to introducing innovative ideas and technologies and proliferating their beneficial use throughout the nation.

1.5 The Path Forward

The Office of the Federal Coordinator for Meteorological Services and Supporting Research (OFCM) has collaborated with representatives of its 15 federal partners (Figure 1-4) to sponsor meetings and symposia to identify the weather support needs of national transportation systems. These gatherings highlighted the need for, and merits of, coordinating the federal R&D effort to provide a programmatic focus dedicated to weather information for surface transportation**.** This effort would address the needs of users in all surface transportation sectors. An initial task defined in the meetings was to identify, compile, and validate existing and potential needs for WIST of the transportation communities among the constituencies of the OFCM federal partners.

OFCM PARTNERS

Departments of:

Agriculture
Commerce
Defense
Energy
Interior
State
Transportation

Independent Agencies:

Environmental Protection Agency
Federal Emergency Management Agency
National Aeronautics and Space Administration
National Science Foundation
National Transportation Safety Board
Nuclear Regulatory Commission

Executive Office of the President

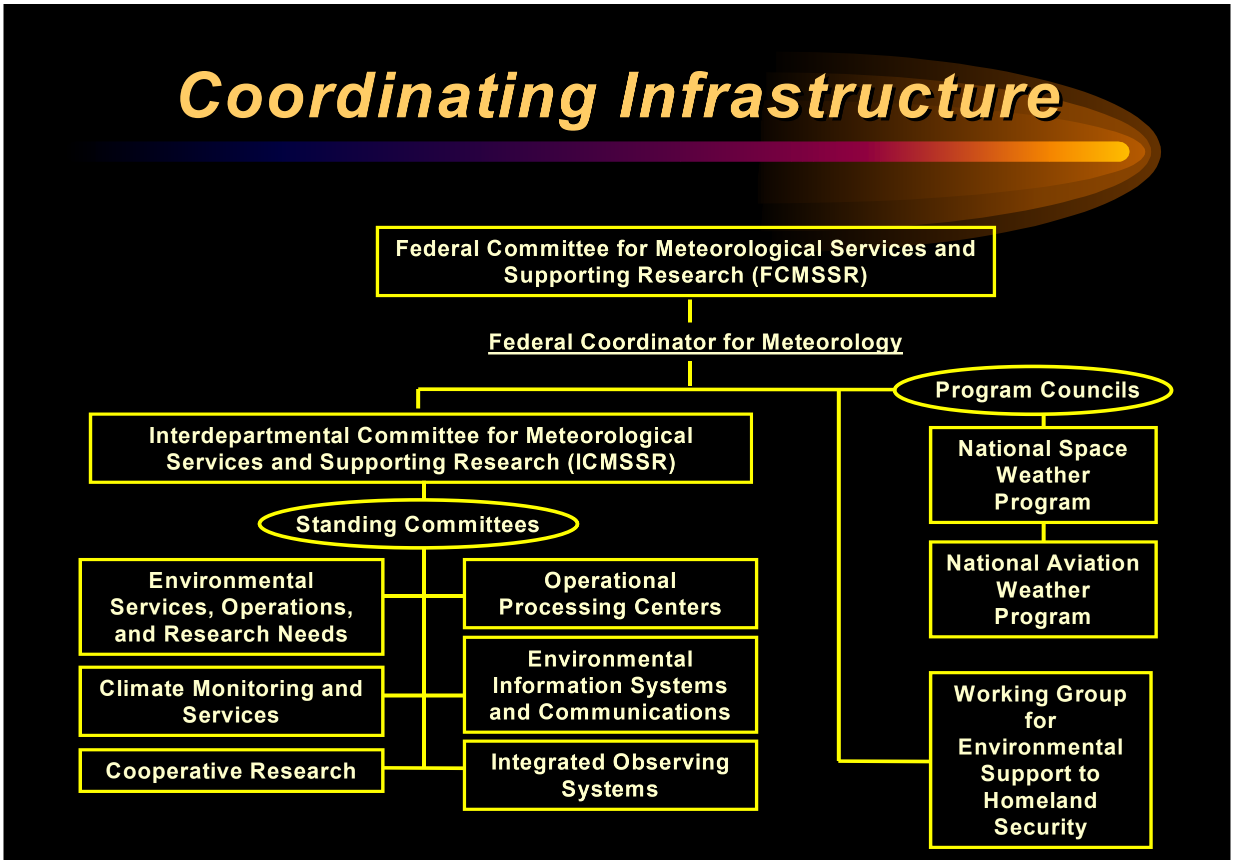
Office of Management and Budget
Office of Science and Technology Policy

Figure 1-4 OFCM federal partners in defining weather information needs.

1.5.1 Initial Endorsement for a Coordinated WIST Effort

Federal programs that include assessment of WIST user needs trace back at least as far as the formation of a Weather Team by the FHWA, under the Intelligent Transportation System program within the DOT (DOT 1998, p. 1). The effort to coordinate the federal effort on WIST began the following year. On September 22, 1998, the Federal Coordinator for Meteorology and Supporting Research presented a “Look to the Future” to the Federal Committee for Meteorological Services and Supporting Research (FCMSSR). The FCMSSR, which is a multi-agency committee of senior-level representatives from seven cabinet-level departments, six independent agencies, and two offices within the Executive Office of the President (Figure 1-4), was established to provide policy guidance to OFCM (Figure 1-5).

The “Look to the Future” report identified priority areas, issues, problems, and ideas to help improve the effectiveness of interagency coordination and cooperation. Surface transportation needs (including ground and marine transportation modes) were highlighted for attention. Support for WIST was described as minimal, relative to the unmet needs of travelers, transportation maintenance and traffic management operations, and transportation industries. Both safety and economic productivity were emphasized as benefits to be gained. Coordination among the FHWA, other partners from the Departments of Transportation and Commerce, state and local entities, and others in the public and private sectors would be essential for defining requirements and developing tailored decision aids. The FCMSSR agreed on the importance of addressing WIST user needs through a coordinated effort.



Coordinating Infrastructure

Federal Committee for Meteorological Services and Supporting Research (FCMSSR)

Federal Coordinator for Meteorology

Interdepartmental Committee for Meteorological Services and Supporting Research (ICMSSR)

Standing Committees

Environmental Services, Operations, and Research Needs

Climate Monitoring and Services

Cooperative Research

Operational Processing Centers

Environmental Information Systems and Communications

Integrated Observing Systems

Program Councils

National Space Weather Program

National Aviation Weather Program

Working Group for Environmental Support to Homeland Security

Figure 1-5 OFCM infrastructure.

Subsequently, in December 1998, the director of DOT's ITS Joint Program Office spoke before the Interdepartmental Committee for Meteorological Services and Supporting Research (ICMSSR) on the connection between ITS and WIST. This presentation concluded with a recommendation that a relationship be established between the FHWA and NOAA for surface transportation weather, similar to that between the Federal Aviation Administration and NOAA for aviation weather. In response, the ICMSSR tasked the OFCM to establish a Joint Action Group to address mission needs and meteorological requirements for surface transportation weather.

In June 1999, the OFCM sponsored an interagency meeting with 35 participants representing key federal entities. The meeting, which focused on the federal entities' views on WIST needs and potential requirements, featured presentations by users, providers, and research organizations. The participants supported an effort to identify and publish WIST needs that could be identified by the federal entities, state and local governments, trade associations, and commercial and private enterprises. In addition, the group endorsed the ICMSSR direction to establish a Joint Action Group.

Also in June 1999, the OFCM formed an interagency Joint Action Group for Weather Information for Surface Transportation (JAG/WIST). The JAG/WIST consisted of representatives from 15 federal entities whose mission areas give them regulatory or operational responsibility in four surface transportation sectors. The JAG/WIST met in July 1999 and began planning for a symposium on WIST (the First WIST Symposium), which was held in December 1999 under the joint sponsorship of the OFCM and the FHWA.

To cover the spectrum of current and potential WIST users, the needs identification effort gathered perspectives from intermodal, interstate, national, and international transportation entities; the public and private sectors; and local and regional organizations. Organizing and validating the needs submitted from these sources required extensive coordination with federal, state, and local transportation agencies; metropolitan planning organizations; the transportation industry; the transportation research community; resource agencies; law enforcement and emergency response agencies; educational institutions; public interest groups; and others committed to quality transportation. This process is discussed in detail in Chapter 2.

A second symposium (WIST II) was held in December 2000 to report on progress in identifying and validating WIST user needs and plan next steps. (See Chapter 2 for the role of both WIST symposia in the needs identification and validation process.)

1.5.2 FCMSSR Endorsement for Continuing the WIST Effort

The FCMSSR met on November 14, 2000, to focus on issues relevant to the transition team for the newly elected administration. To improve road weather information, the committee recommended investments in expanding observing networks and developing decision support systems. The FCMSSR thus endorsed continuation of the objectives of the WIST effort it had initiated in September 1998.

1.5.3 Strategic Thrust Areas and Next Steps in the Coordinated WIST Effort

Because of the great diversity of roles and responsibilities in the WIST provider community, a validated set of WIST user needs does not automatically generate a corresponding set of requirements. Understanding the needs of users is an initial step in an ongoing process. The analysis of WIST needs in Chapter 4 supports both cross-sector and sector-specific conclusions. In Chapter 5, these conclusions, informed by all the information gathered during this study, provide the basis for defining the next stage of a coordinated WIST effort. Next steps are recommended for each of six strategic thrust areas.

The opportunities for improving safety and economic efficiency across all surface transportation sectors are burgeoning. We also have good reason to invest resources, time, and talent to pursue those opportunities. But we must find the will and the way—politically, fiscally, and programmatically—to seize them.