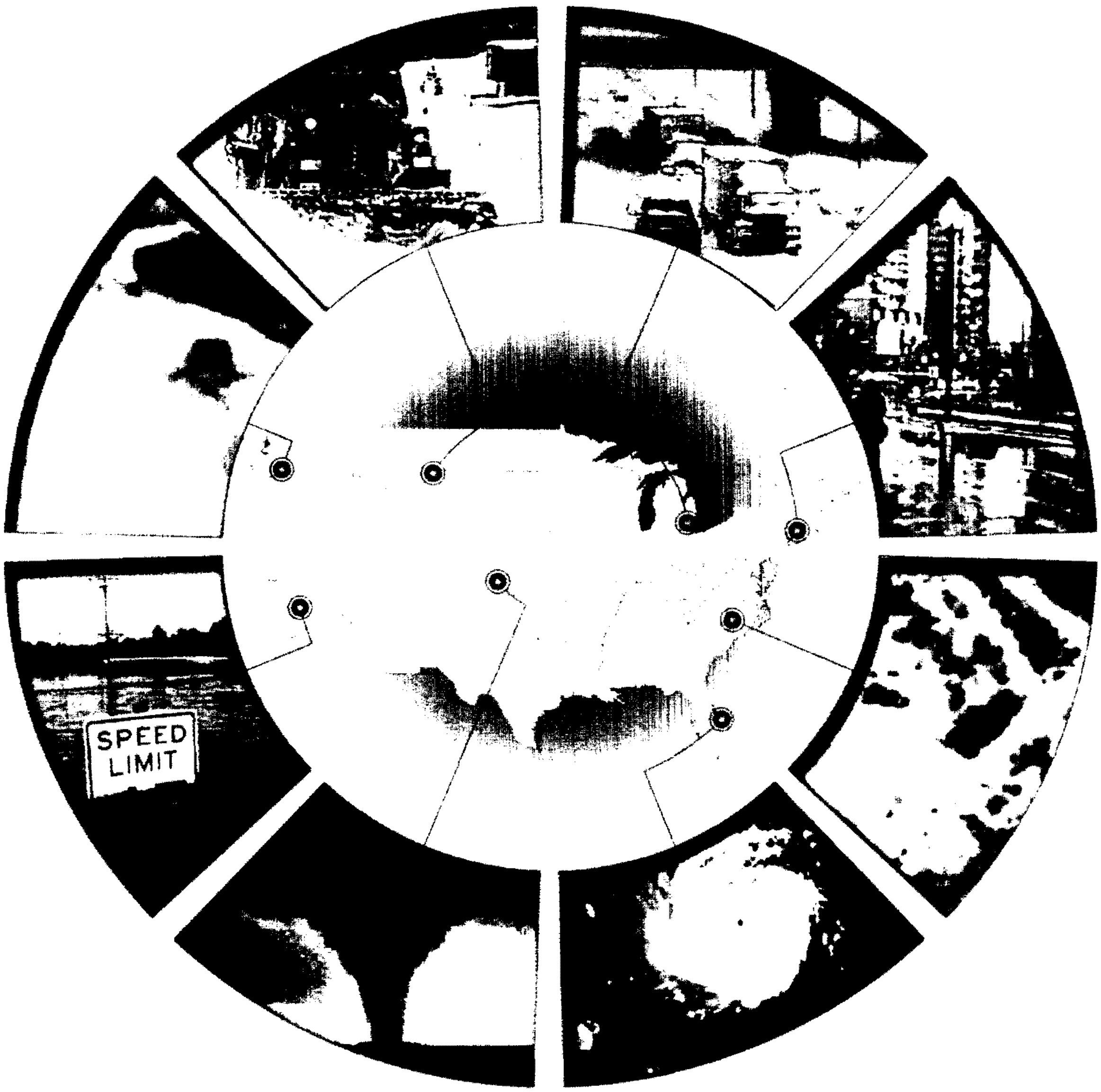
Road Weather Requirements:

Executive Summary



Advanced, Integrated Decision Support Using Road Weather Information

U.S. Department of Transportation
Federal Highway Administration

SEPTEMBER 2001

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Road Weather Requirements: Executive Summary		5. Report Date 9-10-1 6. Performing Organization Code
7. Author(s) Gary G. Nelson		8. Performing Organization Report No. FHWA-OP-01-023
9. Performing Organization Name and Address Mitretek Systems, Inc. 600 Maryland Ave., SW, Suite 755 Washington, DC 20024		10. Work Unit No. (TRAIS) 11. Contract or Grant No. DTHF61-00-C-00001
12. Sponsoring Agency Name and Address Office of Transportation Operations Federal Highway Administration 400 7th St. SW Washington, DC 20590		13. Type of Report and Period Covered Research Report July, 1999 - October, 2000 14. Sponsoring Agency Code

15. Supplementary Notes
Task Order Manager: Paul Pisano

16. Abstract
Mitretek Systems, Inc., is conducting the Surface Transportation Weather Decision Support Requirements (STWDSR) project for the Federal Highway Administration (FHWA), Office of Transportation Operations, Road Weather Management program. The STWDSR project has completed two phases. The first phase documented needs for decision support by operators and users who must contend with weather threats on the surface transportation system. The second phase defined the high level requirements for decision support to winter road maintenance, and is the basis for on-going development. This Executive Summary describes the main results of these two phases and their relation to on-going projects.

17. Key Words	18. Distribution Statement
Intelligent Transportation Systems (ITS), Weather, Decision Support, Road Weather Information Systems (RWIS)	

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	16	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

Contacts

For comment or information on this document, contact either of the following:

Paul Pisano
Federal Highway Administration
HOTO-1
400 Seventh St. S.W.
Washington, DC 20590
Tel: 202 366-1301
Fax: 202 366-3225
paul.pisano@fhwa.dot.gov

Gary G. Nelson
Mitretek Systems
600 Maryland Ave. S.W., Suite 755
Washington, DC 20024
Tel: 202 488-5718
Fax: 202 863-2988
gnelson@mitretek.org

Contents

The Surface Transportation Weather Decision Support Requirements (STWDSR) Project

Introduction

Mitretek Systems, Inc., is conducting the STWDSR project for the Federal Highway Administration (FHWA) Office of Transportation Operations, Road Weather Management Program. The STWDSR project has completed two phases. The first phase documented needs for decision support by operators and users who must contend with weather threats on the surface transportation system. The second phase defined high level requirements for decision support to winter road maintenance and is the basis for ongoing system development. This Executive Summary will describe the main results of these two STWDSR phases and their relation to ongoing projects.

Reference Documents

The full documentation on the STWDSR project can be found in the following materials that are available online:

Table ES-1: STWDSR Documents

Presentations and documents for the Surface Transportation Weather Decision Support Requirements (STWDSR) project: http://www.mitretek.org/its/stwdsrt/	
Phase 1 Report	STWDSR--Draft Version 1.0 (Needs Analysis) http://www.itsdocs.fhwa.dot.gov/jpodocs/repts_te/9dc01!.pdf
Phase 2 Reports	STWDSR--Operational Concept Description (OCD) Draft Version 2.0 http://www.itsdocs.fhwa.dot.gov/jpodocs/EDLBrow/401!.pdf STWDSR--Preliminary Interface Requirements (PIR), Draft Version 2.0 http://www.itsdocs.fhwa.dot.gov/jpodocs/repts_te/@701!.pdf

Road Weather: What to Do About It

Surface transportation agencies must focus on what to do about weather threats to system performance, not weather information by itself. The missing link between weather information and performance is decision support.

The FHWA and State departments of transportation began in the 1980's to be concerned with weather information, with the arrival from Europe of road condition monitoring equipment and its use for anti-icing pretreatment. The importance of information to highway operations was further emphasized in the 1990's with the creation of the Intelligent Transportation System (ITS) program. In 1999 the FHWA reorganization created the Office of Transportation Operations under which weather information, and operational techniques to treat weather threats, were consolidated into the Road Weather Management Program. This Program developed the STWDSR project from efforts under the Rural ITS program.

Weather is a significant threat to surface transportation. There are almost 7,000 highway fatalities and 450,000 injuries that occur in adverse weather conditions. About $2 billion is spent annually by public agencies for snow and ice control. Other economic impacts on production and sales because of loss of transportation services are probably much greater. Any reduction of these impacts through better-informed treatment, travel and incident-response decisions will be very cost-effective. Decision makers usually articulate requirements in terms of more timely, accurate and relevant weather information. With the quality of weather information being outside of FHWA responsibility, the role of the FHWA should be to sponsor research and issue guidance to apply weather information to meet highway performance goals of safety, mobility, productivity, environmental quality and national security. The needed activities include:

- Better prediction of road surface and driving conditions from weather and other information.
- Better support to the decisions that respond to weather threats.
- Development of improved operational techniques to treat road conditions, manage traffic (including evacuations) in adverse weather, and respond to incidents from adverse weather.

The STWDSR project focuses on decision support as the critical missing link. Decision support consists of ITS applications that filter and fuse available information, to advise on the best actions one may take. It is necessary for effective operational techniques. Current decision support cannot take advantage of the great advances being made in weather information. To do so, decision support applications need easy access to all relevant information in an open ITS infostructure in order to better operate the surface transportation *infrastructure*.

Weather information comes from public agencies, like the National Weather Service (NWS) and private vendors, classified as Value Added Meteorological Services (VAMS). But weather, meaning the atmospheric effects that meteorologists measure and predict, differs in important ways from the direct threats to transportation performance. For instance, road surface freezing is not a meteorological product, but is a condition particular to road segments through the interaction of atmospheric, topographic, road surface, subsurface, and traffic conditions. The VAMS serve the market for tailored road condition information, using weather information and Environmental Sensor Stations (ESS) that measure road and local atmospheric conditions directly. The STWDSR documents use the term "environmental conditions" to include weather, weather-related road conditions, and other road conditions that create performance threats.

State and local agencies, through contracts with VAMS, are implementing Road Weather Information Systems (RWIS). These systems do not meet decision support requirements. They give information on environmental conditions but do not relate these directly to operational decisions. These systems are fragmented, delivering information through various channels and presentations of NWS information, ESS observations, and tailored road-weather predictions. That current RWIS are not designed as open systems is considered a significant impediment to improved operations.

The STWDSR project focuses on *needs,* defined as the decisions to be made for actions in the transportation system with respect to weather threats. The needs levy *requirements* on an advanced decision support concept. Advanced decision support will *evolve* from the RWIS, as part of the ITS through research, testing, deployment and commercialization of improvements within an open information system.

The information going into decision support is partly from within the ITS (transportation and treatment assets) and partly external (most environmental information except direct ESS observations). The lack of an open system inhibits access to this information. Quantifying requirements on the information sources is more difficult. This depends on more evaluation to identify causal and economic impacts in the entire information-to-outcomes chain and over sufficient time periods to control for climatic variations. So far, only the 3-year evaluation funded by the ITS Program for the Foretell operational test of the Road Weather Management Program approaches what is needed. The assumption is that sharing and use of existing information via decision support will be more cost effective than trying to improve the environmental information sources. An exception is where warning of immediate and frequent hazards needs more direct ESS observation (e.g., road segments and bridges especially subject to fog, icing, flood or avalanche).

The following sections further describe the STWDSR project and its findings in its first phase (completed in 1999) and second phase (completed in 2000). The sections are organized around the three major documents and spinoff projects produced by the STWDSR project.

STWDSR V1.0: Needs Analysis

The STWDSR project started by defining needs (decisions) of all types of surface transportation decision makers who respond to weather threats.

Needs and Scale

The STWDSR V1.0 document contains an initial matrix of 426 types of decisions across 44 decision maker categories in all surface transportation modes (road, rail and inland waterway). The decision maker categories include operators of highways and vehicle fleets, vehicle drivers, those who are dependent on surface transportation (passengers, shippers), and those who construct facilities. The needs are also categorized by *scale*. This refers to the span of control and time horizon of the decision. Table ES-2 shows the names of the three scales used for transportation and examples of the kinds of decisions in each case.

Table ES-2: Scale Definitions

Scales	**Time Horizon Functions**	**Corresponding Weather Scale**	**Winter Road Maintenance Example**
Planning	months + Provides resources.	Climatic	Buying equipment or chemical stocks; Hiring and training staff.
Operational	hours to days Manages the deployment of resources.	Synoptic/meso	Calling up crews, readying vehicles, dispatching treatment beats.
Warning	sub-seconds to minutes Operates the resources.	Micro	Operating a treatment vehicle (snow plow and spreader); Control of automatic equipment.

The scale parameter is important for two reasons. Functionally and organizationally there is a natural separation between scales. Scale also defines categorical differences in the geophysics, observational technique, prediction and information processing of environmental information.

The explicit definition of scale eliminates a lot of confusion caused by use of the term "real time". Information is either an *observation* of a real condition or a *prediction* of something unobservable because it is removed in space and/or time. All decisions are about the future so the information they use is always predictive. The decision scale is set by the action to be taken, including the area of responsibility (a vehicle, a maintenance district, a state DOT, etc.) and the time lead necessary to effect the action (seconds, hours, months). Decision support supplies the best available predictive information for the decision. This includes fusion of various predictions weighted by their past performance against observations. The warning scale of decisions can rely mostly on direct observations, the operational scale tends to rely on more sophisticated numerical prediction models, and the planning scale mostly on climatic statistics.

Winter Road Maintenance

It was decided that the operational scale of winter road maintenance was a priority for further STWDSR work. Decisions involving the deployment of resources for snow removal and ice treatment directly depend on environmental conditions, and they affect all of the performance goals through faster and more efficient restoration of level of service, and more efficient chemical use. Winter road maintenance also has the most experience in RWIS use.

Environmental Information Sources

The STWDSR V1.0 document scanned environmental information sources and their quality. NWS sources became a basis for winter event scenarios that were used to elicit more detailed user needs in two meetings of maintenance managers, VAMS, and decision support system developers. These stakeholder meetings were held in February and May, 2000, and attracted maintenance managers from 28 states.

A count of ESS installations shows about 1200 in the U.S. (counted as remote processing units that cover some nearby road segment). They are few compared to the route network to be covered—160,000 miles of the National Highway System, or 4 million miles of public roads. This is partly because ESS are expensive (a range of $15,000 to $35,000 each plus operating costs). More mobile or remote sensing of road conditions could mitigate the rarity and expense of ESS data.

Most ESS data are used only locally, or in proprietary RWIS from the same VAMS that supply the ESS equipment. Quality control on the data, open systems for data dissemination, and decision support applications are all deficient and negatively reinforce each other. Some progress has been made by the public and private sectors in pooling ESS and other observational data, either in regional "mesonets" or nationally. This is a precondition for assimilation processes that can improve quality control by cross-checking data and models. Decision support application development is promoted by, and creates a demand for, further data pooling and assimilation.

The prediction of freezing road-surface temperatures, using time series data at an ESS site, is very good out to about 24 hours. Thermal mapping can extend these predictions over a road system through mobile snapshots of road temperature that are correlated with the fixed ESS site. Full characterization of environmental conditions on the entire road network must depend on weather information that can also be used to infer road temperature by heat balance modeling. This technique predicts road temperature with high resolution numerical weather prediction models that determine insolation through cloud and other heat exchanges. The technique also requires a detailed initial survey of the roadway. Such surveys, and thermal mapping, could benefit from aerial or satellite remote sensing approaches. The optimal mix of ESS, other observational sources and various prediction techniques is not clear now and will keep changing over time with technology and prices.

Uncertainty and Risk

The predictive information needed by any decision will be uncertain. Uncertainty in environmental condition predictions is a function of the quality and density of observations on which the prediction is based, and uncertainty will grow with the time horizon of the prediction. Many operational-scale decisions for transportation are made with horizons beyond 12 hours. At this horizon the high resolutions now available from meso scale weather models (1-10 km grids) blur into synoptic scale resolution (30+ km grids) as the differences between grid points falls below the overall uncertainty. The ideal of road-segment specific weather predictions cannot be achieved for many operational decisions, now or in the foreseeable future. That is why safety-critical warnings to drivers (e.g., maintenance truck navigation in blizzards or variable speed limits in fogs) are for short time horizons and depend on direct observation of local road segments. Dealing with significant uncertainty in the threat has to be accommodated in decision support, no matter what the ultimate investment in observations and models.

It is important for decision support to use statistics on predictive uncertainty. This includes the weighting of various predictive sources according to their reliability, and support to risk decision making. Various processes in environmental prediction now produce the necessary statistics. Their use in risk decision making on the transportation side will be an important way to improve outcomes by eliminating the intuitive, and often biased, manual assessment of predictions that present point values regardless of horizon. How risk is used by decision makers is an important human-factors research topic.

STWDSR V2.0: Operational Concept Definition (OCD)

The OCD contains further detail on winter road maintenance needs, collected from the stakeholder meetings. It also moves from needs to requirements for development of advanced decision support.

The WIST-DSS

The OCD is the high-level specification of a system to fill the missing link between environmental information and transportation performance. That system is called the Weather Information for Surface Transportation Decision Support System (WIST-DSS). The WIST-DSS filters and fuses external information and presents decision support advice to humans or automatic control devices.

Research and Development Roles

The evolutionary development of the WIST-DSS contemplates a public sector role in requirements, research, and testing. But WIST-DSS deployment must evolve from the RWIS and be supplied by the private sector, to public or private users. The information resources used by the WIST-DSS will be a combination of public (the NWS, many ITS information elements) and private sources.

Research for road weather applications presently has a small federal role, a larger but more diffuse state and local role, and proprietary private roles. In contrast, the Federal Aviation Administration (FAA) conducts an aviation weather research program of about $20 million per year, ten times what the FHWA spends centrally on road weather research. Surface modal agencies are not yet full participants in the longstanding and effective coordination between aviation, the military and the NWS. However, interagency coordination is being achieved through the Office of the Federal Coordinator of Meteorology (OFCM) that has, just since 1998, entered the surface transportation field.

The relative size and organization of road weather applications research, and the attention paid to it by federal agencies, is not in proportion to the national importance of surface transportation. Modest improvements in surface safety and mobility with respect to weather threats would outweigh, in lives and dollars, what can be accomplished in air travel. A larger federal role among the surface modes would also enable better leverage of the applicable research and operational investments of aviation, the military, and the NWS.

OCD Research

The STWDSR V2.0 stakeholder meetings brought the national meteorological research community in contact with the VAMS and winter road maintenance managers. Six national laboratories were enlisted to participate. These include three federal labs under the National Oceanographic and Atmospheric Administration (NOAA), two military-funded labs, and the National Center for Atmospheric Research, representing the university research community. The FHWA will continue to be an important catalyst to this three-way partnership, contingent if research funding is available.

The OCD analyzes the deficiencies of the baseline RWIS, and defines the logical functions that have to be provided by any improved system. The current RWIS has two major deficiencies:

- "Stovepiping"--the environmental information sources are difficult to integrate because of the lack of open system standards. This results in...
- "Swivel chair integration"--the RWIS output is really just multiple environmental information sources. The environmental threats have to be fused and processed *manually* to derive transportation decisions.

The needs research for the OCD expanded the STWDSR V1.0 list of 10 operational winter road maintenance decisions into 53 decisions. The OCD reorganized these into 16 clusters according to time leads that determine the mix of predictive information that can be used and the decision risk. It was found that decisions start about 96 hours before a threat event (average of 48 hours for the earliest clusters), then throughout the treatment campaign of up to 48 hours (average of 15 hours) after the start of a snowstorm. Managers maintain both a retrospective view of what has happened, as well as a prospective view, in making decisions. Managers intuitively relate time horizon to predictive risk. Better risk information would enable managers to commit resources with less bias in weighting of wasted treatment (including excess chemical use and its environmental impact) versus missed treatments and the disaster that can imply to the road system.

The OCD emphasizes collaborative decision making. Collaboration between different jurisdictions, with traffic management, and with traveler information is obvious. Less obvious is that every environmental prediction should also be collaborative: The transportation decision maker needs to understand the uncertainty in the prediction and the predictor needs to understand the sensitivity of actions to the predictions. Manual collaboration on predictions is not possible with the NWS and can overload the VAMS that do provide consultation. Producing and communicating risk information among automated decision support systems, on the environmental prediction and end-user sides, will be an important innovation.

STWDSR V2.0: Preliminary Interface Requirements (PIR)

The Intelligent Transportation System (ITS) is intended to provide an open system for the information needed by decision support applications. An open information system will expand the market for information providers and better serve the application consumers.

Decision Support Interfaces

The PIR looks at how and what information comes into decision support, and what information goes from decision support to human users. The PIR cannot quantify improvements needed for the information sources, but it concludes that the obvious problems are structural. An open information system is needed to improve processing of weather and road condition information outside of the decision support applications, and to ensure access by all applications to the information they need. This is the concept of the "infostructure".

ITS Architecture

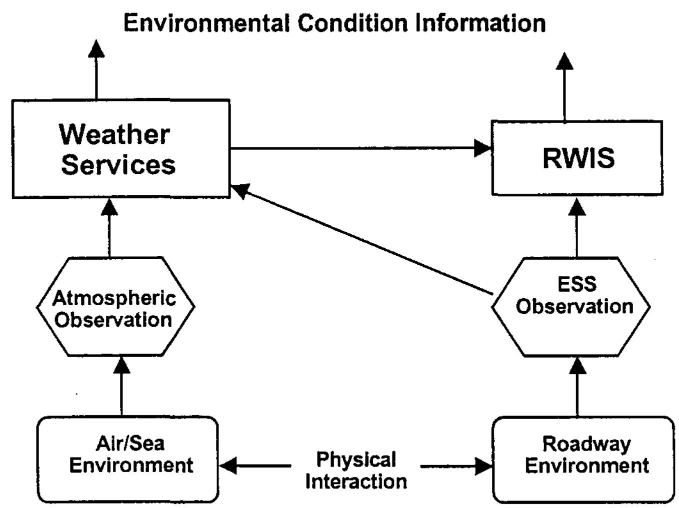
Since the WIST-DSS is in the ITS, the immediate interfaces are specified in the National ITS Architecture. The important aspects of the architecture for an open system are the structure of information flows/processes, and the definition of standard data objects. The PIR borrowed from the ITS data objects, especially the ESS standard, to define a list of 212 information elements needed for the WIST-DSS. These elements can be broadly divided into those on the transportation system (e.g., traffic volume), those on the assets whose deployment is decided (e.g., treatment vehicle tracking), and environmental conditions.

Unfortunately, the National ITS Architecture has not previously focused on environmental information. A user service that includes winter road maintenance, called Maintenance and Construction Operations, had not been completed before STWDSR V2.0. However, a thorough review of environmental condition information in the architecture is still necessary. This includes data objects and message sets in the standards, and a review of the structure of the logical and physical architectures. In September, 2000, the Canadian ITS Architecture was published. The Canadian architecture starts with two additional user services called Environmental Conditions Management, and Operations and Maintenance. The Canadian architecture improves the environmental information structure, especially the two way interaction between the ITS and the weather services, and it recognizes separate weather and road condition services.

Environmental Information

Environmental information is outside of the WIST-DSS application and largely outside of the ITS, except for ESS observation. The PIR cites the need for an open system everywhere in environmental information processing to provide appropriate information to the ITS. This processing is shown, greatly simplified, in figure ES-1:

Figure ES-1: Interaction of Environmental Information Processes



Environmental threats consist of combinations of weather and road conditions. The RWIS predicts road conditions from direct ESS observations and from weather predictions. ESS observations also serve weather prediction. The ability to pass data from process to process, particularly from ESS Observation to Weather Services, is only sporadically available today and requires an open system. Within the weather services and RWIS are many information processes to get the needed threat predictions and their risk parameters. At present, there is no clear guidance on the optimal economic/performance mix of processes and observation with respect to decision support needs. For instance, remote sensing and inference of road conditions from weather competes with predicting road conditions directly from scarce ESS observations.

In any case, the many processes on the weather or RWIS side should not be stovepiped by one organization, but rather the best process mix should be created with respect to the decision support application. Every process involved in generating environmental information is also an application. The open system concept applies to decision support, to make all relevant information easily available, and it applies in exactly the same way to every environmental information processing application. For instance, if an RWIS vendor has a road icing application based on heat balance methods, the vendor also needs meso-scaled weather predictions. Rather than stovepiping the two applications together, it is better to have the weather prediction information available in an open system to all possible users. Similarly, ESS observations should be available to all possible prediction applications.

There is still a long way to go to achieve an open system. Progress toward a truly open "infostructure" needs:

- The technical framework (architecture and standards);
- Security/protection of property rights in information and;
- Institutional cooperation on adopting standards.

These tasks are partly within the ITS, and partly between the ITS and other information domains. One barrier to automated decision support is textual information, such as NWS watches and warnings, that must be parsed into standard data objects. The ITS standards must be reviewed to ensure that all relevant data objects are included. An important open system standard across domains is the Internet and within that the eXtended Markup Language (XML) as a format for data object definition. There is already a Road Weather Markup Language (RWML) developed in XML by the Japanese. The standards concept also needs to be extended to the computer-human interface. That is beyond what the ITS currently does, but it is within the purview of FHWA research on human factors and standards such as the Manual on Uniform Traffic Control Devices. Standards should include the graphical representations of weather threats shown to humans.

The open system can facilitate, but not guarantee that the most efficient network of applications evolves. There is an institutional and geophysical separation between weather and road conditions. Part of the reason gets back to scale. Road segments are climatically peculiar in very local areas based on topography, traffic, and road structure. Meteorology is moving into the finer scales needed by surface transportation. Consequently, surface transportation is in an excellent position to catalyze a further integration of land, sea and air geophysics as part of an overall effort to model and understand the common environment, at all scales. Surface transportation also has a role in atmospheric water vapor observation through the Differential Global Positioning System.

The most obvious issue in integration of environmental information is to achieve assimilation of ESS observations with the national pool of environmental observations. This would be beneficial to the ESS itself through the quality control checks against other observations and model predictions, and would expand the total observations available to all applications.

Program Plans

The FHWA has a role to apply weather information to decision support, through the ITS and on behalf of better road performance. Funding, including a dedicated weather applications research program is necessary to fulfill the role.

The FHWA Role

The FHWA mission includes research leading to decision support applications and techniques to improve surface transportation performance in the face of weather threats. Developing an open "infostructure" through the ITS is analogous to the FHWA role in developing the highway infrastructure. There is need for national coordination in the research program, among federal agencies but involving local public agencies and the private sector. It is difficult to achieve this with no dedicated program for road weather applications research.

Important tradeoffs and synergies between weather and road condition information have been identified. Likely areas for cooperative research with weather services and VAMS are in:

- The common assimilation and dissemination of all types of observational data.
- The organization of regional, high-resolution numerical weather prediction applied to road weather generally, and temperature through heat balance modeling.
- Prediction model ensembles to provide risk statistics for use in data fusion and risk decision making.
- Better characterization of weather attributes relevant to surface threats (e.g., precipitation type and moisture content).
- Deployment criteria for ESS based on added value to environmental information, and in combination with non-weather predictive techniques like thermal mapping.
- Improvements and applications of remote sensing for road conditions.

Planning for programs to fulfill the FHWA role is continuing. Programs that are underway are listed below.

The MDSS Project

The OCD has led to a development project being sponsored by the FHWA, called the Maintenance Decision Support System (MDSS). Starting in September, 2000, the six national labs included in the STWDSR project are developing an initial prototype that embodies the WIST-DSS concepts and is devoted to operational scale decisions for winter road maintenance. In the one-year prototype effort, a partnership of state DOTs and VAMS will be enlisted to review the project and conduct an operational test starting in September, 2001. The operational test will incorporate MDSS components in an operating RWIS. One such test will competitively receive FHWA incentive funds. However, the objective of the labs= development is to make

The COMET Road Condition Forecasting Project

The FHWA has provided research funding, via the National Science Foundation, to the Cooperative Program for Operational Meteorology, Education and Training (COMET). COMET solicited proposals from partnerships of NWS offices, state DOTs, and universities to research aspects of ESS investment and its relation to road condition forecasting. This will fund multiple two-year projects. The projects will address the questions raised in the PIR about the best density of ESS and networking of information processes for environmental condition prediction supporting surface transportation decisions. The project will also foster strategic alliances between the three parties.

Ongoing STWDSR Project

The STWDSR strategy is to expand the scope of requirements to other user groups, and spin off additional development projects. In 2000/2001, emergency/traffic management and travelers are prioritized as the next user groups. There will be a needs analysis and extension of the OCD and PIR for these groups. Given the cross-cutting nature of this work, data collection on requirements and the development tracks will be done jointly with other FHWA programs, primarily within the Office of Transportation Operations and the Office of Travel Management. In addition, new inter-federal links will be forged through continued OFCM activities.

U.S. Department of
Transportation
**Federal Highway
Administration**

**To access an electronic version of this publication
and other ITS related publications:**

**ITS Electronic Document Library (EDL):
www.its.dot.gov/welcome.htm**

**ITS Joint Program Office: www.its.dot.gov
Office of Transportation Operations:
http://www.ops.fhwa.dot.gov/Traffic/**

Publication No. FHWA-OP-01-023
HOTO/09-01 (2000)