Surface Transportation Weather Decision Support Requirements

Draft (truncated*) Version 1.0

Advanced-Integrated
Decision Support
Using Weather Information
for
Surface Transportation
Decisions Makers

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for

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Office of Transportation Operations
Federal Highway Administration

by
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* This version has certain figures removed for compact e-transmission.

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Appendix material, primarily the needs tabulation, is removed and contained in a separate document.

Executive Summary

The full Executive Summary is published as a separate document. It can be found as document 11823 in the Electronic Documents Library (EDL) at http://www.its.dot.gov/welcome.htm. A brief project summary is below:

Summary

The Federal Highway Administration (FHWA) of the U.S. Department of Transportation (USDOT) has a responsibility to coordinate and promote projects that will bring the best information on weather to decision makers, in order to improve performance of the surface transportation system.

To fulfill its responsibility, the FHWA's Office of Transportation Operations (HOTO) Weather and Winter Mobility Program is documenting the weather information requirements of all road users and operators under this Surface Transportation Weather Decision Support Requirements (STWDSR) project. The STWDSR project is being conducted for the FHWA by Mitretek Systems, Inc. Developing requirements through the STWDSR project will support the Weather and Winter Mobility program by:

1. Promoting deployment partnerships between users, private vendors and non-profit meteorological systems developers to realize advanced surface transportation weather decision support system concepts;

2. Producing deployment guidance for local public/private development of the advanced system;

3. Guiding further federal research projects and operational tests, and;

4. Helping coordinate surface transportation weather requirements and projects across federal agencies, especially with the National Weather Service (NWS).

The advanced system will be conceptualized within the Intelligent Transportation System (ITS). The initial phase of this project has enumerated needs for weather information across all surface transportation decision makers. Requirements development will focus on winter road maintenance managers for a deliverable (the version 2.0 of this document) in June, 2000. The version 1.0 document follows.

1.0 Purpose

The Surface Transportation Weather Decision Support Requirements (STWDSR) document, version 1.0 (V1.0) provides background for stakeholder participation in the development of requirements for a concept called the Weather Information for Surface Transportation Decision Support System (WIST-DSS). Stakeholder participation will result in the STWDSR V2.0 in June, 2000. The STWDSR is presented in an Operational Concept Description (OCD) format per MIL-STD-498, augmented by a needs analysis. This STWDSR V1.0 gives baseline information on current practices and deficiencies and outlines the methodology for stakeholder participation in two stakeholder meetings. STWDSR V2.0 will:

1. Enumerate and analyze needs for weather information of all surface transportation decision makers.

2. Analyze weather event and operational-decision making scenarios to document the baseline and deficiencies of the Road Weather Information System (RWIS), particularly from the operational perspective of winter road maintenance.

3. Describe available technologies to address RWIS deficiencies.

4. Allocate high-level requirements to subsystems and interfaces of the WIST-DSS within the context of the Intelligent Transportation System (ITS).

5. Outline programmatic activities necessary to deploy the WIST-DSS, focusing on activities of the Federal Highway Administration (FHWA), inter-federal coordination through the Office of the Federal Coordinator for Meteorology (OFCM), and federal promotion of local public-private deployment partnerships.

1.1 Definitions

Stakeholders include the users of, developers of, and information suppliers to the systems that include weather information in decision support to decision makers who affect or are affected by the surface transportation system. Development of the STWDSR V2.0 focuses on user stakeholders involved in winter road maintenance but considers needs of, and system integration among, all users.

The *Intelligent Transportation System* (ITS) is the collection of communication, information and control subsystems defined in the National ITS Architecture.

The *surface transportation system* includes highway, rail and inland waterway modes, and intermodal connections to the air and maritime modes of transportation. This is intended to be identical to the modal scope of the ITS.

Level of service (LOS) is a measure of traffic-flow performance (specified as traffic LOS) or a measure of pavement-surface conditions as affected by weather (specified as pavement LOS).

Road-condition information is defined as information on road subsurface, surface or near-surface as it affects pavement and traffic LOS. This will include conditions of other surface-mode rights of way (track, waterway) where appropriate.

Decision support systems (DSS) present information, interactively, to persons or devices whose actions (outputs) affect performance of a goal-oriented system. The STWDSR is concerned with the surface transportation system, whose outcome performance is measured against the goals articulated by the ITS program, the FHWA Strategic Plan and other modal strategic plans.

Open System Integration uses a single, modular, information system structure (also called "architecture") and associated public standards for information exchange. This enables various applications to be tailored to different end user needs while accessing and exchanging information easily.

An *Integrated DSS* uses open system integration to present the end user with a single, tailored interface that meets specified needs. This contrasts with "stovepiping" which is the delivery of multiple information flows via separate communication channels and interfaces to the end user.

The *Road Weather Information System* (RWIS) is the baseline (current) system of road-condition information sensing and delivery of weather information to surface transportation decision makers.

The *Weather Information for Surface Transportation Decision Support System* (WIST-DSS) is an advanced and conceptual integrated DSS that fuses weather and other information for decision support to specific surface transportation decision makers, within the ITS. The WIST-DSS will evolve from the baseline (current) RWIS.

Environmental Sensor Stations (ESS) are fixed or mobile collectors of road-condition information. ESS are within the ITS and RWIS and interface to the WIST-DSS.

The *National Weather Service* (NWS) is the part of the National Oceanographic and Atmospheric Administration (NOAA) under the Department of Commerce that produces meteorological products for the public. The NWS will be used broadly to include other products produced by NOAA agencies collateral to NWS products proper.

Tailoring is the filtering, fusion, processing and presentation of information for specific end-user decision support. Tailoring specifically implies decision support services beyond the charter of the NWS, although the bounds of that charter are not precisely specified.

A *Value Added Meteorological Service* (VAMS) is a private entity providing meteorological and/or road-condition services and products tailored for specific user groups, and requiring further processing of NWS and other information.

An *Information Service Provider* (ISP) disseminates information to end users, especially by maintaining server functions in client-server networks, but also by broadcast means.

A *requirement* is a qualitative or quantitative attribute allocated to subsystems (any functional, logical or physical partition) of the WIST-DSS and its interfaces to other-ITS or outside-ITS subsystems. Requirements ultimately are validated against performance of the surface transportation system.

A *need* is an expression by decision support system users for a service that will improve their contribution to surface transportation system performance. The STWDSR translates needs to requirements. The STWDSR defines needs as decisions involving weather information.

A *weather scenario* is a space-and-time sequence of weather conditions, in the atmosphere and affecting surface transportation facilities. The focus of the STWDSR V2.0 is on winter weather conditions.

An *operational scenario* is a collection of time-sequenced decisions resulting in actions (outputs) on the surface transportation system. The focus of the STWDSR V2.0 is on winter weather road maintenance decisions, primarily for ice treatment and snow removal.

1.2 Documents Referenced

Documents referred to in development of the STWDSR are listed in an appendix. However, three documents are fundamental to the purpose, scope and format of the STWDSR:

1. MIL-STD-498, Software Development and Documentation, 5 December 1994. This is the source of Data Item Descriptions (DIDs) used to document systems developments, especially the Operational Concept Description (OCD) adapted to the STWDSR. The full document is at:
http://astimage.daps.dla.mil/docimages/0001/07/58/114847.PD7
The standard has been canceled and replaced by IEEE/EIA 12207, Information technology-Software life cycle processes. See cancellation notice at:
http://astimage.daps.dla.mil/docimages/0001/04/84/498.PD3
However, while IEEE/EIA 12207 should be consulted for process standards, the OCD DID (now the

ConOps document) remains the same and is more freely available through MIL-STD-498.

2. National ITS Architecture. Listed in the Hypertext Architecture Version 2.2, generation date 6/1/99 found at: http://www.odetics.com/itsarch/.

3. Weather Information for Surface Transportation, FHWA, May 15, 1998. Available as document 11263 at the Electronic Document Library, accessed through:
http://www.its.dot.gov/welcome.htm

2.0 Background

2.1 The FHWA Weather-Information Program

The STWDSR project is being conducted by the Weather and Winter Mobility program of the FHWA Office of Transportation Operations (HOTO). The project is funded by, and grew out of the rural ITS program of the ITS Joint Program Office (ITS-JPO). Both the HOTO and the ITS-JPO are under the Operations Core Business Unit of the FHWA after re-organization in 1999. The STWDSR project is managed by Mitretek Systems Inc., under their support contract to the ITS-JPO. Paul Pisano, Transportation Specialist of the HOTO is the FHWA project manager.

The STWDSR project originated in work of the FHWA Weather Team, created in January 1997. The Weather Team was founded with membership from various FHWA offices involved in weather programs and a state DOT representative from the AURORA pooled-fund research consortium of states concerned with weather information and winter road maintenance. The first major actions of the Weather Team were to draft its White Paper based on a stakeholder symposium in 1997, and initiate the Foretell™ operational test of advanced weather information for road maintenance and other users. The White Paper defined the FHWA weather information program focus and Foretell, which is undergoing a 3-year evaluation funded by the ITS-JPO, will be an important experience base for WIST-DSS development and requirements validation. The Advanced Transportation Weather Information System (ATWIS) operational test in the Dakotas is also an important basis for the WIST-DSS along with other weather-related projects sponsored by the USDOT and the many commercial developments of the VAMS.

Mitretek is a non-profit research corporation that supports the federal ITS program in program development and procurement. Under its FHWA-support contract, Mitretek cannot compete for other projects nor be recipients for procurements it helps develop. This establishes Mitretek as a disinterested facilitator of several parties in ITS standards and requirements, on behalf of the FHWA. Mitretek supported the FHWA Weather Team as an extension of the rural ITS program support efforts. Another department in Mitretek, that similarly supports NOAA for NWS systems development is assisting the FHWA weather program with meteorological and NWS-operational expertise. The ITS origins of the FHWA weather program are appropriate for framing weather information within the complete surface transportation information systems of the ITS. The rural ITS program has lately been supported by a research support contract operated by competitive award to SAIC (a private corporation). The rural ITS program continues to lead the effort to incorporate weather, and the road maintenance operations dependent on weather information, into the ITS program. This includes the definition of the Operations and Maintenance, and the Environmental/Weather Information

Management user services for the National ITS Architecture. That effort parallels and supports the more detailed system requirements effort under HOTO.

After the FHWA re-organization in 1999, the mandate to carry out the program that the Weather Team had outlined in their White Paper, *Weather Information for Surface Transportation* was given to the Weather and Winter Mobility program within HOTO. This reduction of institutional fragmentation concerning weather and winter maintenance reflects a new FHWA emphasis on operations embodied in the creation of the Operations Core Business Unit. The weather-related program also was broadened, as indicated by the goals and objectives of the Weather and Winter Mobility program:

Goals and Objectives of the FHWA Weather and Winter Mobility Program, Office of Transportation Operations	
Goals	Objectives
Reduce the impacts of adverse weather by:	
Developing weather information systems that meet the demands of all users and operators	1. Strengthen the relationship between the transportation and meteorological communities
Developing improved maintenance technologies for winter mobility	2. Improve the processing and display of weather data (especially decision support systems)
Developing road weather management practices for all types of weather	3. Develop advanced maintenance technologies
	4. Develop weather traffic management practices
	5. Develop outreach and training material.

The STWDSR project addresses primarily the first goal, and objectives 1, 2 and 5. The STWDSR project was initiated in May of 1999 to produce this V1.0 document and to organize the stakeholder participation that would produce V2.0.

Although the STWDSR is under the FHWA, the ITS program is multi-modal and includes transit programs under the Federal Transit Administration (FTA), rail programs under the Federal Rail Administration, and safety programs under the National Highway Transportation Safety Administration (NHTSA). The FHWA will coordinate with other administrations to ensure the multi-modal integration of the WIST-DSS. Coordination will also be pursued with the National Science and Technology Council program for weather information and the Remote Sensing Applications for Transportation program, both managed under the Research and Special Projects Administration (RSPA), and with the surface-transportation safety concerns of the National Transportation Safety Board.

The surface administrations of the USDOT are distinct from the Federal Aviation Administration (FAA) of USDOT. Unlike the surface administrations, the FAA is the operating agency for the airspace with its own facilities and close operational relations with the NWS. Coordination with the FAA and other federal agencies, especially the NWS, will be achieved through activities of the OFCM. The OFCM has recognized surface transportation by the creation of the Weather Information for Surface Transportation Joint Action Group (WIST-JAG) in 1999. The FHWA will participate in the WIST-JAG, and other OFCM committees, to formulate the national weather research and deployment agenda. Although the possibility exists for FHWA to enter into joint federal deployment programs (e.g., the doppler weather radar and integrated observing system), the decentralized organization of surface transportation generally defines states, regional authorities and localities as the public operating and deployment entities.

2.2 Assumptions and Objectives of the STWDSR Project

The STWDSR project was initiated based on the findings of the Weather Team White Paper. Key findings that lead to the assumptions and objectives of the STWDSR project are:

1. Surface transportation decision makers, including maintenance managers, are faced with a profusion of weather information from different sources, bundled through different channels and displays (called "stovepiping"). Integration of the information is at best manual, and colorfully described as "swivel chair integration". The issue is less the quality of individual information sources than the filtering, fusion and presentation of tailored decision support information.

2. The NWS is a key provider of weather information supporting all possible decision support systems. As such, it is distinguished as providing a "weather information infrastructure". Also as such, it is limited in its ability to tailor products as decision support for myriad decision-making niches. The envisaged WIST-DSS must use NWS products, but must be created primarily within the surface-transportation community allied with meteorological researchers and private-sector system developers.

3. Specialized road and other surface right-of-way observational systems are needed and must be provided outside of the NWS infrastructure. However they must also be assimilated (put into an open database with cross-checking of data for quality control) with broader observational networks and other weather data sources.

4. The FHWA operates no part of the surface transportation system and will not be a WIST-DSS

deployer. The role of the FHWA, in addition to managing the federal-aid grants by which the WIST-DSS can be deployed, is to promote the coordination between the surface-transportation community, meteorological researchers and private-sector system developers, and to advance the state-of-the-practice to the state-of-the-art.

5. Unlike surface transportation, weather information has a strong federal operating presence. This is primarily among the NWS, the FAA and the Department of Defense (DOD). There are two corollaries to this: 1) The surface transportation community, while primarily local and both public and private, needs a strong federal liaison to the weather information infrastructure, and; 2) There is an institutional gap between private sector system developers and other researchers and developers, including several federal and non-profit laboratories, allied with the federal operating agencies.

6. The National ITS Architecture is the integrating framework for the WIST-DSS and provides the basis for open system integration. However, the National ITS Architecture must still mature to account fully for rural operating contexts, weather information, and maintenance functions.

These assumptions support the FHWA role as a modal focal point of inter-federal coordination (via the OFCM), as a convener of public/private, user/developer activities at a national level (via existing organizations), and as the promoter of national system integration (via the National ITS Architecture). The FHWA role and the specific objective of promoting an integrated DSS defines the objectives of the STWDSR project as follows:

1. Promote deployment partnerships between users, private vendors and non-profit meteorological systems developers ("national labs" sponsored by various federal agencies) to realize advanced surface transportation weather decision support system concepts;

2. Produce deployment guidance for local public/private development of the advanced system;

3. Guide further federal research projects and operational tests, and;

4. Help coordinate surface transportation weather requirements and projects across federal agencies, especially with the National Weather Service (NWS). This includes participation in the WIST-JAG of the OFCM and contributing to its surface transportation requirements compilation to be completed in July 2000.

The WIST-JAG target date sets the date for completion of STWDSR V2.0. Although that version will focus on winter road maintenance it will be complete in terms of user needs and will include system-integration considerations within the ITS and to the NWS. The decision to focus initial STWDSR efforts on winter highway maintenance is based primarily on level-of-effort constraints: Going beyond a simple level of requirements involves a great deal of operational analysis even for one user group.

However, consideration of integration requirements will always keep the WIST-DSS open to other users. It is expected that there will be a great deal of commonality between requirements of winter road maintenance and of other uses. Later efforts will consider other users in more detail.

2.3 From RWIS to WIST-DSS: Issues and Approaches

The term currently used to cover weather information systems for highway decision making is the Road Weather Information System (RWIS). This term likely will extend to any improvements defined here to be the WIST-DSS. The terms are separated only to emphasize that the WIST-DSS is an idealized concept that should guide the evolution of the RWIS, and extend to non-road systems as well. RWIS will be used here to refer to the state of the practice, as the baseline for improvements.

The RWIS sometimes refers strictly to sensor systems, usually the fixed roadside condition and weather sensors and their associated communications and display. The ITS term for this is Environmental Sensor Station (ESS). ESS will be used here to include fixed and mobile sensor systems for surface rights of way. RWIS has grown to encompass the variety of weather information sources, channels and displays, until it is not really a system at all but a collection of unrelated information sources. The problem here is the bundling of information sources with dissemination channels and displays. This is also called "stovepiping", to imply the parallel and non-communicating paths whose information can be neither physically nor logically integrated. Stovepiping occurs because systems are not open: They were created piecemeal to meet various needs end-to-end by private and local interests. Their information formats, and often the information itself, are proprietary, meaning that other applications of other users and vendors cannot make use of the information.

Stovepiping should not be confused with the legitimate functional partitioning of decision making. Each kind of decision needs a particular kind of information. Decision makers are different because they are in contexts that allow and require different kinds of actions on different kinds of objects. The ideal image of an open system is to have multiple information sources feeding multiple applications, each for a single kind of decision support. The application does the selective "tailoring" or "fusion" of information and displays it in a way appropriate to each decision maker. The decision maker is relieved of having to collect and process information manually ("swivel chair integration").

The functional organization of decision making is based in part on informational limitations, and these reflect historical technology limitations, including "stovepiping". It follows that innovations in decision support can change the functional organization of decision making, and therefore how needs are defined. This could include the automation of some decisions that have been manual. However, the primary issue is that the requirements definition will be based inevitably on current operations and their organization. It is difficult to foresee different kinds of decisions (needs) in the future. This is the reason why any system must be able to evolve, and this is also facilitated by open systems integration. The STWDSR process is designed to be open ended and iterative to accompany evolving requirements.

The automation of weather forecasting (any forecast also being a decision) has long been an ideal, but one that has not been realized, nor is likely to be. The same holds for surface transportation. A human decision maker usually will be "in the loop", with the possible exception of very short-horizon control systems (e.g., vehicle skid control, chemical application control for ice treatment, etc.). For this reason, decision support should be read as *to a human*, with all the human sensory presentation and processing limitations that implies. Since the human remains in the loop for the NWS, there are state-of-the-art systems being developed for the NWS, and other customers such as air traffic controllers, that have applicability to the WIST-DSS. There are issues of how well users can absorb information or make good decisions under uncertainty. This gets to the issue of whether decision support remains a display of diverse information as the precursor to a decision, or becomes a "red light, green light" indicator that really is the decision itself, with a human merely as actuator. The extent to which this is desirable must be measured against bringing human experience and judgment to decisions. The intent here is not to automate decisions, but to support human decision makers.

The STWDSR project will define requirements primarily at the operational concept level. This is defined within the Operational Concept Description (OCD) documentation standard. The OCD format calls for detailing the state of the practice and its deficiencies. This should not diminish the fact that substantial improvements have been made in the RWIS, especially in the last decade. The improvements still needed, based on an open system architecture, are what define the WIST-DSS. Besides an open system architecture, there are other perspectives that stipulate the WIST-DSS. These include uncertainty and the related concept of scale.

Decisions are to control assets in the surface transportation system in order to achieve performance goals. All decisions are prospective, meaning that they act from past data but on future situations. Scale is dimensioned by the time horizon of decisions (how far in the future they are effected) and their spatial domain (how many things or what geographic area are controlled). The larger the scale, the greater the uncertainty about the current or future state of the system being controlled because of informational limits. An example to imagine is the prediction of road surface temperature from a single ESS measurement: it becomes less reliable farther into the future, and moreso for road segments away from the sensor. Investment in data collection can overcome the spatial uncertainty, and combined with investment in prediction models this can reduce the future uncertainty. But economics dictates that less certainty can be afforded at larger scales.

Uncertainty demands use of risk-decision procedures. Scale is set by the nature of the system being controlled and the decisions being made on it. For instance, a decision to pretreat roads to prevent freezing must cover some road network. Pretreatment must occur before a critical temperature and humidity, and that time lead is determined by the physics of how fast treatment can be dispatched and reach throughout the network, limited by economic investment in crews and equipment. In order to be sure that sufficient chemical is deposited before freezing, the statistical distribution of the timing and severity of the freeze need to be considered in order to achieve an objective of, say, no more than 5% cases of untreated freezing and no more than 20% cases of unnecessary treatment.

The information used to support a decision should be of a scale appropriate to the decision. Most treatment decisions are not discrete events but must contend with weather and road conditions that are themselves a continuous scenario of many scales. This dictates that a decision support system should be able to integrate many scales, and the corresponding information that has various uncertainty. A stovepiped system with one information source (an ESS, a complex weather model, or just a climatic average) cannot adapt across scales.

Uncertainty is often ignored in favor of simple point values, both of current observations and forecasts. This in turn prevents meaningful risk decisions, and promotes biased decisions that do not meet reasonable risk criteria (which are not even defined if they cannot be used in decision making). The STWDSR project is concerned with uncertainty to specify appropriate risk decision making and to assure that risk measures (as distributional statistics such as standard deviations) are available as a tool of information fusion.

WIST-DSS requirements can be boiled down to "more accurate, more timely and more relevant (geographically-specific) forecasts". The NWS and the VAMS are both progressing in this way as technology improves independently of specific user needs. The concern of this project is to allocate improvements at existing levels of technology, and that concerns the best use and combinations of information whose inherent uncertainties are known. It is hoped that stakeholders will appreciate that at a given level of technology, uncertainty at a given scale cannot be much improved. This will shift attention from requiring unrealistic combinations of time horizons, spatial resolution and accuracy. The requirement is <u>not</u> for "perfect forecasts" at arbitrarily high resolutions out to arbitrarily long futures. Also, there are sources of information other than point observations and complex numerical weather forecasts. Using and extrapolating rich sources of remotely-sensed area and volume data, as from radar and satellite, and then merging these with point observations and full atmospheric numerical modeling (and ensembles of models) at a succession of scales is an important target for data fusion, and it depends on characterizing each data source by its uncertainty in a given application.

The WIST-DSS can be technically specified, but its performance depends on constraints that are outside of this technical endeavor. As will be seen, the scope of the WIST-DSS is defined so that there are external *resources* (especially weather information from the NWS and observations from the ESS) as well as *constraints.* The focus is on meeting DSS requirements, not on the weather information resources. Constraint and resource issues generally must be addressed by policy actions of the FHWA, other federal agencies coordinated by the OFCM, legislation (both federal and local), and programming processes for transportation funding. Primary among the constraints are institutional ones between the public and private sectors. Weather information is very much a mixed enterprise, dominated by the NWS for basic weather information and dominated by VAMS and private system vendors for tailored decision support. The boundary is not clear, and therefore neither is the boundary of the WIST-DSS. With the NWS and other public agencies involved in weather information are a number of non-profit, federally funded development labs. The STWDSR process can help to promote partnerships that break down institutional barriers, and proprietary barriers that prevent open systems integration. However, those partnerships will work beyond the requirements process.

3.0 STWDSR Process

3.1 Schedule and Products

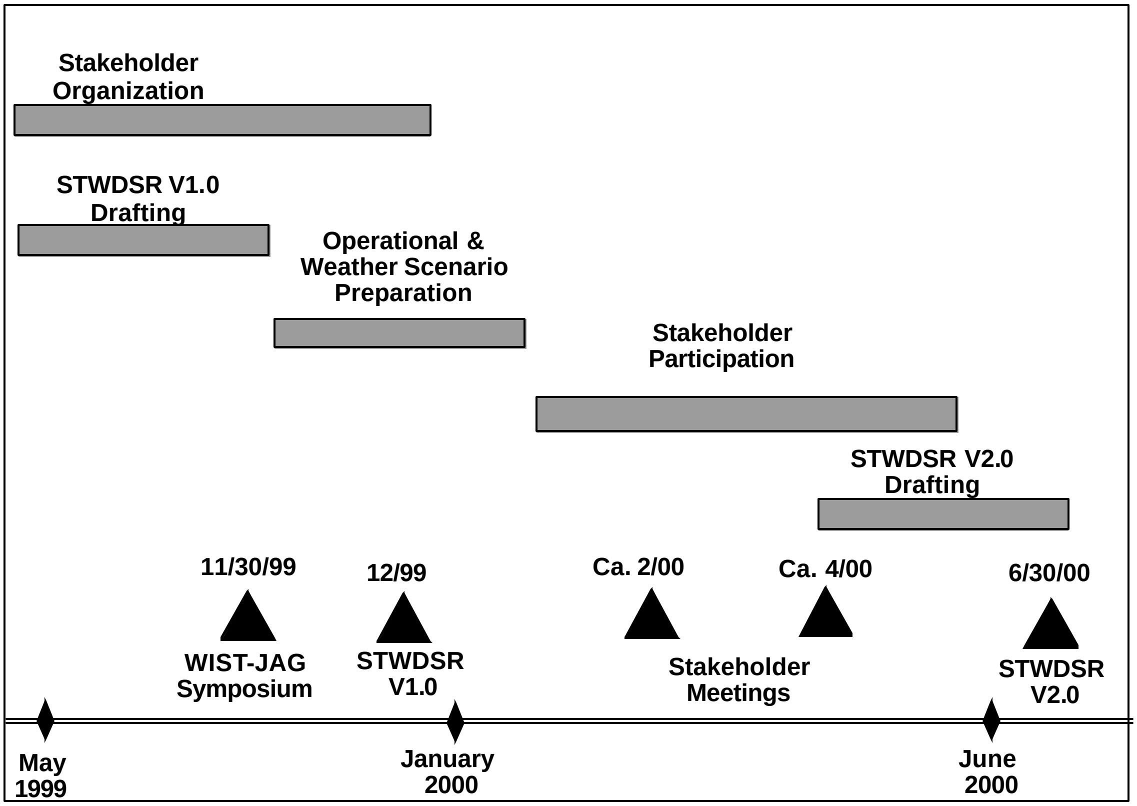

Figure 3.1: Schedule for Completing STWDSR V2.0

The STWDSR project began in May of 1999 and has been planned as far as the V2.0 deliverable that is due at the end of June, 2000. The V1.0 deliverable (this document) is the introductory material for stakeholders to enable them to participate in the drafting of the STWDSR V2.0. The OFCM has scheduled the WIST-JAG symposium for 11/30/99-12/2/99 and will include many of the stakeholder group.

A large part of the interval up to release of STWDSR V1.0 has been concerned with project planning and stakeholder organization. This includes subcontracting with selected national labs and elicitation of stakeholder participants. Public sector participants (primarily state DOT representatives) will be reimbursed for participation expenses at designated meetings.

After the WIST-JAG symposium, two other waves of stakeholder participation are planned, leading to release of STWDSR V2.0. Stakeholder participation will involve both meetings and remote review of documentation. It is expected that a larger number of stakeholders will choose to participate in remote review than in the meetings. Two meetings will be held, in the winter and spring of 2000. Stakeholder participation will be focused on response to the STWDSR V1.0, drafts of STWDSR V2.0 and scenarios of weather events and operational decisions. The meetings will also be the opportunity for the national labs to make presentations on technologies that will contribute to the WIST-DSS.

The weather and operational scenarios are described in more detail in later sections. A set of weather scenarios will use real weather events. These will allow description of the NWS process of weather forecasting, and other information sources that should be considered as inputs to the DSS. These are being developed by the meteorological systems staff of Mitretek. The operational scenarios will be drafted based on previous surveys of winter road maintenance decision and treatment sequences. Since the real experts of the operational scenarios will be among the user stakeholders, participation will be vital to detailing the kinds of decisions, and their DSS requirements, with respect to the weather scenarios. The stakeholder consideration of available technologies and gaps in current information to the operational scenarios will then generate the WIST-DSS requirements. Responses from stakeholders will be structured cumulatively into the STWDSR V2.0.

The STWDSR relies on empirical results from the many RWIS activities in the U.S. and abroad. These are captured in the STWDSR literature review. The Foretell operational test is also an important basis of operational scenario information. The operational test is being evaluated under a three-year program of the ITS-JPO. This will give a unique opportunity to get a longitudinal comparison of operational practices and information use. Some preliminary operational scenario data were collected over the winter of 1999 and will be formally collected over the winter of 2000 and beyond. Presentations on results for the 2000 winter will be available for the second stakeholder meeting.

It is intended that the STWDSR will be broadened to other user needs, and deepened by subsequent research projects, operational tests and other system developments. However, no specific STWDSR activities beyond June, 2000 have yet been defined.

3.2 Participants

The STWDSR project is managed by Paul Pisano as HOTO Weather and Winter Mobility Program Coordinator. The project is being conducted by Mitretek Systems, Inc. under their support contract to the ITS-JPO. Completion of the STWDSR requires participation by users and developers. The inter-federal coordination requires participation by the several federal agencies organized by the OFCM in the WIST-JAG.

The STWDSR stakeholder participants specifically include state DOT maintenance staff to represent users, a selected set of national labs engaged in weather information system research and development, and a set of private vendors of weather information systems. It is planned that the group of stakeholders participating directly in meetings for the two waves of STWDSR review be no more than 50. Others may participate through written comment.

The state DOT representatives were solicited via identification by the FHWA division (state) offices, coordination through the American Association of State Highway and Transportation Officials (AASHTO) and invitation to persons known to the Weather Team. Private sector vendors were solicited through publication of a request for letters of interest in the Federal Register[1], and were subsequently self-identified according to their level of involvement.

The "national labs" are all non-profit research and development organizations (as is Mitretek Systems). Six labs were chosen for the relevance of their work to the STWDSR. They are:

1. The National Severe Storms Laboratory (NSSL) under the National Oceanographic and Atmospheric Administration (NOAA)

2. The Forecast Systems Laboratory (FSL) under NOAA

3. The Environmental Technology Laboratory (ETL) under NOAA

4. The National Center for Atmospheric Research (NCAR) under the University Consortium for Atmospheric Research (UCAR)

5. Lincoln Laboratory (LL) operated for the U.S. Air Force (USAF) by the Massachusetts Institute of Technology (MIT)

6. The Cold Regions Research and Engineering Laboratory (CRREL) under the US Army Corps of Engineers (USACE)

These organizations are being coordinated by Mitretek Systems (under subcontract, with the exception of Lincoln Labs working under an intergovernmental agreement between the USAF and FHWA), specifically to define state of the art components for the WIST-DSS, based on the labs' development work for other customers. The labs will participate in the stakeholder meetings to demonstrate these components.

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[1] Federal Register 64(243), December 20, 1999, pp. 71179-80. Available at http://www.access.gpo.gov/su_docs/aces/aces140.html

The STWDSR project is also funding the participation of the state DOT representatives. The private sector vendors will participate at their cost. Because the FHWA can act only as a coordinator and funding source in eventual system deployment, it is intended that the stakeholder groups also will form deployment partnerships to realize requirements articulated in the STWDSR. This may occur within or outside of the group invited into the STWDSR process. Such partnerships will be funded by various combinations of federal, local and private funds outside of the STWDSR project.

3.3 Evolutionary Systems and Spiral Processes

The STWDSR process is founded upon a system engineering process. Such processes are goal-oriented, in that system requirements are based on improving outcomes, in this case of the surface transportation system, via meeting decision maker needs for weather information. These processes are both hierarchical and iterative, and best represented by a spiral sequence of steps. The hierarchical iteration is characteristic of evolutionary systems, that keep responding to new technology and contexts by adaptation of structure and requirements.

The system hierarchy consists of external constraints (policies) and goals leading to the conceptualization of a working system to meet the goals within the constraints. The system is specified in successive levels of detail with the final level being a build-to specification for a deployed system. An example of requirements levels is as follows (hypothetical only):

> Goal: Fewer crashes, better level of service, less maintenance cost and minimum chemical use through efficient and timely ice pretreatment.
>
> Need: More reliable and spatially-specific forecasts of road icing and residual chemical concentration, approximately 2 hours in advance for treatment dispatching.
>
> Level 1 system requirement: From DSS to maintenance manager, at least two hour warning of ice formation by route segment with probability of detection (POD) of at least 90% and miss rate (MR) no greater than 10%.
>
> Level 2 system requirement: From meteorological forecast to icing forecast model, atmospheric temperature forecasts with root mean square (RMS) error at 2 hour horizon of no greater than 2^{o}C averaged over each route segment. From ESS to icing forecast model, current road surface chemical concentration at sensor points no greater than +/- 15% at concentrations above 20 g/m.

Level 3 system requirement: From ESS assimilation to meso scale forecast model, current surface air temperature estimated at 5 km initialization grid points with RMS error no greater than 1.5^{o}C. From NWS to meso scale forecast model, initialization boundary condition forecasts provided 6-hourly on 30 km grid, including....

Level 4 system requirement: etc.

At each level, requirements are allocated to a structural decomposition of the system. This results in a hierarchy from few "black boxes" to many that are nested inside the original set. The more boxes there are with their own functional requirements, the more interfaces there are between the boxes. The number of separate requirements at each level can increase even more rapidly than the number of boxes (parts or subsystems) that typically increase exponentially (1, 3, 9, 27, etc.). This is because the interfaces can increase in number as the square of the parts. The hierarchical decomposition and allocation of requirements makes the complexity of design manageable at each step by splitting it up among specialist groups. This is exactly what is being done by making the WIST-DSS a subsystem of the ITS.

Upper levels of the hierarchy set constraints that become the requirements (functional and interface) that the designers of each part at the lower level can focus on. This process is iterative because there is also an upward interaction from what is technically possible, or that results from testing, at the lower level. It is hoped that design converges downward. Technological changes, operational changes, or locally specified needs from lower levels tend to be propagated upward, all the way back to policy and goals. It is this possibility of lower level adaptations changing the high level structure and requirements of the system that defines evolutionary systems. This *evolutionary* process is contrasted with a strictly top-down system *development* process, that was characterized by what are called "waterfall" system processes, now largely obsolete in complex system processes.

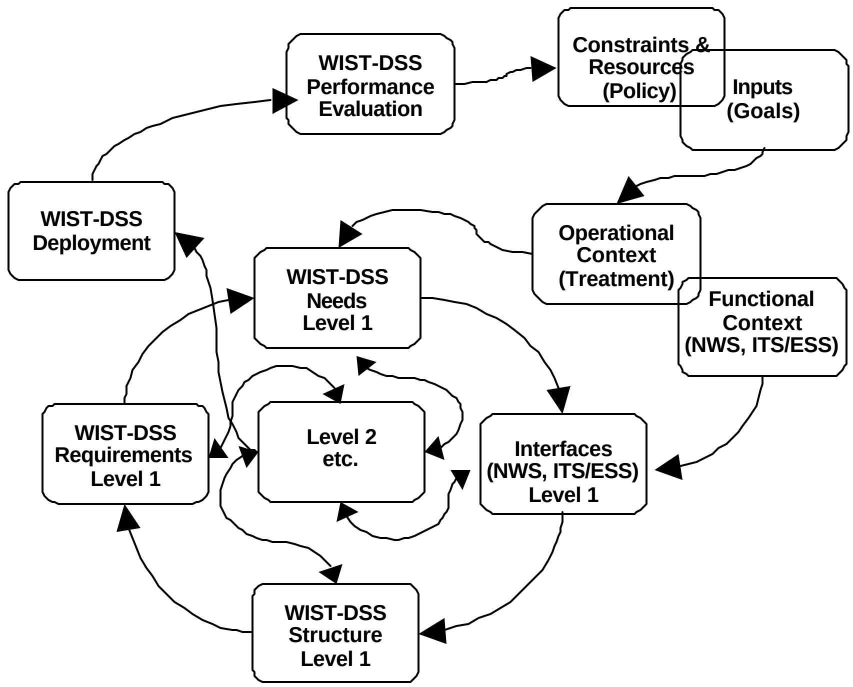

Figure 3.2: A Spiral Representation of the Evolution of the WIST-DSS

In the figure above, the inner spiral is the development process for a deployable WIST-DSS. This goes through a hierarchy of specification levels for needs, requirements, structure and interfaces. This STWDSR will not go very deep in level, and final levels for deployment will be by the deployment partnerships. The boxes at the outside of the figure are the external constraint and goal-setting processes. There are also external systems to which the WIST-DSS interfaces, and the external systems are established by other, parallel, spirals.

A deployed system will result in new operational experience, the application of new technology (that is really introduced at low system specification levels) and realization of new operational approaches with the new systems (including new ways of allocating decision responsibility). These will then feed back to the policy level and to external systems. This is a view of an inward spiral followed by an outward spiral. The steps can be arranged sequentially and the spiral can be viewed either as winding outward to "spin off" a product, or winding inward to converge on a definite design.

For practical purposes, this STWDSR project will try to converge inward to a few specification levels within a stable context. However, iterative requirements for changes in policy and external systems will be noted for further action. Deployment and evaluation, and its consequences for higher level policy and external systems, obviously must wait a while and are beyond the scope of the immediate process.

3.4 Open Systems and the ITS Architecture

The meaning of an "architecture" should be understood in the evolutionary context, especially since the National ITS Architecture is a major functional context for the WIST-DSS. The same applies to the architecture of the NWS after modernization.

The term "architecture" has gained ascendance over what used to be called simply a "system level specification". The term "architecture" was used in the 1950's to refer specifically to the high level structure of computers, that were among the first machines complex enough to require a hierarchical distinction between the specifiers of the systems and the builders. As such, architecture strongly conveys the idea of taking the user's needs and reflecting them as requirements on some high level of system structure. Since the 1950's,"architecture" has become more associated with computer networking (an even higher level of complexity) and the "open system architectures" needed so that many machines can communicate as the network evolves at its nodes (machines) and links (communications channels). The network continues even as the machines change (operating systems or "platforms"), the applications on the machines change, and communications technology (phone lines, fiber optics, etc.) changes.

In an open system architecture for computer-to-computer communications, the emphasis is on a "protocol" specification. This is a structural decomposition of the end-to-end data communication into modular "layers". Between layers are standardized interfaces that must be maintained even though the particular technology and structure within a layer can be adapted.

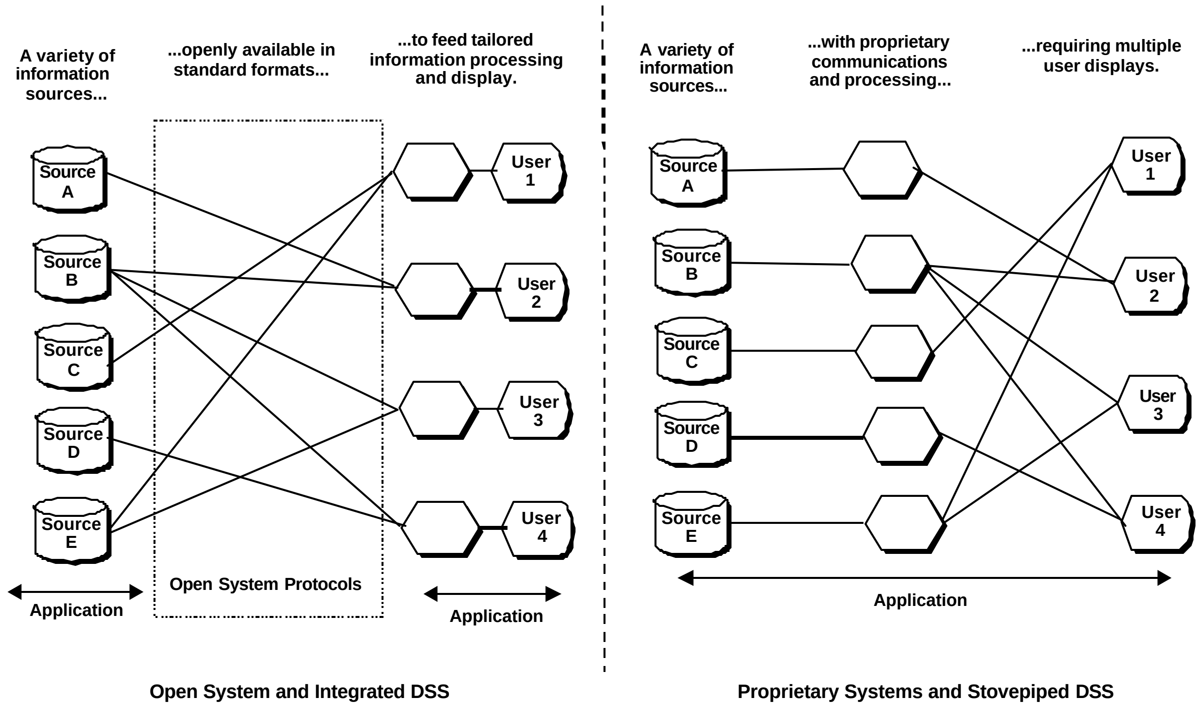

Figure 3.3: Contrasting open and proprietary systems for DSS.

The figure above contrasts an open system with a proprietary information system for decision support. In the open system, interfaces to user applications are one of the modular layers in every protocol stack. User applications themselves (whatever a user sees and manipulates, such as word processing, spreadsheets, Internet browsers or database processors) include information processing (as opposed to communication) and display but are beyond the protocols. This is why the protocols can be standardized, but the applications can be tailored and varied for each user. The figure shows information sources on one side and decision support applications on the other, but both are "applications" relative to the data communication protocol structure. In general every database is created through a user application, whether the "user" is a human inputting data or a an automatic device, like an ESS. An open system protocol structure allows the variety of user applications to mix and match the data sources or, more generally to arbitrarily connect multiple applications (which is what happens on the Internet).

In contrast, a proprietary system bundles components. Usually this involves data sources, communication links and processors. The current ESS is a good example of this. This means that if a user wants to access a number of data sources, it requires delivering a number of stovepiped channels and displays to each user. In effect, it is all one big application. A proprietary structure prevents data fusion within a single decision support system because the data formats are not made public, not standardized and otherwise unavailable to decision support deployers. The mixing and matching is then on the part of the user who receives each stovepiped channel (swivel chair integration). A proprietary system prevents the separation of the data communications from the applications on either end. The model for the WIST-DSS is the open system architecture that is standardized to support decision support applications that are separate from the data source applications, individually tailored to user needs, but integrated so that the user perceives only a single system.

Most of the communications of information for the WIST-DSS will be handled by the National ITS Architecture. In the interface requirements, it may become necessary to pay attention to the architecture below the applications level. One important protocol model is the 7-layer protocol reference model devised by the International Organization for Standards[2]–the ISO 7-layer model of physical, data link, network, transport, session, presentation and application layers. The "application" layer is the interface to user applications, so there is often confusion between the technical and colloquial use of the terms. The more current terminology of application process interface (API) therefore is preferable to "application layer" in the protocol stack. The ISO 7-layer model is not the only one, and de facto standards for some of the middle layers of the 7-layer stack, e.g., the Internet with its TCP/IP protocols, do not follow the ISO model completely.

The WIST-DSS is defined as a sub-part of the National ITS Architecture and is focused on user applications for decision support. Rather than saying that the WIST-DSS has an architecture, it is more appropriate to refer to its contextual ITS and NWS architectures and the open system protocols that underlie those. However, it is also true that the WIST-DSS will evolve from the current RWIS, and the STWDSR process will be examining the structure of the RWIS that is not an open system and has not been built within a single architecture.

The RWIS is a response to needs for better pavement levels of service under adverse weather and the adoption of pretreatment operations. Both required more accurate, predictive information on road conditions. Based on progress under RWIS, we now expect more and include goals such as minimizing pretreatment or anti-icing chemical usage and reduction of maintenance costs, even as pavement levels of service are improved and crashes reduced. The use of road sensing systems (now called ESS under the ITS architecture) goes back decades but RWIS may be dated to the Strategic Highway Research Program (SHRP) report[3] of that name in 1993. The cost and accuracy of ESS has not improved much, but remote sensing and mobile-probe strategies become feasible. Assimilation of ESS data with NWS surface observations and forecasts becomes important. Meso-scale meteorological modeling, with resolutions that start to make route-segment specific condition

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[2] Information processing systems–Open Systems Interconnection–Basic Reference Model, International Standard 7498, ISO, 1984.

[3] Road Weather Information Systems, Vols. 1 and 2, Strategic Highway Research Program, National Research Council, Washington, DC, 1993.

predictions feasible, has been enabled for private vendors or local weather forecast offices (WFOs) of the NWS by advances in computer technology. Digital products in geographical information system (GIS) databases from the NWS and VAMS have increased immensely. All these changes require a review of RWIS structure and requirements and an open-system architecture approach.

The National ITS Architecture is not an open systems architecture in the pure sense of the ISO 7-layer or other computer-to-computer communications models. It is an architecture more in the original sense of a high level, user-needs driven, system structure that frames lower level deployment activities. The National ITS Architecture as it now exists is the result of a convergent process between needs and structural concepts. The current structure is the basis for many standards development efforts now underway. The structure is specified in both physical and local perspectives. The physical perspective shows a network of information processed in subsystems and communicated by physical interconnections. The logical perspective deals with process specifications (pspecs) and data flows.

Since the National ITS Architecture is now baselined (standardized, although subject to change), the change process has been formalized. Generally this is via user services, representing user needs, translated to requirements on the ITS that may be allocated to subsystems and interconnections, or pspecs and data flows, of the ITS. At present, the rural ITS program is generating a new user service, for Environmental/Weather Information Management. This is an appropriate channel for the STWDSR, but unfortunately the parallel timing makes it questionable whether the STWDSR will have much impact via the new user service and its requirements. Another related user service, for Operations and Maintenance, is similarly underway. In addition, the ITS America organization, through their Weather Information Applications Task Force (WIATF) is also undertaking an architecture review. Therefore, although the WIST-DSS needs a stable context to converge on its requirements, the ITS architecture context may change. This emphasizes the need to keep the spiral process going.

The STWDSR project and the WIST-DSS may be viewed as deploying the National ITS Architecture at a lower level of detail. In this case it is important to recognize the regulatory standing of the architecture. Legally, the force of the National ITS Architecture in the "conformity" legislation from the Transportation Equity Act for the 21st century (TEA-21). This makes federal-aid contingent on use of critical ITS standards, that relate to various data flows and performance specifications. Also required is use of the National ITS Architecture as guidance for integrating ITS deployments in *regional architectures*. It is probable that forthcoming regulations will *not* require exact use of the National ITS Architecture in the regional architectures or deployments. Nonetheless, it will be impossible for the WIST-DSS requirements to proceed, nor an open system to be realized, without depending on the National ITS Architecture to represent its external interfaces. Certainly the underlying open system principles need to be adhered to, and this is a major change for the RWIS that is now a fragmented and largely proprietary system. It will be important for the WIST-DSS to adhere to a nationally uniform architecture because weather information is not local, or regional, and because the interface to the NWS is important. Although regional architectures inevitably will be part of the federal-aid deployment process by states and localities, the WIST-DSS probably should propagate a uniform, and more detailed level of the National ITS Architecture to all regional architectures.

Structurally, the National ITS Architecture carries "weather service" as a terminator with relatively few data flows, and only into the ITS. For this reason it is relatively easy to separate out the NWS (or its equivalent VAMS data flows) as an interface that is particularly important to the WIST-DSS. All weather information for the WIST-DSS flows through the ITS but in practice the flow from the NWS is fairly direct from outside of the ITS.

There is only one ITS standard that directly addresses weather information primarily, and that is for the ESS within the ITS. To be precise, the sources of ESS data ("roadway environment") is an external terminator in the National ITS Architecture, but the processing and communications that go along with the ESS are within the ITS, and the WIST-DSS will get ESS information via the ITS. But it has also been decided to show the ESS as its own interface to the WIST-DSS, because of its significance and the possibility of structuring a direct ESS-NWS interface (that does not now exist with the one-way flow from "weather service" in the National ITS Architecture). The ESS standard is not a "critical" standard that is mandatory for federal-aid funding under TEA-21. However, weather information messages are increasingly being included in other critical data dictionary and message set standards (especially center-to-center and Advanced Traveler Information System (ATIS)).

The means for getting WIST-DSS requirements back through the National ITS Architecture are, as mentioned, specified by the ITS program but problematic in view of the timing of ongoing efforts. Similarly, the mechanism for WIST-DSS requirements to be reflected back to the NWS, especially if they are considered in the ambiguous realm of "tailoring" are problematic. However, the WIST-JAG of the OFCM now offers the forum for raising such issues. As surface transportation becomes a bigger player, it is also hoped that more joint-agency weather system development activities will include representatives from surface-modal agencies (e.g., the Tri-Agency Requirements (TAR) body that includes the NWS, DOD and FAA in Doppler radar requirements). What is or is not tailoring ultimately has to be decided at the detailed level of what requirements properly can be accommodated in the common NWS infrastructure.

3.5 The OCD Format and Operational Scenarios

Given the diffuse location of the STWDSR process in the system evolution spiral, it cannot be expected that a systems development standard can be followed by rote. Most of the process discipline for the STWDSR will be provided by the system development document called the Operational Concept Description (OCD). As given in MIL-STD-498 for software development, the outline of OCD contents has been adapted for this STWDSR document as follows:

Section, this document	OCD Section	OCD Contents
5.0	1.	System scope
1.0, App.	2.	Referenced documents
6.0	3.	Current system or situation
8.0	4.	Justification for and nature of changes
9.0	5.	Concept for a new or modified system
7.0	6.	Operational scenarios
10.	7.	Summary of impacts
11.0 (part)	8.	Analysis of the proposed system (advantages, disadvantages, tradeoffs)

The Background, Process and User Needs sections of this STWDSR document have been added for a new and diverse stakeholder group and to conduct a needs analysis normally prior to the OCD document. This somewhat alters the discussion of needs that is supposed to occur in OCD section 4 and the mission of section 5. This deviation is considered necessary, but is not trivial. The only formal needs analysis process for the ITS has occurred over the last several years for the National ITS Architecture. It just happens that rural, maintenance and weather information needs were not a focus of that process. An integrated needs analysis should then allocate requirements to various system developments. The National ITS Architecture stops short of that, as is proper for a pure architecture. The need to focus on decision support for weather information, and the idea of starting with a focus on winter road maintenance are not the results of comprehensive needs analysis in the ITS. This effort fills a gap in ITS and FHWA programs generally, and the Weather Team's White Paper makes the case for decision support. The focusing of limited resources on winter road maintenance is an implicit prioritization decision.

Another deviation is that OCD section 6 on operational scenarios are placed before section 5, concept for a new system. This also has to do with the way this spiral is being conducted. The OCD should specify a new system and then demonstrate how it operates. The process here uses detailed weather and operational scenarios in order to identify baseline system deficiencies. This involves a fairly strong assumption that the operational scenarios are constant with the new system (another context issue). In this turn of the spiral, consideration of the operational scenarios will lead to the new system concept, and so the sections are in that procedural order. A mature OCD will define an improved system and then describe it by means of operational scenarios.

OCD section 8 above is not included. Tradeoffs analysis is more appropriate to a better specified design. The larger tradeoff issues of whether the right needs and mission have been focused on is, as stated, more in the policy context. Section 11 of this document deals with deployment issues that discusses tradeoffs only in the sense of institutional roles.

Despite the linkage of the STWDSR and WIST-DSS *requirements* to the OCD format, the OCD is *not* intended to house requirements. Requirements are associated with the System/Subsystem Specification (SSS) or the Software Requirements Specification (SRS) in the MIL-STD-498 structure. Also, interfaces are to be specified in the Interface Requirements Specification (IRS). These other documents reflect lower levels of requirements. Sections 5 and 6 the OCD are a high level of requirement matching the STWDSR process that is based on scenarios of operational decision making. The OCD format is used because it suits this more preliminary level of requirements, and operational concepts are the main tool for generating and representing the WIST-DSS. If and when the STWDSR progresses to lower level requirements, they will be expressed in corresponding SSS, SRS and IRS formats, or as modifications to user requirements, data flow and process specification formats in the National ITS Architecture. The formats to be used in system design are up to the deploying agencies.

4.0 User Needs

The potential users of the WIST-DSS are people, or automatic controllers, who use information on weather and the surface transportation system to make decisions for the sake of exercising control over some aspect of the transportation system. User needs are defined as decisions and categorized in a way to aid WIST-DSS requirements derivation.

4.1 Needs and Goals

Needs respond to transportation system goals (outcomes) and are served by the system being specified. This is illustrated in the figure below:

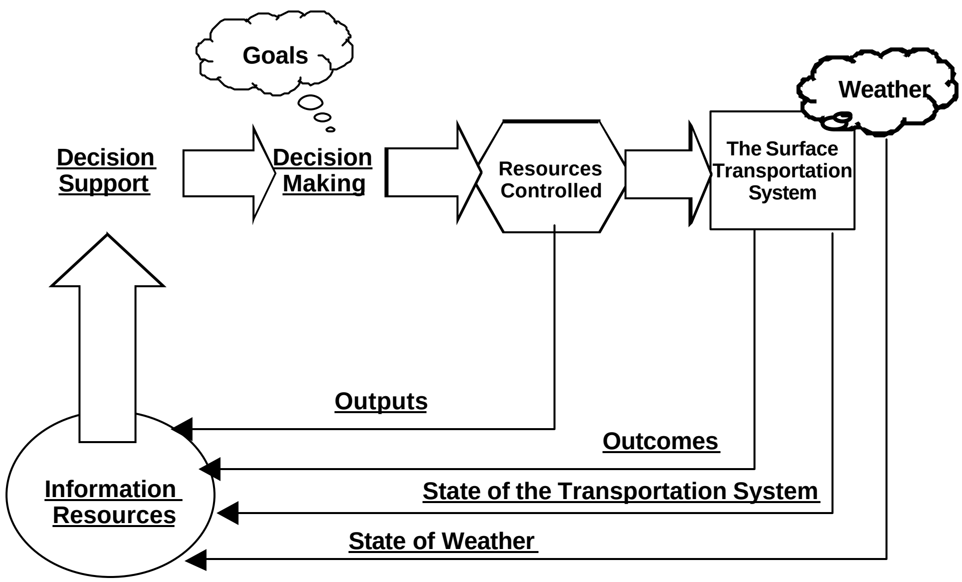


Figure 4.1: Structure of Goal-Oriented Decision Making

The focus is on the decision maker. The decision maker compares goals with the system state via decision support systems. The STWDSR focuses on decisions relating to weather and the transportation system, and initially on treatment decisions for winter road weather, meaning primarily snow and ice. The STWDSR deals with the WIST-DSS as the information system to support the treatment decisions. The decision maker usually will be a human in this case, but could also be an automatic control device.

There are inputs, outputs, outcomes, feedforwards and feedbacks in this scheme. The input is the set of goals that motivates the decision maker. Information will be defined as a resource and not the input that drives the system. The goals, translated into needs for decision support are what drive the system. Each decision maker will be in an institutional context of goals. The FHWA 1998 National Strategic Plan (January, 1998) lists five strategic goals, and objectives under the goals (see below under the needs sources). The decision maker uses information resources through a decision support system, in this case the WIST-DSS, or the RWIS in baseline.

The decision maker controls resources that act on the state of the transportation system (and usually *not* on weather). A feedback loop is created between the decision, the state of the transportation system and the information used to make the decision. In this sense, learning is built into the system. The feedbacks sometimes are divided into "evaluation" and other kinds of information. The scale concept unifies these kinds of information. Although we think of evaluation as *ex post facto* decision-performance measurement, all decision inputs act to modify decisions with respect to goals. The information may be immediate, it may be predictive, or it may be from long study of past decisions. That is not essential. In some of the decision support technologies considered, it will be seen that continuous evaluations of the uncertainty of predictive information (including weather forecasts) are built into the DSS. Expert system approaches to DSS are based on evaluations to match kinds of actions to circumstances. All DSS information resources should be considered uniformly for inclusion in the DSS.

4.2 Information Resources

User needs for *information* are defined by the decisions to meet goals. The decisions are supported by the DSS using information resources. Translating from user needs to requirements on the DSS can start by looking at the kinds of information to be processed. The information resources are divided into four types because they may have different paths in the DSS and eventually may have different requirements. Weather information is the only type not in a feedback loop with the decisions, on the assumption that no decisions affect the weather. The four types are defined as:

- State of Weather is various scales of past, current or predicted information on atmospheric attributes that affect the surface transportation system.
- State of the Transportation System is various scales of past, current or predicted information on attributes of the surface transportation system and its intermodal connections.
- Outputs are various scales of past, current or predicted information about the disposition of resources affected directly by the decisions (e.g., snow removal crews and equipment).
- Outcomes are various scales of past, current or predicted information about states of the transportation system that can be compared against goals (e.g., safety as number of crashes).

Note that the concept of "road weather", as in RWIS, really refers to attributes of the transportation system, not of weather as an atmospheric state. This relates to where the boundary of "tailoring" is drawn and how ESS data are assimilated with other NWS data. Meteorological terminology uses "surface observations" to mean attributes of the atmosphere measured by sensors some distance from ground surface, and certainly not indicative of ground temperatures (aka "skin temperature"). Most weather analysis and forecasting is concerned with the pure state variables of the atmosphere, of which there are six: the three wind vector components, pressure, temperature and humidity. These will vary considerably and locally from the bulk of the atmosphere in the "boundary layer" close to the physical surface. The boundary layer is the almost exclusive interest of surface transportation. The atmospheric state variables are of a nonequilibrium system driven, or "forced" by energy transfers. The energy source most considered in meteorology is the Sun, but the terrestrial and ocean surface is a heat reservoir that can also be important in small-scale forcing. The boundary layer conditions, with local forcing, are highly affected by physical surface characteristics and height. Terrestrial topography and physiography are called "orography" in meteorology. Orographic forcing is a term describing flow disturbance effects in the boundary layer, and is associated with heat and material (dust, water vapor) transfers. Orographic forcing becomes important only in very-high resolution weather modeling.

Merging road weather and meteorological information is a function of the DSS. However, these information flows may merge due to other institutional interests. At present the view is mostly that VAMS will tailor meteorological information into road condition information. But NWS interest in the terrestrial boundary layer at high resolution also has reason to increase. Meteorological forecasting is getting to the resolution where orographic forcing is significant. In turn such resolution is a necessary, but not sufficient condition to produce road weather. It is not sufficient because the meteorological state variables still have to be converted to the state of the transportation system. The assimilation of ESS data with atmospheric data is a related issue. The ESS is one source of subsurface temperature, and hence terrestrial heat transfer data. However, data from non-roadways (e.g., the agricultural soil temperature sensors) and water bodies is more significant meteorologically. ESS surface data (in the meteorological sense) also includes temperature, humidity and winds, but this is only an augmentation for the NWS's Automated Surface Observing System (ASOS) sites along with other surface sensing (e.g., by power utilities and the manual, cooperative observation network). The NWS also is depending more on remote sensing for observational data. There are incremental benefits from more intensive surface observation in "mesonets" for higher resolution forecasting. However, the biggest benefit of assimilation is probably for the surface community, not the NWS, in the ability to cross-check ESS data quality through statistical smoothing and error detection within a larger database. In any case, assimilation requires an open ESS database, and that is fundamental to the WIST-DSS.

The conversion of meteorological to road-weather information involves what is called "sensible" weather, or the physical effects the atmosphere produces on the road, on vehicles, and on visibility (e.g., precipitation, wind gusts, fog, etc.). Atmospheric conditions may result in "meteors" of condensed moisture falling to the ground. Precipitation and its accumulation are of great practical interest and therefore included in NWS products. This is a case where "tailoring" may just involve specifying the form of precipitation on road surfaces. This has to be based on better meteorology and better remote sensing of the atmosphere, both of interest to the NWS, as well as better characterization of the road surface.

Also of some importance is the division of outputs and outcomes. In this goal-driven system, goals are compared with outcomes in the state of the transportation system. These usually are produced by a long and not entirely controlled (e.g., weather) causal chain. It is difficult to assess the relation between specific decisions and outcomes in a spatially diffuse network. That is why “evaluation” is typically at a different scale from decisions, and requires long time series and controlled samples of data. For practical reasons, decision performance often resorts to output measures, e.g., “did the treatment crews get out in time”, or better “was the road LOS restored promptly”, both of which are short of the direct outcomes of safety, mobility, etc. Outputs used as outcome surrogates are a practical alternative, but the two need to be kept conceptually distinct.

Two other facts ought to be kept in mind with respect to the decision making scheme:

- Usually multiple decision makers are affecting the transportation system. Therefore coordinative information is also important. This may be in the form of common information resources, or may require additional decision-to-decision channels.

- Almost all decisions need information other than weather. Therefore, the WIST-DSS must consider all information resources. It may be that non-weather, and non-road-weather, information is the critical source for goal performance.

The latter point is the problem with starting with a focus on weather information in a process that is supposed to be goal-driven. It is assumed implicitly that other requirements are allocated to the ITS appropriately, and reflected by WIST-DSS interfaces according to the National ITS Architecture. Still, outcome performance of the WIST-DSS, that is the basis of validating all requirements, cannot be determined fully until those other information sources are characterized.

4.3 Needs Sources

The easiest way to move from needs to requirements is to define needs as decisions, because decisions are what need decision support. Needs as decisions carry the goals into the WIST-DSS. Although requirements are developed here only for winter road maintenance decisions, a full needs list is developed for surface transportation and contained in the Appendix. The process to define needs uses three approaches:

1. Needs follow from goals allocated to institutions and their decision makers, so needs can be derived from stated goals translated to the kinds of decisions needed to meet those goals.

2. Decision support projects (e.g., ITS projects, or the process specifications in the National ITS Architecture) directly imply the kinds of decisions that are made and that need decision support.

3. "Needs" lists exist for weather information, and often were not created within the framework used here. But these can be combed for those needs that are decisions in need of decision support.

Some source analysis and the resulting needs list is also contained in the Appendix. However, it is useful to show here the first approach applied to the FHWA goals:

Table 4.1: Needs for Weather Information Derived from the FHWA Goals

FHWA Strategic Goal		
	FHWA Objective	
		derived need (decision)
1. Mobility		
	1a. Preserve and enhance the infrastructure...with emphasis on the National Highway System (NHS)	
		Climatological information relevant to infrastructure design and maintainability. Predictive information for construction scheduling and integrity of construction materials.
	1b. Improve the operation of the highway systems and intermodal linkages to increase access	
		Current and predictive information on all weather attributes that: require highway maintenance treatment; require repair of structures or pavements; require control settings or interventions, or; affect the service and schedules of intermodal services by which connections are made.
	1c. Minimize the time needed to return highways to full service following disasters	
		Current and predictive information on weather threats to highway pavements, structures and control systems. Current and predictive information on weather attributes relevant to HAZMAT remediation. Decision support coordination with other response agencies.
2. Safety		
	2a. Reduce the number of fatalities and injuries	
		Current weather information relevant to immediate warnings on driving conditions. Predictive weather information relevant to road conditions and visibility for advanced route and schedule planning by travelers. Current and predictive information for highway maintenance to alleviate threats to driving safety and prompt repair of weather-related outages and defects. Current and predictive information to highway operators for control interventions. Current weather-related road surface and visibility conditions for enforcement of speed limits. Current and predictive weather-related road surface and visibility conditions for road closures. Archival weather data for crash analysis to devise design and control strategies.
3. Productivity		
	3a. Improve the economic efficiency of highway transportation	

		Predictive information on weather-related highway transportation times, with explicit uncertainty, for scheduling production and transportation. Predictive information on weather conditions affecting integrity of loads. Predictive information on road conditions and status for efficient route and schedule planning by travelers. Predictive information on weather related to event planning for advanced cancellation of unnecessary trips.
	3b. Improve the return on investment of the highway system	
		Weather information as cited above for efficient highway maintenance, operations and use.
4. Human and natural environment		
	4a. Enhance community and social benefits of highway transportation	
		Weather information as cited above for efficient highway maintenance, operations and use.
	4b. Improve the quality of the natural environment by reducing highway-related pollution and by protecting and enhancing ecosystems.	
		Current and predictive weather information to minimize applications of ice-treatment chemicals and grit. Current and predictive weather information to increase effectiveness and reduce dispersion of herbicides. Predictive weather information that factors into air pollution control strategies, both climatological for SIP strategies and meso/synoptic for tactical mitigations concerning traffic demand management, maintenance and construction activities. Climatological data for highway location and design that mitigates runoff, erosion and other environmental impacts of highways. Current and predictive weather information relevant to efficient response to HAZMAT spills and plumes.
5. National security		
	5a. Improve the capacity and operation of the highway system to support mobilization	
		Predictive weather-related road condition and visibility for planners of surface mobilization movements regarding weight limits, speeds, routing, scheduling and integrity of loads. Weather conditions affecting air and maritime transport connections.

In the case of winter road maintenance, not all requirements deriving from the goals will apply to the WIST-DSS. There may be operational practice, institutional organization, training, other ITS improvements, non-ITS improvements that should be pursued to meet the goals. These will be identified throughout the process, as part of the "outer spiral", leading to the STWDSR V2.0

4.4 Decision Maker Categories

The list of needs in the Appendix was created by defining the list of all possible surface transportation decision makers, applying scale categories, and then listing the decisions that each decision maker must make within a scale category. The list of decision makers emerges from considering all the previous needs compilations. The list is based primarily on working back from outcomes, in terms of the kinds of resources controlled. For instance a traveler controls trip itineraries, and a maintenance manager controls road treatment resources. The categorization of decision makers has the unfortunate effect of partitioning consideration of the WIST-DSS more by outputs than by the kinds of decision support needed. However, the STWDSR is based on operational scenarios that do relate to kinds of outputs. Based on consideration of all needs documentation, the following hierarchical list of decision makers was created:

Index	Decision Makers
1.0	Infrastructure Operators
1.1	Highway maintainer (winter)
1.2	Highway maintainer (other)
1.3	Traffic manager
1.4	Information system manager
1.5	Traffic device controllers
1.6	RWIS Maintainer
1.7	Rail maintainer
1.8	Waterways operator
2.0	Infrastructure Builder/Planner
2.1	Transportation designer
2.2	Transportation builder
2.3	Transportation planner
2.4	Transportation evaluator
3.0	Information service provider
4.0	Fleet Operators
4.1	Transit-fixed
4.2	Transit-demand responsive
4.3	School bus/district manager
4.4	Commercial fleet dispatcher
4.5	Railway dispatcher
4.6	Barge dispatcher
4.7	Military movement managers
4.8	Hazardous/special cargo managers
5.0	Vehicle operators
5.1	Highway drivers
5.2	Vehicle control system
5.3	Train engineers
5.4	Barge and boat navigators
6.0	Travelers
6.1	Traveler awaiters
6.2	Personal traveler/recreational
6.3	Personal traveler/commuter
6.4	Personal traveler/business
6.5	Personal traveler/discretionary
7.0	Incident/emergency response
7.1	Emergency medical dispatcher (PSAP)
7.2	Public safety dispatcher
7.3	Infrastructure incident dispatcher
7.4	Disaster evacuation manager
7.5	Disaster response manager
7.6	Search and rescue manager
7.7	Insurer
8.0	Activity managers
8.1	Special event planner
8.2	Recreation managers

8.3	Retail managers
8.4	Production manager-industrial
8.5	Production manager-agricultural
8.6	Brokerage and futures
8.7	Power system managers

This list can be used to organize further operational analyses and requirements. This project is focused on decision maker type 1.1, and must consider coordination with all other types via the ITS.

4.5 The Scale Concept

The Weather Team White Paper articulated the scale concept [pp. 31 et. seq.]. With user type, the scale concept is the other primary categorization of needs.

The physics of weather determines certain space-time relations for weather phenomena: Spatially small weather events develop and dissipate quickly. These include severe convective storms (tornadoes, thunderstorms, hail storms) and other cases of large changes (gradients) in weather attributes over small spatial volumes. These cases have limited time horizons of reliable predictability. Models and observational assimilation tend to smooth extreme variations, or if they do not are subject to instabilities and spurious indications. It is for this reason that forecasts tend to have the poorest performance for the most extreme, and rarest events. Attempts to forecast localized storms require more intensive observational data to support finer model resolution, but the models must be updated more frequently, cover smaller regions and have more limited time horizons. This is the meso scale. At the smallest scale (micro scale), minimal processing of direct observational information is necessary (e.g., wind shear and micro burst detection at airports or highway fog detection and warning).

Persistent systems, with longer time horizons of reliable predictability are larger in spatial area (e.g., large air masses and their frontal weather). This is the synoptic scale, typically forecast twice a day, for national regions and out to horizons of days. Beyond that is the seasonal or climatic scale. These longer horizon forecasts are coupled with coarser spatial resolution, and give weather attributes as averages for large areas. The physics of weather, coupled with information collecting and processing limitations determines that spatial localization and accuracy of weather attributes go together with smaller analysis regions and shorter predictive horizons, and conversely. Pasting together (or “mosaicking”) several small regions to cover a larger one requires reconciling differences at the regional boundaries. A similar case occurs when meso scale models are bounded by synoptic scale models results, as is typical for locally run meso scale models nested within NWS forecasts of larger scale (or the NWS Nested Grid Model). The result tends to be a smoothing of results toward averages, and a loss of what may be real local variation, or just anomalous results from unstable models. Also, since weather can be characterized as “moving” from larger domains to smaller ones over time, the longer horizons of small scale forecasts are also spoken of as tending to the coarser boundary aggregates. This kind of smoothing is also the case for point observations when assimilated into grids representing large spatial areas. Consistency imposed on the grids by previous forecasts and nearby observations can identify observations that are faulty, but also suppresses what may be real variations local to only one sensor. The idea of scale is therefore a fundamental attribute of weather information: What is needed to get it and how far it is reliable.

From the decision perspective, all decisions are based on past information in order to affect future resource controls and system states. Resource deployment also has a “physics” that defines characteristic space and time scales. For instance, crews can be called-up and dispatched to their beats only in time horizons related to crew scheduling, commuting time, equipment speed and beat geography. When weather combines with the transportation system, space-time scales of outcome response are imposed. For instance, snowfall rate and highway network size, relative to the maintenance crew resource, determine how quickly a level of service can be achieved.

How resources respond and how they can be scheduled are what set the time lead needed for decisions and hence the predictive horizon of decision support information. The area over which resources are controlled (i.e., a highway network subject to considerable climatic variation) determines the spatial region and resolution of the information. Efficiency considerations on resource use (e.g.,the cost of crews and materials) determine how much accuracy of the information can be afforded, subject to the scale limits of weather information. While this can be a very complicated problem for benefit-cost analysis, in practice there is a prevalent quality of weather information at each scale. It is a question of assuring that a decision maker uses the best available information at the appropriate scale. Stovepiping, that prevents integrated access to information across the scales, may be the biggest barrier to this. The improvement of weather information at any scale is a function of technical advance in weather physics and computer power, coupled with investment in observational data. The physics and computer advances tend to be exploited fairly rapidly in the meteorological field. However, better benefit documentation in surface transportation can lead to improvements via more observational investment. In any case, technology applied to mobile sensors or remote sensing should be exploited.

Scale remains the primary parameter for matching information to decisions for greatest efficiency. Anything that is a barrier to matching decision and information scales will reduce efficiency. This also applies to decisions that do not respond with appropriate risk considerations to the uncertainty inherent at each scale, or that try to stretch information from smaller to larger scales without considering the real loss of reliability. This is common when forecast grids are arbitrarily interpolated to finer resolution, where point observations are stretched to large areas, or where observations are extrapolated too far into the future. Sometimes the data just are not there, but it is essential that DSS provide the next best source.

There is a continuum of space-time scale. However, weather information has a conventional set of discrete scale categories, defined as follows (with some liberties given the imprecision of the scale category boundaries) and matched to decision-scale regimes:

- Micro scale: sub-hour (minutes) time horizons and local areas (<few kilometers). Typifies

severe convective events (e.g., micro-bursts) and safety-critical controls (e.g., vehicle operation) or local adaptations of treatments (e.g., speed- and surface-temperature controlled chemical applications).

- Meso scale: approx. 1-12 hour time horizons and few-to-hundreds of kilometers areas. Typifies convective storms and moderately-high gradients of effects (e.g., snow bands with large spatial variation). Includes many operational decisions of interest in transportation (e.g., resource dispatching).

- Synoptic scale: 12 hour-week(s) time horizons and continental areas. Typifies large air masses and frontal weather. Transportation-operational decisions tend to overlap between synoptic and meso scale, but decisions for surface transportation in this scale generally concern response-preparation or travel planning.

- Climatic scale: beyond weeks in time horizon and up to global (and extraterrestrial) area. Surface transportation decisions in this scale typically concern planning of fixed assets and facilities, advanced purchasing and advanced travel planning.

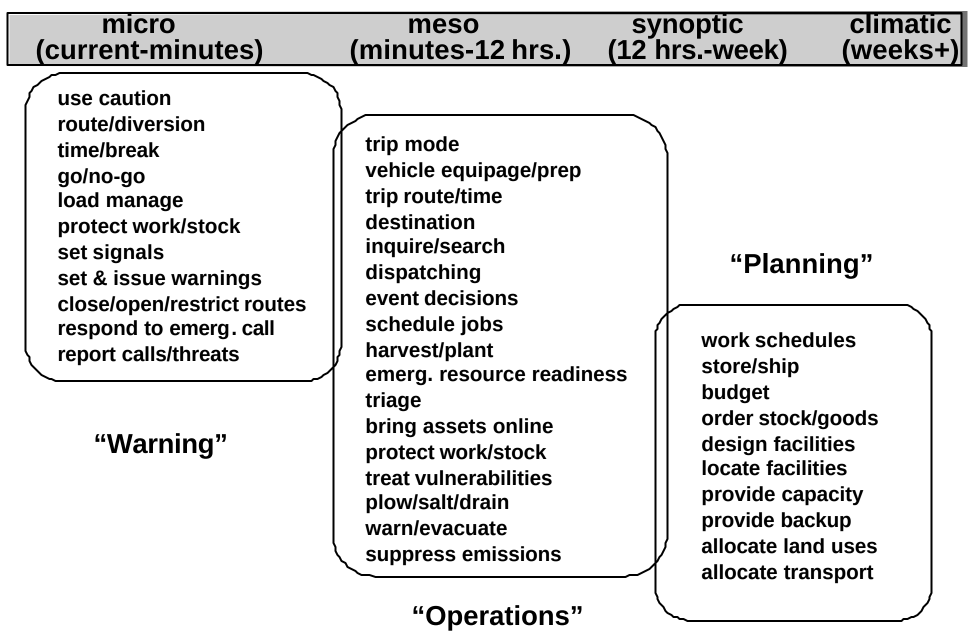
While the space-time rule of longer time and larger area holds, there are variations on how the dimensions can be mixed. For instance, climatic scale information can refer to spatially-local points (e.g., the freezing climatology of a road on bridge structure as opposed to on soil in a cut, or fog obscuration on bridges over rivers). Nonetheless, climatic forecasts are specified by averaging long time series of information (long horizon). This time series cannot determine a condition at a specific time. Climatological models use statistical relations from long time series to estimate variations around local (micro-scale) observations. For instance, "thermal mapping" is used to extend point ESS measurements over route segments. Model Output Statistics (MOS) products result from regression relations between sets of model forecasts and their validated results, and typically are presented as the ranges (e.g., a standard deviation of temperature) that may result when the model gives a point prediction. These kinds of products carry with them the statistical risk of the model. Observational assimilation does the same for point observations, by giving a risk parameter (like a standard deviation range) to an observation based on how much it disagrees with its surrounding observations and other model forecasts.

The Weather Team White Paper defined three categories of decision scale: warning (micro), operations (meso/synoptic) and planning (climatic). For transportation decisions it is typical that the micro- and climatic scales are relatively distinct while the meso and synoptic scales overlap. The synoptic scale has conventionally been defined by a twice-daily observational cycle and forecast model initialization. The advent of continuous remote sensing has blurred this distinction, and there is now much more variety in the regional scope, resolution, time cycle and time horizon of numerical modeling.

A lot of surface transportation decision support has focused on numerical atmospheric modeling to improve the range of scale choices down from the synoptic to the meso scale. This has diverted attention from filling the micro-to-meso scale gap by better processing of observations, especially from remote sensing (radar and satellite). There are cases where a finer scale is misused for large scale decisions (the typical "look out the window" for regional dispatching), or where numerical models are used at near horizons and very high resolution in place of micro scale observations, or where the models themselves mismatch resolution, horizon and update cycles. In any case, the risk parameter associated with scale will be the clue as to how well the match is made.

The figure below indicates some of the kinds of decisions in each of scale range:

Figure 4.2: Meteorological Scales and Categories of Decisions



4.6 The Matrix of User Decisions and Scale

Needs as decisions and decisions categorized by decision maker and scale determine the structure of a matrix to list needs. Decisions are the cell entries with scale as the column headers and decision maker types as the row headers. The decision derivation was also helped by considering the generic kinds of actions possible in transportation decision making with respect to weather:

- Treat: To act upon transportation facilities in a way to mitigate the effects of weather on the outcome goals: Examples are ice treatment, snow removal, snow fence installation, standing-water pumping, flood control.

- Respond: To mitigate a negative effect of weather on a transportation outcome when it has occurred. Examples are repair of storm damage, restoration of power/communication circuits, search and rescue.

- Cope: To alter transportation activities because weather has limited options or reduced service on the transportation system. Examples are rescheduling activities, changing routes, changing destinations.

- Seek: There are cases where weather creates opportunities on the transportation system. Examples are recreational trips that pursue sports like sailing, surfing, skiing or skating. Weather and road conditions may be sought for research, treatment or response preparation. While this is a distinct use of weather information, it can be treated as a precursor to the other activities.

The structure of the needs table in the appendix therefore is as shown below:

	Scale		
Decision Maker	*Micro (Warning)*	*Meso/Synoptic (Operational)*	*Synoptic/Climatic (Planning)*
(hierarchical list)	treat: cope: respond: seek:	treat: cope: respond: seek:	treat: cope: respond: seek:

The full matrix is in the Appendix, but the matrix portion for winter road maintenance is shown below:

		Micro-Scale	Meso/Synoptic	Synoptic/Climatic
D M #	Need#	Warning	Operational	Planning
1.0	Infrastructure Operators			
1.1	Highway maintainer (winter)			
	1.1	control spreader application		
	1.2	control plow		
	1.3	control static (bridge) deicer		
	1.4	observe/report		
	1.5	navigate spreader/plow truck		
	2.1		detect/monitor weather event	
	2.2		schedule crews (split shifts)	
	2.3		prepare equipment	
	2.4		mix/load/replenish expendables	
	2.5		dispatch crews	
	2.6		program treatment control	
	2.7		repair/adjust equipment	
	2.8		coordinate (e.g., traffic mgt.)	
	2.9		request resource aid	
	2.10		dispatch damage repair	
	3.1			devise response plan
	3.2			hire staff
	3.3			train staff
	3.4			buy equipment/services
	3.5			stock stores
	3.6			budget
	3.7			schedule seasonal tasks
	3.8			calibrate treatment controls

The table contains indices for both decision-maker type and the decision by scale. All entries in the matrix can be specified by the index with format (T.t.S.d) where (T.t) is the major and minor decision-maker Type index. S is the scale index (1 = micro/warning, 2 = meso/synoptic/ operational, and 3 = climatic/planning). The (d) index is a sequential number for the particular decision. The table currently contains 44 decision maker types and 423 needs (decisions).

Many kinds of decisions are generic over decision maker types. Identifying clusters of decision types should guide further requirements analyses. Transportation system managers (as opposed to vehicle drivers), maintainers (possibly integrated with other incident respondents), fleet dispatchers and travelers (including vehicle drivers) are the main categories that could be considered.

For winter road maintenance, the decisions are almost all of the treatment type, but span the scales. It is intended that each scale category will support relatively distinct WIST-DSS approaches, but integration must always be considered. The general approaches indicated are:

- Immediate control of treatment applications combined with truck control (warning/micro scale);
- The scheduling, preparation and dispatching of treatment resources (operational/meso-synoptic scale);
- Decisions on staffing, facilities, equipment fleets, and material inventories that determine what treatment activity is feasible at any time (planning/climatic scale).

Information clearly should be integrated across these categories. For instance, onsite treatment observations are the basis for larger scale decisions and ultimately the source of climatic-scale information. Planning must be based on performance that is a function of both micro-scale treatment and the meso-synoptic scale management. However, the DSS in a vehicle (or for a fixed chemical spray system or warning system) will be different in many ways from a maintenance-office system, or a resource planning system.

There is also an issue of what outcomes become dominant goals at what scales, rightly or wrongly. A very local focus tends to promote excessive chemical application and scraping when those resources may need to be allocated more strategically. At the budgeting level (climatic), if there is too little investment in treatment resources, the outcome costs concerning crashes and mobility (almost certainly the major cost components) increase severely. Yet budgeting tends to magnify the direct treatment costs and limits treatment capability (there may also be risk-bias effects here given climate variability). Climatic information (including its uncertainty) could do much in matching investments to weather threats on a seasonal aggregate, potentially with great outcome savings. Otherwise, coordination (borrowing resources, managing traffic under weather threats) and efficiency in treatment at the operational and micro-scales must cope with resource constraints. These examples suggest how integration must occur across the hierarchy of scales, even if separate decision makers are making different decisions with different scales of information. This kind of hierarchical decision system adds new dimensions to DSS design.

5.0 Scope of the WIST-DSS

This section starts the format of the Operational Concept Description (OCD) as specified in MIL-STD-498 and the IEEE/EIA Software Standards. The scope of the system subject to the requirements allocation is described relative to current and intended decision-making practices.

5.1 Identification of the System

The system to be specified is called the Weather Information for Surface Transportation decision Support System (WIST-DSS). This is a hypothetical system on which state-of-the-art requirements will be imposed to improve surface transportation system outcomes as affected by weather. The WIST-DSS will improve a baseline system referred to as the Road Weather Information System (RWIS).

The requirements allocated to the WIST-DSS will meet needs for making weather-related travel and transportation-operation decisions in the surface transportation system and its intermodal connections. The focus of this document is on road-winter-maintenance decision makers, primarily in their role of treating highway facilities to mitigate effects of weather, in order to improve highway pavement levels of service (LOS) and thereby to enhance all goals of all modes of highway transportation. However, all surface-transportation decision maker needs are considered in order to expose integration requirements for the WIST-DSS as it is deployed within the Intelligent Transportation System (ITS).

The WIST-DSS will be deployed by system developers, primarily in the private sector, for customers in the private and public sectors. The Federal Highway Administration (FHWA) is sponsoring WIST-DSS requirements definition but will not be a purchaser or operator of the WIST-DSS. WIST-DSS requirements will not be federally mandated other than through legislation that currently requires use of critical ITS standards and the National ITS Architecture for ITS integration[4]. The WIST-DSS requirements are intended to stimulate customer demand for improved information systems, and promote applications of state-of-the-art technology by system builders.

5.2 System Overview

The WIST-DSS was established conceptually by the FHWA Weather Team[5]. This was based on a prevalent desire of state departments of transportation (DOT) and other surface transportation interests

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[4]The Transportation Equity Act for the 21st Century (TEA-21), Sec. 5206(e). Revisions to 23 CFR forthcoming.

[5] Weather Information for Surface Transportation, FHWA, May 15, 1998.

for better information on weather as it impacted surface transportation, mitigated by decisions that could treat, respond to or cope with those impacts. The WIST-DSS concepts build on previous research for the RWIS[6] and development of operational practices such as anti-icing/pretreatment[7].

Weather information comes from the National Weather Service (NWS), private value added meteorological services (VAMS) and observations made by specialized observing systems (Environmental Sensor Stations, ESS) operated by the DOTs and others. Preliminary analysis shows that:

- There are inherent limits on the quality of predictive weather information;

- There is an overload of weather information that is not being utilized effectively by decision makers, and;

- ESS deployment and information sharing is limited.

The response to facts by the weather team was to recommend:

1. Emphasis on the scale concept of decisions and weather information that coupled decision needs with types and limits of weather information;

2. Emphasis on the filtering, fusion and presentation of weather, and related transportation information, in a decision support system, and;

3. Emphasis on cross-jurisdictional system integration under the National ITS Architecture and ITS standards.

Appropriate institutional roles must be considered. The FHWA is concerned with meeting its strategic goals for surface transportation. The mission of providing common weather information is allocated to the NWS. For the NWS and other federal agencies, an important set of non-profit national laboratories has been established who make important contributions to weather-related decision support systems. Transportation facilities including the RWIS, and in the future the WIST-DSS, are built by the private sector for public or private operators, often with federal-aid funding. The FHWA

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[6] For instance, Road Weather Information Systems, Strategic Highway Research Program, National Research Council, SHRP-H-350, 1993.

[7] For instance, Manual of Practice for an Effective Anti-Icing Program, FHWA-RD-95-202, June 1996.

will not be concerned with production of weather information or funding weather information facilities in any way that infringes on the NWS mission. The FHWA has funding and regulatory roles with respect to surface transportation, but is not an operator of surface transportation. The role with respect to the WIST-DSS is strictly to promote research and deployment by local agencies in partnership with the private sector and non-profit system developers, to promote best management practices and to make users aware of best available technologies.

The WIST-DSS concept originated as part of the ITS. The ITS will deliver information, including weather information, to decision makers in the surface transportation system. The National ITS Architecture provides the integrating framework for the WIST-DSS, along with standards to promote an open system, namely one that uses published and uniform interface standards to allow information interchange and to facilitate system evolution under technological and other changes.

A WIST-DSS is not defined as a discrete subsystem of the ITS. WIST-DSS requirements will be embodied in the deployment of various user services, subsystems, processes and data flows described in the National ITS Architecture. It will receive weather information from systems outside of the ITS, especially the NWS, and from within the ITS through the ESS. The Information Service Provider (ISP) subsystem of the ITS processes and disseminates information for third-party use. The WIST-DSS requirements will support what the National ITS Architecture intends: local deployments within a systems integration strategy that embody adaptations to local needs, best management practices and best available technologies.

As embedded in the ITS, the WIST-DSS provides multi-modal services through many of the user services, and will integrate with information systems for non-surface modes. In this case, the FHWA includes highway-transit and non-vehicular highway transportation, and intends to consider needs and requirements other than for highway transportation. However, as a matter of practicality, the initial focus is on winter highway maintenance. This affects all highway, and inter-modal, transportation and is judged to have the most potential benefit from the WIST-DSS. It is believed that many requirements on behalf of winter highway maintenance will readily be apply to other decision makers as well, but that eventually all needs must be analyzed fully.

5.3 System Context

The WIST-DSS can be bounded by its context, and must be described in a hierarchy of detail-levels. Only the highest levels of description exist now, and further levels will developed along with the requirements. A context diagram, based on the IDEF systems representation format, and known as the level-0 diagram in that format, is shown below:

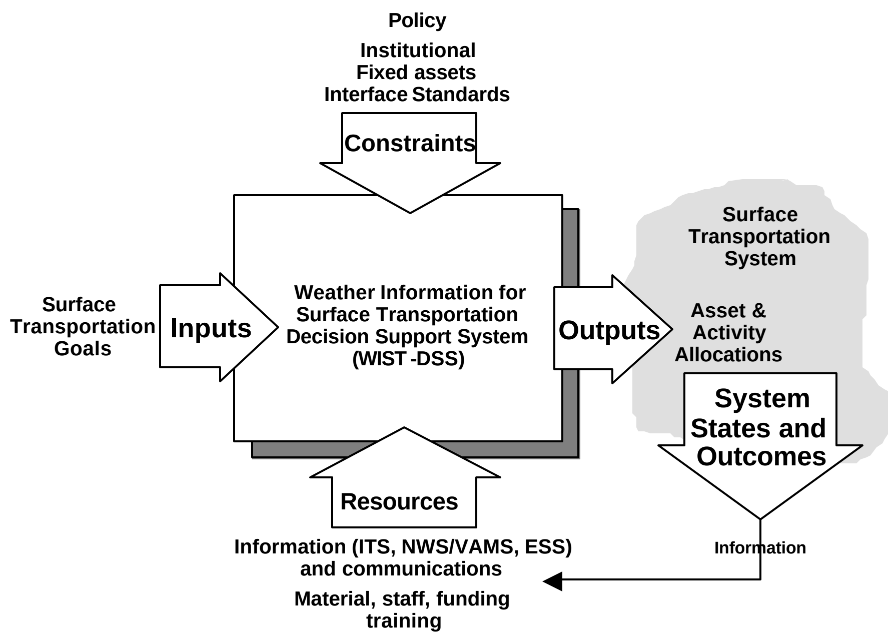

Figure 5.1: WIST-DSS Context Diagram

The context diagram defines the inputs to be the surface transportation performance goals that motivate decisions. The outputs are controls applied by decisions on asset and activity allocations in the surface transportation system. The WIST-DSS connects the inputs and outputs via an informational system for decision support.

Resources and constraints surround the WIST-DSS and its operation. The WIST-DSS is specified and operates within constraints of budgets, the decision-making power allocated to people and other systems institutionally, and the interfaces to other systems especially as defined by the National ITS Architecture and its standards. The resources available include information on the state and outcomes of the transportation system, the state of the weather, material, staffing, funding and training. The WIST-DSS is not an original source of information on weather or the transportation system, but is concerned with the filtering, fusing, processing and presentation of external information for decision support. This does, however, reflect onto requirements for information quality and dissemination at the WIST-DSS interfaces. In particular, the NWS is outside of the WIST-DSS, as are road-condition observation systems (ESS), and other ITS sensors and information processing subsystems. Clearly outside of the WIST-DSS are the assets controlled by decisions, that are typically part of the surface transportation system itself. Outputs and outcomes are measured in the transportation system and become information resources.

The National ITS Architecture also uses a layering decomposition. This includes the physical transportation layer, a communications layer and the ITS (information processing) layer. The context diagram above maps the transportation system and its outcomes to the transportation layer, and the WIST-DSS to part of the ITS layer. Not to be overlooked is the communications infrastructure that is a resource to the ITS as the conduit for the information resources.

5.4 Requirements Allocation and Validation

The figure below shows an alteration of the context diagram to detail where requirements will be allocated by the STWDSR and how they are validated.

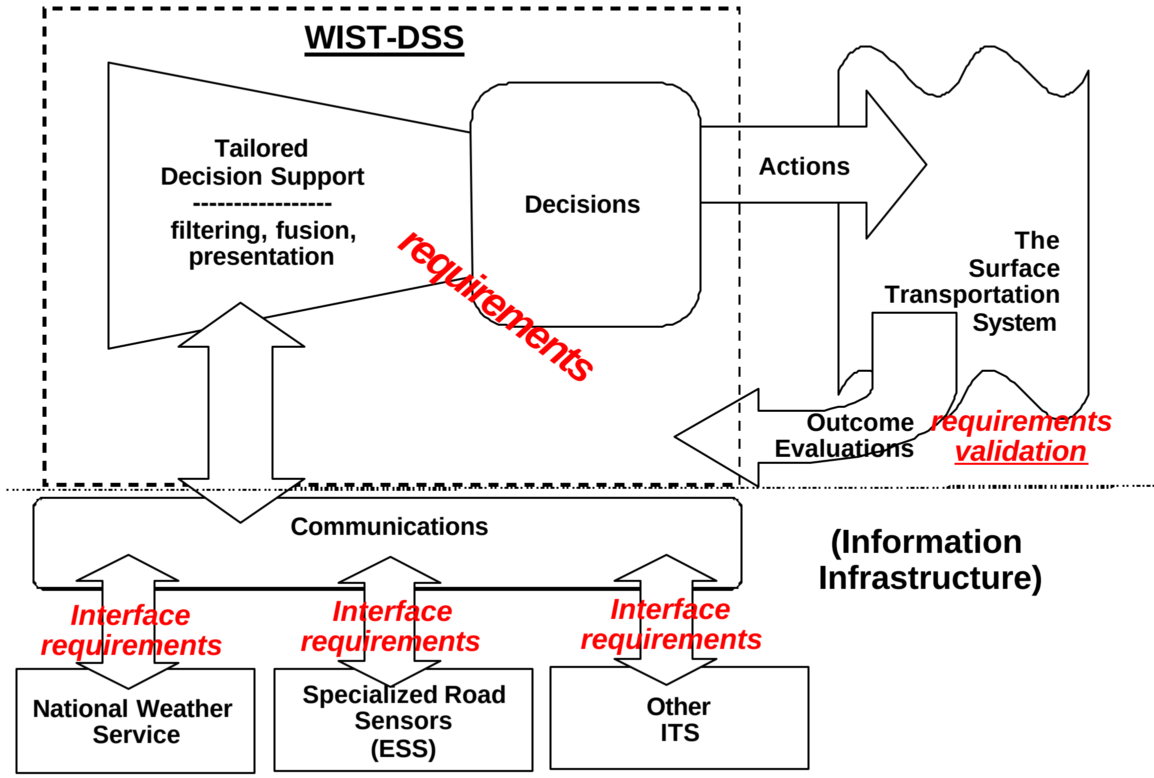

Figure 5.2: WIST-DSS Diagram with Requirements Foci

Three types of information resource are shown that will interface with the DSS, via a communications layer that is assumed to be available: the NWS products (or equivalent VAMS products), the specialized road sensor information (either stationary or vehicle-probe) from ESS, and all the other information flows from the ITS to the WIST-DSS. These external information flows and communications facilities will also be called the information infrastructure, emphasizing that it is a foundation that supports many things besides the particular applications in the WIST-DSS.

In moving from needs to requirements, the requirements will be allocated to four foci:

1. All the components within the WIST-DSS. This may include prescriptions for decision making related to the prescriptions for the DSS since decisions are likely to change in detail with new decision support. Since decisions are needs, this also represents the iteration in the spiral process between needs and requirements on the DSS.

2. Interfaces with the NWS. This is a particular issue in the inter-federal coordination between FHWA and the NWS that is being conducted through the Office of the Federal Coordinator for Meteorology (OFCM).

3. Interfaces with the ESS. The ESS standard is at present a specification of most of the communications protocol and sensor-quality attributes that are necessary. However, there are still significant issues concerning communication of information beyond the sensor-to-center link, allocation of sensors over the transportation system and the assimilation of the specialized observational data with other weather observations.

4. Procedural arrangements will be made to feed requirements back to the National ITS Architecture as required by interface considerations. These include coordination with user needs definition through the rural ITS research activity, coordination with the ITS America WIATF architecture task force and other efforts through the ITS Architecture Team.

All requirements must be validated with respect to transportation system outcomes, although typically many output surrogates are used in evaluation[8]. This is an integral part of the requirements process. Requirements initially will be formulated from expected outcome improvements. Validation will take a long time and must rely on future deployments and operational tests. It is imperative that the WIST-DSS development program coordinate with ITS and other evaluation efforts.

Defining the WIST-DSS with external interface to the NWS also differentiates the common weather information infrastructure from “tailoring”. Tailoring within the WIST-DSS will be the responsibility of users, VAMS and system developers. Requirements of the NWS by the WIST-DSS will focus on the complementary relation between general weather information and decision support tailoring. It is expected that: 1) The WIST-DSS will make use of general NWS product advances; 2) Requirements will address interfaces with NWS systems to obtain those products, and; 3) There is relatively little scope for changes in NWS products based *solely* on WIST-DSS requirements. However the FHWA, as the federal agency representing much of surface transportation, is interested in identifying those NWS improvements it can advocate, and possibly add resources to at the federal level, with common

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[8] See the evaluation structure for the Foretell operational test. Evaluation of the Foretell Consortium Operational Test: Evaluation Plan, Battelle, October 1998.

benefits to users generally.

6.0 Current Practices and Context

This section establishes current practices in the use of weather information for surface transportation, focusing on winter highway maintenance. The baseline information system will be defined as the RWIS. The operational context, and the ITS and NWS system contexts (interfaces) are also described.

6.1 Background on the RWIS

The Road Weather Information System (RWIS) has evolved as the set of road condition sensors and weather information services used to support decisions regarding winter highway maintenance and other highway decisions. There has been no strict definition of the term or bounding of the included system. The phrase was promoted through the title of the 1993 Strategic Highway Research Program (SHRP) report[9]. At the time, a system of road condition sensors and related information processing was characterized as being the state of the practice in Europe for decision support to "roadmasters". European roadmasters typically integrate maintenance and traffic management, more so than in the United States. The RWIS will be defined as all weather information services currently providing decision support to highway users and operators. This includes four kinds of services:

1. The ESS for direct road condition observation (often called RWIS by themselves);

2. Further processing of sensor data for road condition prediction;

3. Supply of general atmospheric condition forecasts and advisories by VAMS (sometimes considered outside of RWIS), and;

4. Dissemination of various weather information products by Information Service Providers (ISPs).

These services are bundled in various ways, with some vendors providing full integration, and in that sense performing functions similar to the NWS but tailored for specified markets.

Beginning in the 1980's, pretreatment techniques were promoted for applying chemicals before icing in order to prevent surface freezing and bonding of snowfall to the road surface through an ice layer. Also, sensitivity to the vehicular and environmental damage of salt applications made control of chemical applications more critical. As a prospective, and carefully-timed treatment strategy, pretreatment requires better road condition prediction. When it became possible to detect and

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[9] Road Weather Information Systems, ibid.

proactively treat black-ice conditions, the expectations of intervention for safety were also increased. As a result, there has rapidly developed a self-reinforcing relationship between better road condition information and more proactive, yet efficient, road treatment policies.

In the meantime, the ITS was also becoming formalized as a system concept and a program of the USDOT. The first Intelligent Vehicle-Highway System (IVHS) strategic plan was published in 1992[10], the first national ITS program plan in 1995[11] and articulation of the Operation TimeSaver/Intelligent Transportation Infrastructure goals in 1996[12]. These marked a progression from an "automated highway"concept to a broad-service transportation information system. This encompassed weather information, especially as part of Advanced Traveler Information System (ATIS) and Advanced Traffic Management System (ATMS). However, the ITS program had been focused on urban areas and their congestion problems, and away from highway maintenance needs. The rural ITS program was initiated in late 1995, but has since emphasized highway maintenance and weather information as constituent needs[13]. The rural ITS program has been closely allied with the FHWA Weather Team, although weather information is <u>not</u> partitioned between rural and urban domains.

The National ITS Architecture integrates weather information flows into the ITS, but the rural ITS program is only now fully articulating weather information needs (an Environmental/Weather Information Management user service is being drafted). In the meantime, most RWIS deployments have been by state DOTs on behalf of highway maintenance needs and through subscription services for railroads and the trucking industry. General-public traveler information has always been provided by ISPs in various ways, but only within the last three years have RWIS capabilities for specialized road-condition information been extended to a general-traveler market. This has been by the Advanced Transportation Weather Information System (ATWIS) in the Dakotas and Minnesota (an ITS earmark program) followed by the Foretell program in Iowa, Missouri and Wisconsin (a Weather Team and rural ITS operational test).

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[10] Strategic Plan for Intelligent Vehicle-Highway Systems in the United States, IVHS America, May 20, 1992.

[11] National ITS Program Plan, ITS America, March 1995.

[12] Operation TimeSaver–Building the Intelligent Transportation Infrastructure, USDOT (publication packet distributed January, 1996).

[13] Advanced Rural Transportation Systems (ARTS) Strategic Plan, USDOT, August, 1997, and the ARTS Program Plan, USDOT, August, 1997.

The RWIS sensor systems will be called ESS[14] consistent with the ITS-developed standard[15]. Fixed-observation equipment collects near-surface atmospheric data (typically winds, temperature, humidity, visibility and precipitation) as well as temperature, chemical concentrations and standing precipitation or ice on the road surface, and temperature profiles below the road surface. The ESS standard also covers the ESS-to-center information exchange and physical-layer protocols for mobile sensors. There are technical capabilities for extended-segment sensors (i.e., fiber optic cable used as horizontal temperature profilers) but these are rarely deployed compared to the fixed or mobile point sensors. ESS information exchanges are being introduced into ITS center-to-center message sets and data dictionaries. Remote sensing (by radar and satellite) are not included within the ESS but are part of the observational infrastructure of the NWS, conveyed by ISPs into the RWIS, especially by the Internet and satellite broadcast systems.

The ESS are provided by a number of private vendors, many drawing on European development backgrounds. Remote station sites may be associated with multiple sensors in a local area, homed to remote processing units (RPUs) that are polled or send data to central processing units (CPUs) for display, processing and archiving (the ESS-to-center link in the ITS architecture). Vendors typically provide some kind of predictive processing of the data as well (qualifying them as VAMS), and this tends to promote proprietary data ownership for the marketable value-added products.

Video surveillance has become significant as an adjunct to the RWIS sensor sites. Video surveillance on urban freeways has become common with ATMS deployment of traffic management systems, but is not usually homed directly to maintenance offices. Video can indicate visibility conditions relative to calibrated landmarks, give qualitative indications of weather and road conditions, and give snow or ice depths against visual gauges. There can be independent utility to video monitoring for weather information, as at critical mountain passes or bridge structures. However, it will typically be used only when justified for other reasons like traffic monitoring, and its use in maintenance is thereby inhibited unless the traffic management and maintenance functions are integrated.

Private vendors as VAMS use NWS products and ESS data to produce forecast products tailored to RWIS users. Products include both weather and road condition predictions. The weather predictions of the VAMS may provide higher resolution, through their own meso-scale forecasts initialized with NWS data, can offer better experience with regional climatology, and pay more attention to the sensible weather of surface interest (especially precipitation and freezing).

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[14] Overview of current ESS in Environmental Sensor Systems for Safe Traffic Operations, by Castle Rock Consultants, published by FHWA as FHWA-RD-95-073, October, 1995.

[15] National Transportation Communications for ITS Protocol (NTCIP) Object Definitions for Environmental Sensor Stations (ESS), AASHTO/ITE/NEMA, Draft version 98.01.12, September 28, 1998.

6.2 Operational Policies and Constraints

The primary policies and constraints affecting RWIS are proprietariness, security, liability, performance, system-capacity allocation, financing and the division of public and private sector roles. These need to be considered for policy action as the result of analysis of RWIS deficiencies.

Proprietariness

Under private ownership, proprietary rights are necessary to secure revenues against costs of services. This is beneficial in supporting a private market where goods and services are divisible and can be adapted according to demand. Proprietariness is extended to data, information systems and data processing techniques. This includes all aspects of the RWIS except for the information supplied directly from the NWS or within public agencies like DOTs. Specifically:

- ESS data are subject to contractual agreements on data usage. In many cases, no use is allowed beyond the immediate customer for the data (e.g., a DOT). This prevents sharing of the data with third parties (e.g., the NWS or neighboring states) or applying common assimilation processing to the data.

- Information systems use proprietary protocols, are not open, and are "stovepiped" (components are bundled to prevent substitution of components or integration with other systems). The ESS standard and contractual specifications based on the open ITS architecture are changing this. However ESS is not yet a "critical" standard required for federal aid funding, and some of the proprietary data protocols for RWIS sensor information are being published as de facto standards. Given a mix of standards and legacy stovepiped systems, it will not be possible to achieve an open system for some time.

- Data processing algorithms, especially those used for road condition forecasting, are proprietary. This reflects the competitive market for such products, but inhibits free intellectual exchange to advance the state of the art.

Federal policy encourages proprietary rights to develop self-sustaining ITS services and to encourage private sector participation in technical development. This includes products developed with federal-aid funding. This in turn creates conflicts between the desire of the federal government to sponsor specified research projects to advance the state of the art, and private interests protecting existing-product viability.

Security

The rise of networked data communications, especially in the form of the Internet, has increased concerns about partitioning internal information systems from external connectivity. This is achieved by “firewalls”, access security such as encryption or passwords, or simply not participating in network connectivity. Where public connectivity is allowed, there is a concern about “hacking” that can disrupt external services.

Firewalls are architectural means, and encryption/passwords are operational or application means of allowing the creation of public and private partitions in agency information systems. Firewalls are typically more secure than passwords. DOTs typically are concerned about the partition of information since there is a contention between releasing information into the ITS that is valuable to transportation users (e.g., road condition, work zone, incident and traffic flow information) versus information that is internally used but is not to be released for various reasons (e.g., uncertified information, personnel records, litigation-sensitivity, etc.). Concerns about data security, especially when implemented via firewalls or non-networking tends to suppress data sharing and use.

The principle here is that each institution must maintain the ability to partition its information for internal or external use. Effective firewall, encryption and password technology must be available to enforce this, in preference to creating systems that are simply physically disconnected from the ITS. However, this does put the burden of proof on system developers to demonstrate that there is benefit, and minimal liability, in making public certain kinds of information. Most at issue is the sharing of local road-condition observations, that are a resource as input to area-wide models, across jurisdictional lines, and as traveler information.

Liability

The concern has been expressed by DOTs about the publication of information that may lead to decisions or actions for which the source of information is liable. This includes RWIS information, and in particular information that may give a false-negative on hazardous road conditions. This becomes a significant factor in the partitioning of information, and hence on the integration of systems requiring certain kinds of information.

Every agency must retain the ability to protect itself from excessive liability. Only case law can define the ambiguous limits of liability. The relevant case law concerns sovereign immunity (generally a limitation on liability for public actions) versus the responsibility of public agencies for feasible and timely actions to protect public safety. Generally, new operational capabilities expand the definition of what is feasible, and the swiftness of treatment that defines timeliness. The development of RWIS is bound to result in changes in the trend of case law regarding weather information and other information dissemination made feasible by ITS. This also concerns the treatments and response made on the basis of RWIS information. A higher standard of performance will be imposed. Liability will therefore become a spur, rather than a constraint on the use of advanced RWIS.

Performance

The performance of the RWIS is the object of this requirements process. However, performance is also a policy issue of investment and the quality of system acquisition specifications, including for system calibration and maintenance. Performance requirements are currently being bolstered in contracts by DOTs (e.g., Virginia) based on analysis of past performance that provides a firm basis for performance benchmarking, at least on the observational systems. Minnesota is an example of a state that provides a high level of ESS maintenance in order to bring the system to standards whereby it can participate in the aviation-weather observational system.

ESS performance assurance is vital to integration into the national network of observations used by the NWS. The NWS, the FAA and the Department of Defense (DOD) cooperatively operate Automated Surface Observing Systems (ASOS) that set the standard for performance. There are additional cooperative observations (usually manual) used by the NWS. Lack of certified performance for ESS has been a barrier to inclusion of those data in the common observational database maintained by the NWS. This in turn prevents quality-control benefits to RWIS that can be obtained through the assimilation process with the larger set of observations. The filtering process used in assimilation can generate bias and defect information on individual sensors.

Contractual and investment policies to assure performance, of ESS observations or forecasts, require performance benchmarks. The issue is simplest for point measurements themselves, such as road surface temperature. The choice of forecast model performance measures is difficult because a model covering a surface area or spatial volume, and variable time horizons is not uniquely characterized by point performances. Statistical measures, and skill measures that relate to climatic statistics, must in turn be related to decision risks.

Information System-Capacity Allocation

Who pays for publicly available information, and its dissemination? The Internet is a good example of how this becomes a policy issue, that is related to the issue of proprietariness. Networking, and specifically the client-server architecture of the Internet creates an informational “commons”. The issue is analogous to that for highways: toll roads are possible, but most roads are paid for “publicly” as an infrastructure that private travelers use. Yet who pays for capacity, how and how much is still a perpetual policy issue. For information systems, the issue is less decided by precedent.

An agency like a DOT will decide it needs some kinds of information for its operations, and will pay for obtaining the information (like ESS data) from its limited budget. But what happens if that information has additional utility to ISPs and the general public? Aside from recovering costs of generating the information (or additional amounts of it), who pays for the communication capacity for what will certainly be more information transfer as information quality and demand increases? In the Internet, it is easy for an internal server to be called upon to serve external clients, at extra cost. If costs are minimized, performance is sacrificed. If an ISP is allocated the server responsibility, who sets performance requirements?

A typical complaint about the Internet for operational use, and especially for critical weather events, is that it is overloaded and least reliable when needed most. This is a function of server capacity, communications capacity (bandwidth), and the end-to-end reliability of the communications system. With enough expense, the Internet (or any other data communication protocol) can meet any performance standard. A communications common carrier (that will be considered different from an ISP) of course charges someone for the communication capacity. An ISP may charge for the information provided and for adding value to original information. But when there is no direct cost-price relation, as in publicly provided services, the policy relations between investment and service quality can be unclear. This is what presently divides expensive subscription services of VAMS from the free or low cost weather information services to most of the public.

It has been decided as a matter of policy that public weather information vital to public safety and commerce will be provided publicly by the NWS. There are service charges for some NWS archived data and subscription services (see section on NWS context). Client-server architectures are a new challenge for the NWS as well as for DOTs in terms of providing high-reliability service and policy decisions on who pays what price for what performance.

Financing

The financing issue for RWIS generally is an extension of the system capacity and proprietariness issues. From the DOT and other public transportation agency perspectives, federal-aid transportation funding is a significant source of RWIS funding. Legislation has ensured that ITS deployments, including RWIS capital costs, are eligible for federal aid highway and transit funding. Operating funds are not covered in the highway program, and are being phased-out in the transit program. However, life-cycle costs for RWIS, including parts and maintenance, can be included in capital buys. Because the competition for all federal-aid funds among projects is intense, it is unlikely that federal-aid funding alone will be sufficient. The allocation of federal and matching funds to projects is the function of the metropolitan planning organization (MPO) and statewide (DOT) programming processes. Therefore the prioritization and extent of RWIS buys is a policy decision within these bodies regarding federal-aid funds and the matching local shares.

Aside from the capital funding, research funds from federal-aid to the DOTs has been significant in RWIS research and development. The smaller part of this is controlled federally (e.g., this project) while states are allocated the larger part and may pool it in multi-state consortiums, of which AURORA is an example devoted to RWIS issues. It is an agency policy decision of how much of the research and strategic planning funding goes to RWIS.

Operational funding, including the staffing and training of highway winter maintenance staff and management, is likewise a policy decision of the DOTs and local road-operating authorities. Establishment of best management practice benchmarks, including through this project will affect these decisions. It is expected that more training, and more staff with meteorological expertise, will be a result. But the overall tightness of public budgets means that funding on behalf of RWIS and its successors must prove its case through documentation of benefits.

NWS funding, from public sources, vitally affects the overall quality of weather information. The NWS budget is a policy decision by Congress. The allocation of NWS funds in ways that affect RWIS performance is partly a matter of Congressional stipulation, and partly a matter of NWS discretion. But this becomes an essential issue to this project: To the extent that transportation-outcome benefits from improved NWS products can be shown, and to the extent that it is appropriate for the NWS exclusively to provide these products, for technical or practical reasons, then NWS budgeting can be altered. This financing issue is coupled with the larger issues of appropriate private and public sector roles.

Private sector funding ultimately comes from pricing to ISP or VAMS customers. For traveler information, and information to private transportation modes like truck and rail, public goals may stipulate the quality of information through the Advanced Traveler Information System (ATIS) component of the ITS. The induction of private-sector financing into the ITS is one reason why it is federal policy to allow proprietary rights even to products developed as part of federal projects.

The Division of Public and Private Sector Roles in Weather Information

The allocation of ITS requirements, including for weather information, to the public and private sectors is partly a policy issue related to other issues above. It depends both on who is better prepared to meet the public interest in providing weather information, and who can finance the service. As for surface transportation, the issue in weather information also depends on a layered structure of the services, consisting of an "infrastructure" and "tailored" services.

The assumption will be made here that the NWS will continue to operate in a role that technically progresses, but is largely the same as at present. Specific services that raise public versus private issues include:

- The assimilated database of point (ASOS, ACARS, rawinsonde, etc.) observations.

As part of its numerical modeling activities, and to support local weather analysis, the NWS collects and assimilates national and international point observations. This includes cooperative agreements with the private air carrier industry for their Aircraft Communications Addressing and Reporting System (ACARS) airborne observations. It is expected that for international agreements, the need for common assimilation, and the criticality of the observational data to all other NWS products, the NWS will and must retain this function. However, many observations are not now assimilated, including ESS and other private systems (e.g., for power utilities and rail systems). Therefore at issue is the extent of the commonality of the NWS database, and third-party rights to certain of the data should they be assimilated. Data such as lightning data is used by the NWS but provided privately with limited third-party rights.

- Remote sensing observations (NEXRAD, satellite, DGPS, etc.).

Technology continues to increase the remotely sensed data used by the NWS. This includes use of the Differential Global Positioning System (DGPS) signals to characterize total-volume moisture in the atmosphere. Similar arguments on the NWS role apply here as to the point observations. The differences are in the very large volumes of data generated, the cost of the technology, and the need for intermediate processing for most end users. NEXRAD data are disseminated through ISPs in the NEXRAD Information Dissemination System (NIDS), but this will be changed under a new radar data open architecture. In the satellite field, private ventures now provide high-resolution imagery, some with transportation applications although resolutions adequate to road temperature radiometry still appear out of reach. The information stream for remotely sensed data, when it extends to the processing to make it useful to end users, involves tailoring and cannot be clearly allocated to the NWS. Yet the Advanced Weather Interactive Processing System (AWIPS) generates products for NWS meteorologists that have outside utility as well. This can enhance VAMS inputs, but also go directly to end users with adequate DSS capabilities to handle the GIS-based graphical products.

- Large-domain numerical prediction models.

The basis of many NWS and private-vendor products is the large-domain (synoptic scale, but now into the meso scale) numerical models run by the National Centers for Environmental Prediction (NCEP) under the NWS. These are global-to-national domain models, currently down to 30-km grid resolution. Such numerical grids are vital to assimilation of observational data, and the bounding and initialization of more local models. The models are used as guidance by the NWS forecasters for weather analysis in support of other products. The need for only a small set of large-domain models, and the need to provide them as critical to NWS functions, makes them logically an NWS responsibility. However, meteorologists are most interested in the atmospheric state variables (temperature, humidity, pressure and the winds) from these models while surface transportation is interested in surface-sensible attributes. Experience shows that some VAMS operate specialized large-domain models to complement their tailored services. Data delivery and format issues for DSS services may also affect the allocation of modeling.

- Local-domain numerical models.

In roughly the last decade, the availability of cheap, high-performance computing power has made it possible to implement high-resolution numerical models on a variety of research and private platforms. Technology and an expanding observational database also allows the NWS to move into the meso scale with its numerical modeling. This puts the NWS into competition with fine-scale, local-domain models privately provided in the RWIS, but it also allows the VAMS to use better NWS numerical products for tailored products. Customers desire higher resolution to relate grid point results directly to their operational domain. In the case of surface transportation, this is desired down to the route-segment level (<1 km.). The ability to reach this resolution through numerical weather models, as opposed to specialized road-condition models, is still limited by observational resolution and boundary-grid sizes. Users should not be deceived by high resolution at long horizons achieved by interpolating model grids, rather than truly reliable fine-scale data that inevitably is limited to short time horizons.

The AWIPS deployment in WFOs (sub-state areas) includes the Local Analysis and Prediction System (LAPS) component. LAPS allows local data assimilation (including ESS inputs) and local numerical modeling. A few WFOs use local numerical modeling. However, it is a contentious issue within the NWS whether this will be endorsed in preference, or addition to, continued progress by the centralized NCEP modeling. In practice, very fine resolutions will be achievable only with local domains and it does not make sense for NCEP to produce many local models. Conversely, the boundary-reconciliation of many local models is an issue.

Specialized models, such as for local road conditions based mostly on local ESS data are not at issue and fall more clearly into the private sector development realm. However, for heat-balance models depending on heat transfer with the atmosphere and solar insolation, there is no real separation between the atmospheric and road-condition models. The derivation of road-condition forecasts directly from atmospheric forecasts is exactly why the fine-scale numerical models for the atmosphere, down to route-segment resolutions, are desired by surface transportation decision makers. The public/private allocation depends on whether the very fine resolutions needed constitute tailoring, or have utility to the public generally. If and when many high resolution models are run, their coordination and use in ensembles becomes the same kind of issue as for observational assimilation: Should numerical model results be pooled in a publicly-accessible database?

- Watches and warnings of severe weather.

The generation of watches and warnings for severe weather by WFOs seems to be a fundamental part of the NWS mission. However doing this for very localized (micro/meso scale) convective storms requires fine-scale information. There is an issue of how much numerical modeling is required for this, versus reliance solely on remotely-sensed observations (e.g., NEXRAD), and this is an issue of lead time in the warning. Privately-supplied lightning data partially indicates a decoupling between who owns the observational data and who issues the watches and warnings. If fine-scaled numerical modeling were considered vital to the watch and warning function, it could be a further argument for NWS and WFO involvement in such modeling.

- Additional, sensible attributes from analysis and prediction.

Once the difference is breached between producing the six state variables of atmospheric modeling and other sensible results of weather (e.g., precipitation), it is just a question of how far the NWS should go in producing products about what affects transportation modes. It is clear that the NWS produces sensible attributes, especially precipitation, as part of its mission. If there is a reason why road icing (cf. aviation icing conditions) is not produced similarly, it is a matter of spatial resolution and dependence on observations other than controlled by the NWS. Technology, and common assimilation of observations, would erode these reasons.

- Expanded NWS digital products.

The NWS has produced its public products of watches, warnings and other advisories through textual message (or voice equivalents on NOAA Weather Radio). Vendors have therefore found a niche in graphical products or digital data sets. With AWIPS, the NWS now has a primarily digital, graphics-based system for WFO decision support. Supporting AWIPS requires the dissemination of digital data (observations, remote sensing and numerical guidance grids), primarily through the satellite broadcast system NOAAPort, that anyone can access. Although the principle is that DSS presentations should be tailored for specific decisions (of which weather forecasting is one and different from transportation decisions), the products generated by the AWIPS may have utility to other decision makers. Alternatively, NWS services such as the Emergency Managers Weather Information Network (EMWIN), available by satellite broadcast or over the Internet, have been developed as graphically-based, for a customer base considered to be in the public domain. AWIPS, and a general tendency to make more use of the Internet, will increasingly raise issues about the demarcation of roles in end-user decision-support delivery. If LAPS can assimilate ESS data and support AWIPS with local numerical models, and with open-system products directly from NEXRAD in the near future, the tendency will be to port these available products directly to other decision makers. The issues in meeting surface transportation needs are still the comprehensibility of the products and the ability to tailor them interactively. This becomes an issue of how far back into the inputs to AWIPS a DSS should reach before filtering, fusing and presenting information to decision makers. Since the affordability of a system like AWIPS is questionable for single maintenance offices, there are practical matters of how this processing is to be organized or simplified. This could lead to regional tailoring centers covering areas as large or larger than those of WFOs. Indeed, ATWIS and Foretell suggest multi-state centers, and existing subscription services run national centers. There could be a national, regional and local hierarchy of processing emulating NCEP and the WFOs.

6.3 Description of the Current RWIS

6.3.1 Operational Environment

The RWIS serves many surface-transportation decision makers. The focus here will be on winter road maintenance.

There are nearly 4 million miles of public roads in the U.S[16]. The highway system is categorized into functional classes: Interstate, other freeway, primary arterial, minor arterial, collector and local roads[17]. A National Highway System (NHS) class has been legislatively defined and consists of 159,315 miles (4% of total mileage) of the most significant routes. These classes correlate with usage, and provide a 5%-50% distribution of traffic volume by route mileage, i.e., the top 5% of route miles, primarily the Interstates and primary arterials, carry 50% of vehicle miles traveled (VMT) while the last 50% of route miles carry only 5% of VMT. This distribution means that there is reason to focus treatment and information on a limited route system, roughly the NHS, and yet there is a very large network (primarily rural) of thin traffic where mobility and individual safety are much at stake. This leads to distinctions in the economics of treatment strategies.

The functional classes also correlate with jurisdictional responsibility as shown in the table below. The states have control of the Interstates, although Toll Road authorities have authority over some freeways that may be part of the Interstate system. State DOTs control 20% of the route mileage, generally in decreasing proportion with lower functional class. State DOTs control about as much mileage as in the urban route system in total. Except for the urban principal arterials (31% of which are under other control) and toll authorities, states control most of the 5% network that carries fully 50% of VMT. The bulk of the tail-end 50% of route miles is under non-state control. Local authorities, along with the federal-lands agencies, control a very diffuse rural network, often with low use.

The extent of state authority over the network in a state varies. Virginia, for instance, has jurisdiction over almost all roads, while other states have jurisdiction only over the higher functional classes. The state jurisdiction in maintenance may be carried out directly, or by contract work, and similarly for localities. Verification of work done, and its quality, is more of an issue with contract work and over the more diffuse, lower functional classes of road.

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[16] Table HM-10, Highway Statistics, FHWA, 1997.

[17] These are functional classes as used in Highway Statistics by the FHWA (e.g., table HM-50) as so can be used easily to define certain attributes of each class from that data source.

Table 6.1: U.S. Highway Route Miles by Class and Jurisdiction (1997)

Rural	Jurisdiction					
	State	State%	Local/Other	Federal Lands	Total	Percent.
Interstate	32,819	100			32,819	1
Principal Arterial	97,652	99	467	138	98,257	3
Minor Arterial	130,921	95	5,413	1,165	137,499	4
Major Collector	198,935	46	228,806	4,991	432,732	14
Minor Collector	68,482	25	194,917	8,952	272,351	9
Local	163,962	8	1,818,751	152,124	2,134,837	69
Total	692,771	22	2,248,354	167,370	3,108,495	100
Percentage	22		72	5	100	

Urban						
	State	State%	Local/Other	Federal Lands	Total	Percent.
Interstate	13,249	100			13,249	2
Other Freeway	8,596	95	414	50	9,060	1
Principal Arterial	36,494	69	16,684	54	53,232	6
Minor Arterial	24,772	28	64,321	103	89,196	11
Collector	11,629	13	76,353	54	88,036	11
Local	17,501	3	564,631	1,201	583,333	70
Total	112,241	13	722,403	1,462	836,106	100
Percentage	13		86	0	100	

Total						
	State	State%	Local/Other	Federal Lands	Total	Percent.
Interstate	46,068	100	0	0	46,068	1
Other Freeway	106,248	99	881	188	107,317	3
Principal Arterial	167,415	88	22,097	1,219	190,731	5
Minor Arterial	223,707	43	293,127	5,094	521,928	13
Collector	80,111	22	271,270	9,006	360,387	9
Local	181,463	7	2,383,382	153,325	2,718,170	69
Total	805,012	20	2,970,757	168,832	3,944,601	100
Percentage	20		75	4	100	

The costs of winter maintenance on the non-federal highway system are collected for state-administered highways[18] and local government disbursements[19]. The 1997 total in the United States is $1.12 billion for the state-administered highways, and $1.14 billion from local funds. In order to get a reasonably normalized cost per highway mile, the data were analyzed by state and state- or locally-controlled highway mileage[20]. Federal-aid and non-federal aid mileages were combined for the state and local categories. Climatic classes were then assigned to each state based on bands of the mean number of days per year with one or more inches of snow on the ground[21].

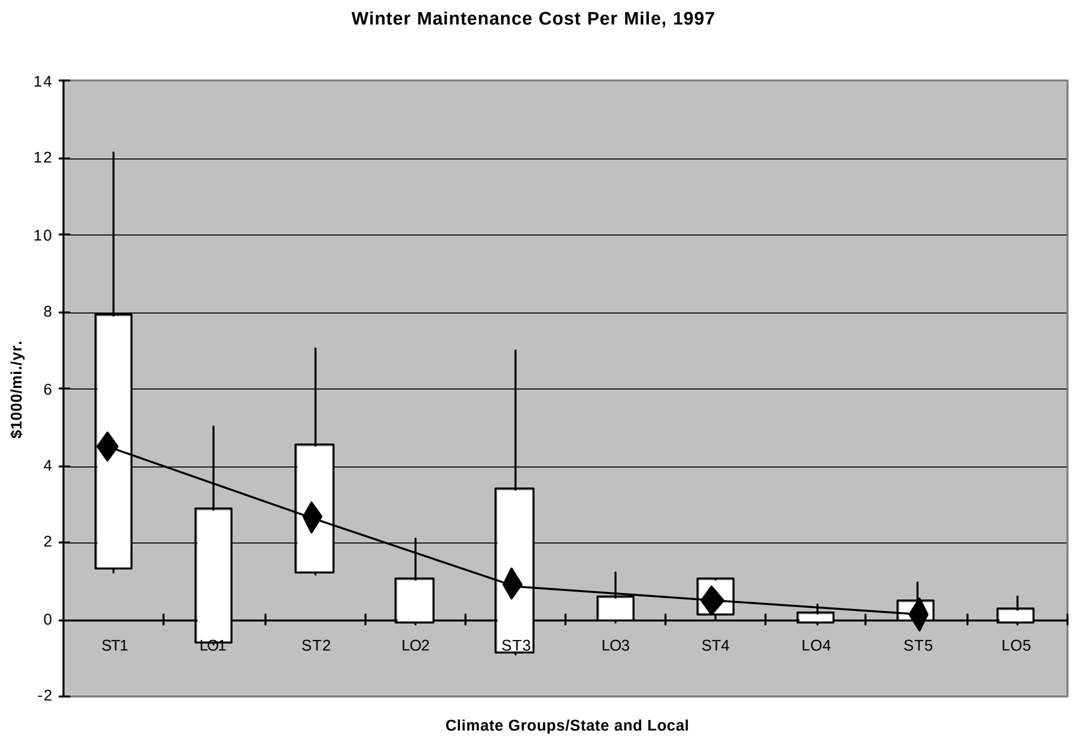

Figure 6.1: State and Local Snow and Ice Costs per Route Mile per Year (1997)

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[18] Highway Statistics, FHWA 1997. Table SF-4C, "snow and ice removal" column.

[19] Highway Statistics, FHWA 1998. Table LGF-2, "snow removal" column (data for 1997)

[20] Ibid. Table HM-14.

[21] Based on fig. 27 in Doesken, Nolan J. and Arthur Judson, The Snow Booklet, Colorado Climate Center, Colorado State University, 1996. Data are for 1961-1990.

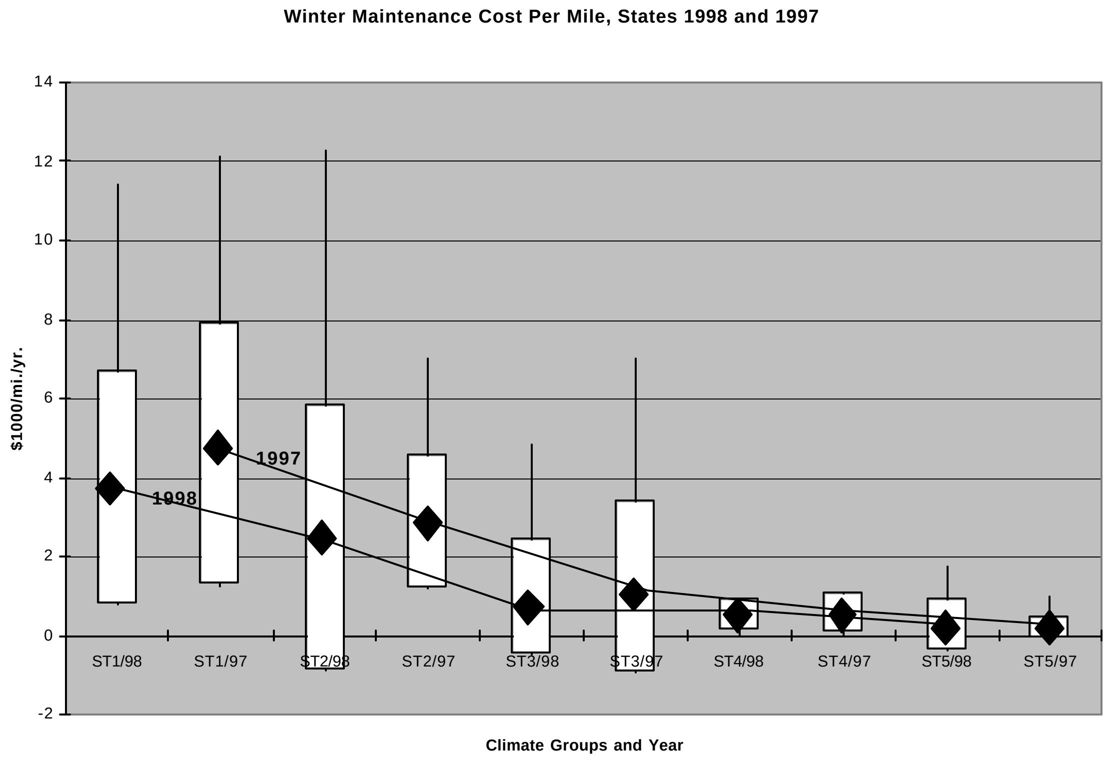

Figure 6.2: Comparison of State-Jurisdiction Snow and Ice Costs per Route Mile per Year, for 1997 and 1998

Figure 6.2 shows just the state-jurisdiction costs, but between 1997 and 1998. This emphasizes the climatic differences that can affect costs. 1997 was a relatively severe year for snow in some states, especially the northeast, while 1998 was a mild year and state-jurisdiction costs totaled $0.95 billion compared to $1.12 billion in 1997.

The horizontal categories on both charts are climate categories designated 1-7 (but combining categories 5-7 that were fairly similar and excluding FL and HI with no snow/ice costs). The state and local costs ($1000/mile/year) in each category are shown with the bar indicating mean plus or minus one standard deviation (s.d.), and a whisker to the maximum value. Since the distributions are skewed non-negative, the mean-s.d. generally encompasses the minimum value whisker. The states in the climate groups are tabulated below.

Table 6.2: States in Snow-Climate Groups and Group-average Snow and Ice Costs per Route Mile Per Year (1997 local and state cost data)

Snow-Climate Group:	Group 1	Group 2	Group 3	Group 4	Group 5+
(based on 1961-90 days	AK	CO	DL	AZ	AL
with 1+ inch snowcover)	ME	CT	IL	KY	AR
	MI	ID	IN	NM	CA
	MN	IA	KS	OK	GA
	MT	MA	MD	VA	LA
	NH	NE	MO		MS
	NY	OH	NV		NC
	ND	PA	NJ		SC
	SD	UT	OR		TN
	VT		RI		TX
	WI		WA		
	WY		WV		
State avg. $/rt. mi./yr.	4600	2880	1220	570	210
Local avg. $/rt. Mi./yr.	1104	477	265	40	76

It is clear that the climatic categories capture a lot of the unit-cost variation and that annual climate variation affects costs. Also, since the state costs are generally higher than local costs per route mile, it appears that the higher functional classes (and often more lane-miles per route mile and VMT) accrue higher costs. If there is a VMT component to costs, denser states should also have higher costs. In climate groups 1-3, the highest 1997 costs were NY, MA and RI respectively. These are all highly urbanized states. In the northeast, notable events were the January 1996 snow northeaster, a heavy December 1996 snowstorm, a heavy April 1997 snowstorm, and the very damaging ice storm of January 1998[22]. It is recognized that the snow-climate grouping does not reflect adequately the surface-icing climatology that is also a cost factor.

Lower local costs per route mile probably is due to the low-volume tail of the 4 million route miles in the local category. Costs probably are concentrated in roads with more use and normalizing over the entire route system lowers per-mile costs excessively. In that case the state costs are more indicative of route miles actively treated. The remaining variation within each state-administered climatic category probably is from differences in the distribution of road functional class and usage, and annual climate variations.

Some analysis has been done on variables affecting snow and ice maintenance costs. A 1970 study

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[22] Climatic data and storm events from National Climatic Data Center, at www.ncdc.noaa.gov on the Internet.

analyzed county jurisdictions in Ohio[23]. Based on three years of data, linear regressions were performed for Interstate, major and local route classes with the results below:

Route Class	Regression for cost/lane mile of plowing, chemicals and clearing bridges
Interstate	9.49(cty. avg. inches snowfall) +107.08
Major	4.87(cty. avg. inches snowfall) +0.03(average daily traffic)-33.19
Minor	4.28(cty. avg. inches snowfall) +0.04(average daily traffic)+4.13

The explanatory power of these was generally poor, especially for the Interstates. The absolute costs will of course need inflating to present costs. However, it is notable that the sub-Interstate routes have unit costs that rise with traffic volume. Also, the constant term and lack of volume term for the Interstates implies either uniform volumes or high attention to that class under any condition.

A more recent study for Denmark[24] uses only a climatic variable embodied in the "Danish Winter Index" (DWI). Graphs indicate good linear fit with rš0.95 for "level of activity", salt consumption and $/m^2 cost. The DWI is a sum of daily DWIs between October and May. The daily DWI is a nonlinear function defined as:

$$DWI_{day} = a(b+c+d+e)+a$$

where

a is 1 if the road temperature is below 0.5°C anytime in the day, 0 otherwise;

b is in the range 0 to 2, according to the number of 3+ hour periods separated by at least 12 hours where road temperature is below 0°C and below the dew point.

c is the number of times road temperature falls from the range -0.5 to 0.5°C

d is 1 if there is at least 1cm of snow, 0 otherwise

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[23] Miller, Edward l., Models for Predicting Snow-Removal Cos6s and Chemical Usage, pp. 267-268, Snow Removal and Ice Control Research, HRB Special report 115, 1970.

[24] Kirk, Jorgen, Danish Winter Index, pp. 1-9, Proceedings, 9th SIRWEC, 1998.

e is 1 if there is significant snow, 0 otherwise

This complicated index shows the level of climatic detail needed to get a linear predictor of costs per road unit (in this case surface area). Since the results are aggregate over the road network, the variables of road type and traffic are not included. It is still possible that the unexplained variance from the Ohio results indicate nonlinear models or other factors to predict costs for a particular network. Further analysis must be done to identify significant variables in winter maintenance costs for a geographical area. Better information on the cost factors could help to get normalized benchmark costs and to target informational improvements.

6.3.2 Major System Components and Interconnections

A high-level structure of the RWIS is shown in the figure below.

This RWIS view is focused on the highway maintenance office as the site where decisions are made and decision support is received. The typical office will have a variety of non-integrated communication termini. A telephone, point-to-point radio to crews, broadcast radio/TV, and fax machine are basic. NOAA weather radio is another form of broadcast radio.

A graphical user interface (GUI) is typically the keyboard/mouse and display associated with a personal computer (PC). These can be multi-purpose GUIs, for Internet communications, local applications, and RWIS sensor displays. However, some ISPs and weather service vendors provide dedicated GUIs, as “dumb” terminals (e.g., some of the NIDS vendors, RWIS vendors and satellite weather information ISPs). It is therefore likely that three different kinds of video displays will be in one office: TV, PC and other dedicated display. This proliferation of interface devices requires manual integration of information, or what is colorfully called “swivel-chair integration”.

The entities external to the maintenance office are shown as the NWS, private VAMS, ISPs, coordinating offices, ESS sites, maintenance crews and other remote resources (e.g., fixed chemical sprays). The NWS services and connectivities are described below under NWS context. Similarly for coordinating offices under the ITS context. It is assumed here that interactions with the public are via other offices (e.g., traffic advisories via a traffic management office).

The communications connectivities to the office will be varied. A complete description must refer to protocol layers, including various modulation techniques, frequency bands, physical connections and network topologies. Some connectivities are typical, such as very-high frequency (VHF) or ultra-high frequency (UHF) radio for point-to-point, office-to-crew, mobile communication. However, satellite and cellular (analog or digital packet network) are becoming common. The Internet is a protocol set that can use various physical layers and network layers (wireline, packet, satellite, etc.). Broadcast radio or TV remains an important mode for ISP information that may originate with the NWS or private vendor services. Subscription services from VAMS are via satellite broadcast, Internet, fax, phone, and dialup data. Reliability and availability issues arise with the various communications modes.

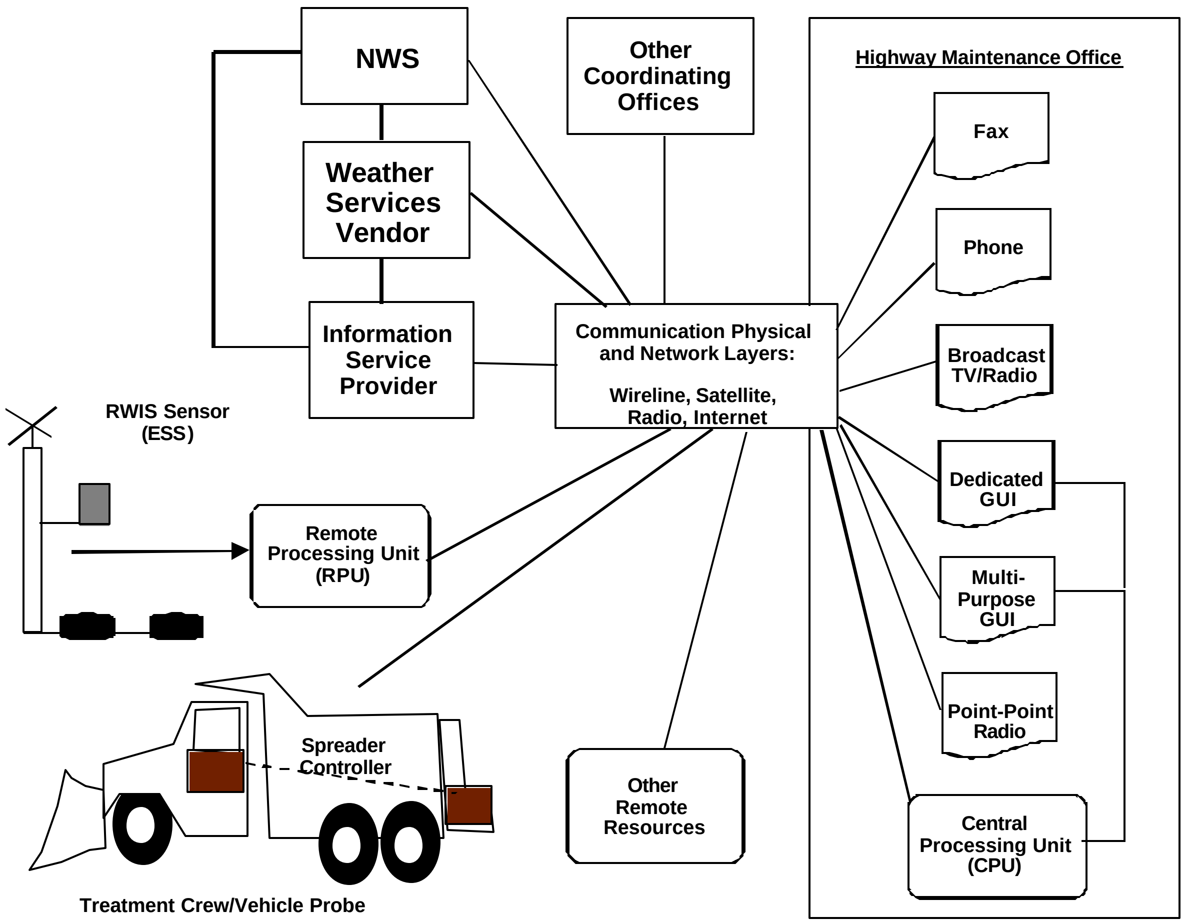

Figure 6.3: RWIS Components and Interconnections

The Internet has become an important dissemination medium. It is integrated to the extent that common communication protocols are used (TCP/IP) on top of various physical media. However, the emphasis on graphical displays and Hypertext Markup Language (HTML) for display formatting virtually eliminates possibilities of information integration: The elements displayed, whether textual or graphical, are not defined as data elements and so cannot be manipulated as discrete entities, except that textual words may be searched.

Both subscription and free services are available on the Internet. Free services typically display NWS products, or representations of more detailed subscription products. Typically available only for subscription fees are high-resolution NEXRAD images and products), lightning data, ESS, specialized numerical modeling and customized warnings. A nominal subscription fee (under $100 per year) can buy services that provide everything but the last three items.

A VAMS may also act as an ISP for product dissemination. An ISP by itself is a conduit for products. However, as “middleware” entities in client-server systems, an ISP may also add value through graphical display or other applications and there can be little difference between an ISP and a VAMS. Internet connectivities are typically through an ISP who may also be providing the originating server (e.g., for small firms and individuals who do not maintain their own servers, but post material to the ISP server). A TV or radio broadcast station is an ISP.

A VAMS may or may not be an ESS provider. If they are, there is typically a link from the ESS to the VAMS for use in road condition or other forecast preparation. The ESS sensor connectivity is generally through a set of remote processing units (RPUs) to one or more central processing units (CPUs) associated with the maintenance office and other receiving sites. The RPUs home one or more sensor units. The CPUs poll or otherwise collect the sensor data, redistribute it (e.g., to the VAMS), process it for display and provide for archiving.

The VAMS can provide any of the types of products provided by the NWS. These include textual messages, static graphics (e.g., via fax), and graphical products through the GUIs. Flash flood and avalanche warnings are two specialized products. However, it is fair to say that for winter highway maintenance, the rationale of VAMS is high-resolution forecasting of precipitation amount and form, possibly with local climatological expertise to improve skill, and road condition (freezing) measurement and forecasting.

Road condition information may rely primarily on the ESS measurements, primarily on atmospheric information, or fuse both. For road temperature and freezing prediction, an ESS measures the sensor points directly. Time series extrapolation gives point predictions. The point measurement or prediction can further be extended over a route segment by the climatological technique of thermal mapping. This uses samples of point measurements (usually by vehicle probe) and regression to the ESS point measurement. Other attributes (wind, precipitation, chemical concentration) can be derived similarly, although the method is usually to assume similarity of nearby areas.

The heat balance method for road temperature prediction uses atmospheric and insolation data to infer surface temperatures. However, the surface radiation and convection terms in the heat balance equations depend on surface temperature itself. Therefore surface temperature measures may be used as inputs to heat balance models. Precipitation, its effect on chemical concentrations, and winds are best derived from the meteorological forecasts or other observations, such as NEXRAD.

Surface temperature and direct detection of surface ice or other coverage can well be achieved by mobile probes. However, chemical concentration still is best obtained by fixed sensors. Remote sensing by satellite radiometry does not presently have adequate resolution for road measurements and airborne sensing will be expensive except for initial thermal maps. In situ temperature profiling by fixed sensors along a route line is technically feasible (e.g., by fiber optic diffraction effects) but little used at present. There is however a synergistic interest in fiber optics for stress measurement, as in bridges, and this may spur additional deployment of this technique. In any case, modeling appears to be necessary to spatially extend road temperature from limited fixed measurements.

The use of vehicle-probe instrumentation for temperature and ice detection is important for thermal mapping and sporadic observations to augment the fixed ESS sites. This requires AVL and data links back to base. Probe data also allow vehicle-based, micro-scale, treatment control. Automated-spreader control has become common in recent years. Spreader and plow mechanical improvements include the necessary hydraulic spreader-gate actuation and the “zero-velocity” (i.e., application within wheel tracks) spreaders. Spreader control generally is based on pre-selection of calibrated application rates, and the spreader discharge rate is based on vehicle speed, and can be coupled with plow position. There is provision for manual override, with “burst” applications if the driver sees a pernicious spot. Applications can be controlled based on local surface temperature and ice cover detection, or by correlation of vehicle position with thermal mapping data, but this is not done commonly at present. More problematic is sensing of the chemical concentration by a moving vehicle, so this is an important missing-variable in autonomous vehicle control of treatment. Pretreatment (anti-icing) must use roadway observations with forecast models extending a few hours, and it is questionable whether this forecasting should be done at the vehicle. This is why applications tend to be pre-programmed out of the garage, or for general beat portions. A controller setting-change command could be dispatched if the base has new information and the beat is relatively long.

6.3.3 Interfaces to External Systems

This will be covered separately under the ITS and NWS context sections.

6.3.4 Performance of the Current System

Performance of the RWIS ultimately is measured by transportation system outcomes, covered elsewhere. The general problems of system integration have been discussed. This section covers performance of weather information sensors and services provided for RWIS. The current RWIS performance may be measured by availability and quality attributes of weather information. Availability is both a system-availability issue (transfer of information) and geographical coverage of the information (especially observations). NWS services are available nationally and internationally. Most VAMS and ISP services are available nationally to highway maintenance offices when accessed by Internet or subscription satellite services. Tailored road-condition forecasts will be for specific regions or sites. Information to other users, especially travelers, is similarly available. However, reliance on terrestrial broadcast media will limit coverage to those transmission radii. FM radio, the NOAA Weather Radio and TV are line-of-sight radii and leave many rural and mountainous areas uncovered. The tailored traveler information services covering roadway conditions by cell phone or pager generally are limited both by the area for which information is available (a metropolitan area or, in a few cases, states) and the coverage of the communications medium. Cellular service, except by expensive satellite service, is still lacking in many rural areas, particularly in mountainous terrain.

The accuracy and geographical extent of ESS measurements will be a factor in RWIS performance. Geographical extent is indicated in the tabulation below of ESS RPUs by state. Two sources were available[25].

Table 6.3: Inventories of ESS Sites in the United States

	Delannoy (1998) Road RPUs	VTRC (1997) Road RPUs	Delannoy (1998) Arpt. RPUs
Alabama		0	
Alaska	0		9
Arizona	7		0
Arkansas	0	0	5
California	37	35	0
Colorado	110		20
Connecticut	4	4	2
Delaware	1		0
DC	9		6
Georgia	0		2
Idaho	15	11	4
Illinois	63	51	38
Indiana	11	8	8
Iowa	50		5
Kansas	50	41	5
Kentucky	3	3	7
Maine	0	0	6

[25] Survey by Paul Delannoy, Ontario Ministry of Transport, disseminated by email, 12/13/98. Survey by the Virginia Transportation Research Council, in Roosevelt and Hanson, op. cit.

Maryland	87	27	4
Massachusetts	9	9	10
Michigan	15		20
Minnesota	17		4
Mississippi		0	
Missouri	26		12
Montana	26	58	4
Nebraska	7	5	10
Nevada	2		6
New Jersey	20	27	7
New Hampshire	27		0
New Mexico	0	0	4
New York	46	40	30
North Carolina	0	0	4
North Dakota	14	15	5
Ohio	85		27
Oklahoma	13		7
Oregon	16		4
Pennsylvania	53		18
Rhode Island	0		3
South Carolina	19		2
South Dakota	23		4
Tennessee	10		18
Texas	11		11
Utah	7	7	11
Vermont	0	0	2
Virginia	42	40	4
Washington	29	25	9
West Virginia	6	0	1
Wisconsin	56	51	8
Wyoming	28	27	0
Total	1054	484	366
Proj. for 2002	1130		

The Delannoy survey also includes airport ESS sites. Each RPU can have several road sensors homed to it, covering multiple lanes or a nearby road segment. On average, the Delannoy results indicate 2.5 sensors per RPU. Comparing the surveys implies growth in the number of RPUs over time. However, at an average of about 28 RPUs per state in the 37 states reporting units, it is clear that geographical coverage is limited.

Surface observations for other purposes, and therefore generally excluding road-surface measurements, are available and vital to the overall weather analysis and prediction process. The Automated Surface Observing Systems (ASOS) are deployed jointly by the NWS, FAA and DOD. A total of 993 sites are planned, mostly covering the CONUS, with 569 deployed by the FAA and therefore mostly at airport sites[26].

Remote Automatic Weather Station (RAWS) sites are deployed for fire-weather monitoring. These report temperature, dew point, relative humidity and winds. There are 826 sites in the U.S., in forested areas and distributed mostly from the Rockies westward and in Alaska[27].

There are many other cooperative (manual) observing sites for the NWS, USDA sites monitoring primarily off-road soil conditions, stream gauges, and private observing networks (e.g., for power grids, and hazardous emissions sites). All of these report some of the surface data measured by the ASOS, meaning at some level near but not at grade. A private lightning monitoring network exists in the U.S. None of these except for the ESS measure road conditions specifically and there will be consistent differences in temperatures between paved and natural surfaces.

In addition to the point measurements, the NWS forecasts are increasingly supported by remote sensing. This includes the terrestrial NEXRAD radars and satellite imagery and soundings. While the satellites are capable of ground infrared radiometry, the continuous data from the geostationary (GOES) satellites are too coarse (tens of km resolution) for thermal mapping on roadways. Of more use may be indications of snow coverage and drift from imagery (when the sky has cleared). Non-stationary satellites, generally polar orbiting, for weather monitoring or other imagery can provide better resolution but have not been employed for thermal mapping. NEXRAD and other radar data (e.g., reflectivity from FAA radars) is an important source of near-surface precipitation. Radar processing to better characterize precipitation (including liquid content of snow and snow/rain phase changes) is under development or available.

A literature search was done on RWIS performance and on NWS forecast performance. The full search is available, and summarized here.

Several performance measures will be referred to in this review. These are defined as follows for numerical comparisons (e.g., temperature):

- Mean error (also called bias error): SUM(model-observed)/total cases
- Absolute Error: SUM(model-observed)/total cases
- Standard Deviation (s.d.) (aka standard error when a regression line is used):

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[26] Nadolski, Vickie L., ASOS Program Update, ASOS–Paper Prepared for the 78th Annual Meeting of the AMS, Phoenix, AZ, January 1998.

[27] Information from www.boi.noaa.gov/fwxweb/misc/rawsinfo.htm. Accessed 9/30/99.

SQRT[SUM(model-observed mean error)**2/total cases]. Note some will prefer the divisor to be (total cases-1) to provide an unbiased estimate of s.d.

- Root Mean Square (RMS) error: SQRT[SUM(model-observed)**2/total cases].

For categorical events [see John E. Thornes, The Verification of Road Weather Forecasts and Performance Related Road Weather Contracts, Proceedings of the 9th SIRWEC Conference, March, 1998]:

- Percent correct or Correspondence: (cases[28] of agreement between model and observed/total cases)*100%

- Hit Rate (HR): (cases of events correctly forecast/total events)*100%

- Miss Rate (MR) (aka rate of type I error): (cases of event not forecast when event occurred/total events)*100%

- Probability of Detection (POD): (cases of event correctly forecast/total events forecast)*100%

- False Alarm Rate (FAR) (aka rate of type 2 error): (cases of event forecast when it did not occur/total events forecast)*100%

- Bias (cf. mean error): (cases of event forecast/cases of event occurrence)*100%

- Total Alarm Rate (TAR): (cases event forecast/total cases)*100%

- Skill Score (SS), one of many variations used in meteorology is: (Percent Correct-climatological average % occurrence)/(total cases*(1-climatological average cases))

The best documentation is for measurement and forecast (usually by heat balance techniques) of road surface temperature at observation points. This is allied with, and followed in documentation by, categorical detection and forecasting of freezing and other surface events.

Quantitative road-surface temperature performance is most easily analyzed because of spatial-point and

[28] Cases and events may be different. Cases are the units of sampling, that may be days, hourly period, etc. An event may be a frost, snowfall, etc. The measures can differ according to how the case sampling is defined. For instance, a case being a day (or night) when frost may be forecast or occur anytime in the period would tend to have a better measure than if the case is an hour period.

quantity-scalar measurement. Temperature error (aka bias), absolute error, standard deviation (s.d.) and root mean square (RMS) error are commonly reported. Events are harder to compare because of different categorization and lack of detail in the conditional contingencies, leaving freeze/no freeze as the most prevalent event for performance comparison.

Almost nothing was found to document temperature forecasting performance over spatial segments away from sensors. The table below summarizes results on the performance of various road-surface temperature techniques, under a variety of comparison conditions. The results are ordered from minimum error (absolute value) to maximum.

Table 6.4: Ordered ESS Point Temperature Forecast Average Errors (Bias)

Avg. Error °C	Source
0.02	Thornes and Shao, 1992, MORIPM with templet, mid-range
0.04	Shao, Lister, 1997, trend fcst.,best case, midnight adj.
0.04	Shao, Lister, 1997, rule-based fcst.,2-hr. best case
-0.1	Parmenter and Thornes, 1986
-0.12	Shao and Lister, 1992, Icebreak
-0.13	Shao, Lister, 1997, trend fcst., midnight adj.
0.13	Shao, Lister, 1997, trend fcst.,best case
0.15	Voldborg, 1992, 1 hr. Fcst. with obs., mid-range
-0.16	Roosevelt, 1997, 2-hr. SSI best case
-0.17	Astbury, 1999, Kalman-filtered forecast, mid-range
-0.17	Schaffar, 1998, H2fcst model, 3-hr. mid-range
0.2	Shao, Lister, 1997, trend fcst.
-0.25	Astbury, 1992, templet,mid-range
-0.25	Voldborg, 1992, 5 hr. Fcst. with obs., mid-range
0.31	Shao, Lister, 1997, rule-based fcst.,6-hr. worst case
-0.49	Shao and Lister, 1992, MORIPM
-0.6	Scharsching, 1992,various sensors, regression, mid-range
-0.75	Thornes and Shao, 1992, MORIPM with meso-fcst, mid-range
-0.93	Astbury, 1992, no templet, mid-range
0.95	Shao, Lister, 1997, trend fcst.,worst case midnight adj.
-1	Robinson, 1985, diffusion model with air temp.
1.36	Roosevelt, 1997, 2-hr. SSI worst case
1.4	Shao, Lister, 1997, trend fcst.,worst case
1.44	Roosevelt, 1997, 8-hr. SSI best case
1.58	Astbury, 1999, unfiltered forecast, mid-range
4.37	Roosevelt, 1997, 8-hr. SSI worst case

It should be assumed that none of these results are strictly comparable, and can represent vagaries of the site, sensor equipment, sample size, forecast horizon, etc. But as such, the ensemble of results say something about the range of errors that could be encountered in a given application. Discarding the worst and best result, the error values range from 0.04 to 1.58 °C. The only type of model extensively reported is the U.K. Meteorological Office heat balance model and its successors (MORIPM and others) that generally predicts for a 24-hour period, with various update and filtering techniques applied. The citations for this show a bias-error range generally from 0.02 to -0.49 °C.

The next table shows the ordered standard deviation (s.d.) or root mean square (RMS) error values. These represent the square root of variance. The s.d. should represent the variation around the mean (bias) error and the RMS the total error (bias plus error around bias). It is not clear that all the authors adhere to this. The data are reported as shown, with the two different types of error measurement. The s.d. and RMS will be similar as the bias error approaches zero (i.e., the templet and Kalman-filtered models).

Table 6.5: Ordered ESS Point Temperature Forecast RMS or s.d. Errors

Error °C	Error Type	Source
0.7	sd	Uchiyama, 1998, MOS-type model, 1 hr fcst.
0.81	sd	Astbury, 1992, perfect prognosis, with templet
0.83	sd	Astbury, 1992, perfect prognosis
0.9	sd	Schaffar, 1998, 3 hr. fcst, min sd among models
0.99	rms	Shao&Lister, 1997, 2-hr rule fcst, mid-range
1.02	sd	Shao and Lister, 1992, MORIPM
1.02	rms	Thornes and Shao, 1992, MORIPM, templet
1.03	sd	Shao and Lister, 1992, IceBreak
1.04	rms	Shao&Lister, 1997, trend model, midnight adjustment, Holland and Norway, mid-range
1.05	rms	Astbury, 1999, Kalman-filtered model, mid-range
1.13	rms	Shao&Lister, 1997, 6-hr rule fcst, mid-range
1.2	sd	Robinson, 1985, diffusion model with air temp., mid-range
1.3	sd	Parmenter and Thornes, 1986, 1984/85 model fcst., 21:00 update
1.31	rms	Thornes and Shao, 1992, MORIPM, roadside input
1.39	rms	Shao&Lister, 1997, trend model, general temp., midnight adj.
1.4	rms	Shao&Lister, 1997, trend model, Holland and Norway, mid-range
1.47	sd	Roosevelt, 1997, 2-hr. SSI fcst, best site
1.48	rms	Shao&Lister, 1997, trend model, min. temp, midnight adj.
1.69	rms	Astbury, 1999, Kalman-filtered model, UK sites
1.73	sd	Uchiyama, 1998, MOS-type model, 16 hr fcst.
1.87	rms	Astbury, 1992, met forecasts, mid-range
1.99	rms	Thornes and Shao, 1992, MORIPM, best meso input
2.04	sd	Schaffar, 1998, 3 hr. fcst, max sd among models
2.1	sd	Parmenter and Thornes, 1986, 1984/85 model fcst.
2.2	rms	Raatz, 1998, model fcst, night
2.78	rms	Raatz, 1998, model fcst, mid-range
3.7	rms	Raatz, 1998, model fcst, noon
4.5	rms	Astbury, 1999, unfiltered model, mid-range
4.85	sd	Roosevelt, 1997, 8-hr. SSI fcst, worst site

These errors group more closely than the mean errors (bias). Over the whole ensemble of generally non-comparable cases, the middle of the range is around 2 °C. A consistent increase in variance is expected with time horizon of the forecast and this is shown in some of the cases. However, a consistent finding is that the heat-balance type forecasts show a minimum error (and variance) over the day around local midnight (e.g., Raatz [1998]). This is not necessarily the case for more general climatological models (Uchiyama [1998]). The heat-balance minimum error appears to be due to the uniformity of heat-transfer conditions in still air without insolation, and therefore without either wind-sheltering or radiation-shading effects. This is a bonus for road maintenance, since that time period generally is the critical one for road freezing predictions. Therefore, even when the heat balance forecasts typically are run midday for 24 hours, variance and bias tend to minimize at about 12 hours out. Where later corrections are made, results are even better. This effect also creates a difference between minimum temperature and general forecasts. If the temperature minima are around local midnight, the variance is expected to be lower.

Filtering of different kinds can be applied. The UK groups have emphasized templets, that use recent-past errors to correct forecasts. The bias results show that these are effective in reducing bias toward zero, but do not have comparable effect on s.d. or RMS. Kalman filtering can reduce both errors, as shown in the Astbury [1999] results.

If the variance results are separated into short-term and general forecast periods (filtered and unfiltered), the results can be clustered better. The lowest s.d. or RMS ranges (0.7-0.99) are for short-term forecasts. Mid-period updates to the 24-hour forecast period can get a s.d. a RMS about 1.3. The general forecast period for the unfiltered heat balance models descended from the UK work run in the s.d. or RMS range of 1.87 to 2.1. Applying the Kalman filter gives the RMS range of 1.05 to 1.69.

It must be remembered that the above results are for point comparisons. The s.d. or RMS results would certainly increase if spatial variation is included, and the filtering results are relative to the data and climatology at one location. However, the heat balance models use atmospheric inputs that are spatially smoothed relative to individual road surface segments. The midnight-minimum error represents the spatial smoothing of road conditions with the homogenized air conditions. Nighttime freezing and daytime/evening freezing are two quite different cases in terms of forecast accuracy and spatial variation.

Event forecast comparisons are more difficult because of the variety of event categorizations and measures presented or derivable from the published data. Some results are tabulated below:

Table 6.6: Performance Measures for Event Prediction and Detection

Source	Events	Measures
Matsuzawa, 1997: sensors at two sites	Dry Wet Frost/snow/ice Overall	POD 42%, Bias 190% POD 70%, Bias 67% POD 82%, Bias 68% 47% correct
Roosevelt, 1997: 2 stations	Freezing precip.	POD 73%, Bias 67%, Correct 94%
Castle Rock, 1995: various systems	Visibility warning	45%-57% correct
MacWhinney, 1975	Bridge snow/ice	59% POD (time overlap) 6% false
Parmenter and Thornes, 1986:	Freezing temp.	Model: POD 95%, Bias 95%, Correct 93% UK Met advisory: POD 63%, Bias 97%, Correct 77%
	Wet Frost	Model: POD 61% UK Met: POD 31%
	Dry Frost	Model POD 81% UK Met: 43%
Thornes 1996	Frost	UK Met: POD 93%, Correct 88% OceanRoutes: POD 80%, Correct 68%
Petrak, 1986	Bridge Ice	POD 67%
Scholl, 1988	Viaduct Ice	wet POD 83% dry POD 64% snow/ice POD 0%
Lo, 1993, area forecast	freeze precip (snow)	POD 47% POD 68%
Johansen, 1986	ice warning	3 alarm classes: PODs 43%, 41%, 30%
	Precip (snow)	POD 50%, Correct 89%

There is a tradeoff between POD (% of alarms that are correct), bias (in this case the % correct forecasts over total events occurring) and % correct overall (of event and non-event forecast). Specific sensors were noted to have various problems. As in the case of temperature, dependence on a single point measurement without some sort of smoothing with other data yields forecasts vulnerable to specific instrumental problems. Fusion of atmospheric models with sets of observations is again the most robust approach. Performance will depend on the discrimination required between events. A simple freezing temperature or not is the simplest dichotomy and should have the best performance. Parmenter and Thornes [1986] indicate a standard of 95% POD there. But critical events like frost/ice will depend on other variables and may lead to multiple event categories. Thornes [1996] suggests frost can have a POD of 93%. However, finer categorizations will not do as well. The issue of spatial variation again enters but the midnight-homogenization effect again works in our favor. The problem of climatological cold/wet spots suggests sensor siting criteria, but over-dependence on the worst-case locations will lead to over-treatment. Any area warning based on a point measurement suggests a strategy of inspection or vehicle-based observation/treatment, rather than wholesale treatment. Treatment must also depend on prospective consideration of conditions, including expected precipitation and temperature trends. The treatment decision must be based on more than a spatial and temporal point.

6.3.5 Performance of Current Meteorological Sensors and Forecasts

6.3.5.1 Background on NWS Numerical Weather Prediction Models

Numerical weather prediction models generate estimates of future conditions in the atmosphere. The results of such models can be used to compute estimates of weather parameters at or near the surface, such as parameters used in NWS public, aviation, and marine forecasts. The essential steps in estimating surface conditions from numerical model output are extrapolation of model conditions to the true surface elevation and use of meteorological algorithms to compute some parameters not provided by the models. The results of these numerical models which are run at the National Centers for Environmental Prediction (NCEP) are sent to NWS Forecast Offices. At the moment, these models include the Nested Grid Model (NGM), Medium Range Forecast (MRF), Eta, MesoEta, Rapid Update Cycle (RUC), and Aviation (AVN). Atmospheric numerical models are based on the physical/dynamical equations that govern atmospheric flow, written as a computer code. The model initial conditions are obtained by combining short model forecasts with new observations (a process called “data assimilation”). When a model is integrated in time (i.e., the model codes are run) starting from the observed initial conditions, the output is a numerical weather forecast. Numerical forecasts provide the guidance to human forecasters and are the basis of all the NWS and media weather forecasts. Characteristics of the NCEP models are tabulated below.

In the last two decades weather forecasts have become much more skillful and reliable. For example, today's 5-day forecasts are as accurate as the 3-day forecasts in the early 1970s, and the present day 3-day forecasts are about as accurate as the 1-day forecasts used to be. This is mostly due to the improvements that have taken place through the better use of observations, the use of more advanced models and of more powerful computers. Current developments in Numerical Weather Prediction (NWP) include the use of very high resolution, non-hydrostatic models (meso scale meteorology), new methods for discretization of the dynamical equations, inclusion of more sophisticated physical processes, ensemble forecasting, coupled ocean-atmosphere-land forecasting to forecast El Nino, etc.

Much work is ongoing in investigating atmospheric models that are used to better understand the nonlinear dynamics of the atmosphere and the internal structure and evolution of storms (e.g., hurricanes, squall lines, meso scale convective complexes, and snow storms). These basic laws of hydrodynamics and thermodynamics are used to compute the current state of the atmosphere from observations and to compute its future state. Briefly, the laws of motion of the atmosphere may be expressed as a set of partial differential equations relating the temporal rates of change of the meteorological variables to their instantaneous distribution in space. In principal, a prediction for a finite time interval can be obtained by summing a succession of infinitesimal time changes of the meteorological variables, each of which is determined by their distribution at a given instant of time. However, the nonlinearity of the equations and the complexity and multiplicity of the data make this process impossible in practice. Instead, it is necessary to resort to numerical approximation techniques in which successive changes in the variables are calculated for small but finite time intervals over a domain spanning part or all of the atmosphere. Even so, the amount of calculation is vast, and numerical weather prediction remained only a dream until the advent of the modern computer.

Table 6.7: NCEP Operational Numerical Prediction Models[29]

Model	Run Completion*	Forecast Horizons	Grid Resolution
RUC	Hourly+0:30 to 1:25 depending on run	12 hrs 8x per day 3 hours hourly	40 km, 40 levels
Eta/Meso-Eta	3:40, 5:45, 15:45, 19:50	48 and 30 hrs.	40/32 km,45 levels
NGM	2:55, 14:55, MOS at 3:45, 15:45	48 hrs.	90 km, 16 levels
AVN	4:45 and 17:00	72 hrs.	80 km, 42 levels
MRF	8:35, MOS at 8:45	10 day	120 km, 28 levels

[29] Data on Times from www.ncep.noaa.gov/director/supercomputer/ncep_delivery.html valid for 10/27/99. Resolutions from COMET briefings and NCEP updates.

* Times are Universal (Zulu). For EST subtract 5 hours, EDT 4 hours, CST 6 hours, etc.

Though numerical forecasts continue to improve, statistical forecast techniques, once used exclusively with observational data at the time of the forecast, are now used in conjunction with numerical output to predict the weather. Statistical methods, based upon a historical comparison of actual weather conditions with large samples of output from the same numerical model, routinely play a role in the prediction of surface temperatures and precipitation probabilities. This is the Model Output Statistics (MOS) technique.

The recognition that small, barely detectable differences in the initial analysis of a forecast model often lead to very large errors in a 12 - 48 hour forecast has lead to experiments with ensemble forecasting. This method uses the results from several numerical forecasts to produce the statistical mean and standard deviation of the forecasts. Ensemble forecasting uses a series of parallel medium range forecast runs with slightly changed initial conditions and medium range forecast runs from different time periods. Success with ensemble forecasting suggests it can be a useful tool in enhancing prediction skill in assessing the atmosphere's predictability. In addition, medium range forecasts up to 2 weeks (primarily 6-10 days) may be improved from knowledge of forecast skill in relationship to the form of the planetary scale atmospheric circulation. The scientific basis for ensemble prediction is that the model forecasts for the medium and extended range should be considered stochastic rather than deterministic in nature in recognition of the of the very large forecast differences that can occur on these time scales between two model runs initialized with only very slight differences in initial conditions. Given that each member of the ensemble (the ensemble consists of 38 different model runs) represents an equally likely forecast outcome, the spread of the ensemble forecasts is taken as a measure of the potential skill of the forecasts. Forecasters look for clustering of the ensemble around a particular solution as indicative of higher probability outcomes as part of a process of known as "forecasting the forecasts".

The choice of a performance measure for forecasts is not simple. A number of scalar accuracy measures for verification of probabilistic forecasts exist, but by far the most commonly used is the Brier Score[30] (BS):

BS = 1/N * SUM [Forecast(y) - Observation(o)]**2

Where N is the total number of forecast/observed data pairs. The Brier Score is essentially the mean-squared error of the probability forecasts extended to discrete events where Observation(o)=1 if an event occurs and = 0 if the event does not occur and similarly for the forecasts . Note that as a score on error, the Brier Score for perfect forecasts is BS = 0 and less accurate forecasts receive higher Brier scores. The score takes on values only in the interval [0,1].

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[30] D. Wilks, Statistical Methods in the Atmospheric Sciences, Academic Press, 1995, pg. 259.

Skill scores are used as performance measures for forecasts[31]. Skill scores measure how well an event type or weather-attribute range is predicted relative to the variability in the weather. Suppose the event is "rain" for a given day, and suppose it rains once every five days as a climatic average. A "skillful" forecast would use some method to identify correctly which days would have rain in a sample period, whereas a forecast based on nothing more than the average occurrence could only predict that it would rain on 20% of the days in the sample period. Suppose the methodical forecast was 80% correct, then the skill score is calculated as:

$$\frac{\text{\% correct forecasts - \% average occurrence}}{\text{100\% - \%average occurrence}} \quad \text{e.g.} \quad \frac{80\% - 20\%}{100\% - 20\%} = 75\%$$

This score is normalized so that a success rate of only 20% gives a 0% skill. An alternative way of calculating this (the Heidke skill score) is based on contingency tables of forecasted and observed events.

In all these cases, a 100% success in forecasting will give a 100% score and the 0% score is relative to the variability of the event. A skill score for a forecast can go negative. A negative score would indicate that the forecast model is trying to stretch its scale too far, for instance running meso scale models too far into synoptic domains. This is over-extending the particular initialization data and ignoring the climatic statistics that should bound long-horizon predictions. Note also that the variability is relative to how finely the event is defined. If the event is not just rain somewhere during the day in a region, but rather between 0.1 and 0.2 inches of rain on a particular route between noon and 1 PM, the occurrence is rarer. Say it occurs in only 1% of the cases. A fine-scale forecast that is right just 10% of the time has a skill score of about 9%, but it would have a negative score in the more aggregate case. Also, the fine-scale forecast would need to be only 75% correct to get the 75% score compared to the 80% in the more aggregate, or coarser scale example. This illustrates that as we demand better resolution (going from synoptic to meso- or micro-scale forecasting) the skill score is more lenient, climatological information is less relevant, and initialization from immediate observations is more important. Skill scores should not be compared across scales.

6.3.5.2 NWP Model Predictive Performance

The accuracy of numerical weather prediction depends on (1) an understanding of the physical laws of

[31] Thornes, SIRWEC 1998, op. cit.

atmospheric behavior, (2) the ability to define through observations and analysis the state of the atmosphere at the initial time of the forecast, and (3) the accuracy with which the solutions of the continuous equations describing the rate of change of atmospheric variables are approximated by numerical means. The greatest success has been achieved in predicting the motion of large scale (>1600 km) pressure systems in the atmosphere for relatively short periods of time (1-5 days). For such space and time scales, the poorly understood energy sources and frictional dissipative forces may be approximated by relatively simple formulations, and rather coarse horizontal resolutions (100-200 km) may be used.

The skill of numerical weather prediction forecast of temperature and winds in the free atmosphere [e.g., above the 500 hectoPascal (hPa) or millibar (mbar) pressure level, approx. 18,000 feet above sea level, which is nominally at 1000 hPa] continues to improve steadily. For example, since the mid-1980s the root mean square vector error (RMSVE) of the 24 hour 250 hPa wind forecasts produced by the operational global NCEP model has declined from 10 m/sec to 7.5 m/sec. Experience with NWS medium range forecast or the European Center for Medium Range Weather Forecasts (ECMWF) day five predictions of mean sea-level pressure over North America indicates that standardized anomaly correlation coefficient scores range from 30 to 65. A standardized anomaly is the anomaly divided by the climatological standard deviation and is used to avoid overweighting anomalies at higher latitudes relative to lower latitudes. Experience suggests that a standardized score greater than 20 has operational forecast value with the higher (lower) scores occurring winter (summer). At NCEP, the forecasters have been able to improve upon the medium range forecast anomaly correlation coefficient scores for 5-day mean sea level pressure forecasts.

Forecasts of surface weather elements such as temperature, precipitation type and amount, ceiling and visibility are prepared objectively the MOS technique using regression equations for individual weather elements at specified locations, with the regression coefficients determined from predictors provided by operational NCEP models. MOS guidance is relayed to NWS offices and a wide variety of external users. The MOS product has become very competitive with the forecaster as measured by standard skill scores. Over the 25 year period ending in 1992, for example, the mean absolute error (MAE) of NWS maximum and minimum temperatures issued to the general public decreased by 1.08 degree F (0.6 degree C).

The skill score in day-to-day temperature forecasting approaches zero at 7-8 days horizon. For probability-of-precipitation (PoP) forecasts the zero skill level is typically reached 2-3 days earlier. Precipitation amount forecasts typically show little skill beyond 3 days, while probability of thunderstorm forecasts may be skillful out to only 1-2 days ahead. These varying skill levels reflect the fact that existing numerical weather prediction models such as the medium range forecast have become very good at making large scale circulation and temperature forecasts, but are less successful in making weather forecasts.

Two examples of how NWS forecasts fare against MOS techniques are shown in Figures 6.3 and

6.4[32]. Here, linear regression on the trends of accuracy of NWS forecasts and MOS indicate that the difference in root mean squared error (RMSE) between the NWS and MOS 12-24 hour temperature forecasts has dropped from 4.4 degrees F to 3.2 degrees over the last two decades (top figure). Similarly, the difference in improvement over climatological PoP forecasts has dropped from 4.4% to 2.4% (second figure). In 1993, for example, MOS temperature forecasts from the Nested Grid Model (NGM) for the 12-24 hour period for the United States were correct within 5 degrees F approximately 85% of the time. Given typical temperature gradients and the relatively large area associated with most current zone forecasts, such as that for metropolitan areas, this probably represents an accuracy that is at the edge of detection for most of the general public.

(figures removed)

A second example is of two performance measures for a critical numerical weather prediction model used in the forecast process[33]. Figures 6.5 and 6.6 refer to the verification statistics for the 40-km. RUC-2 model compared to the 32-km Eta model for the period 10 June 1999 through 15 July 1999. The first figure shows two charts for the temperature forecast errors and the wind vector forecast errors for the atmosphere using the RUC-2 and Eta model runs. The first chart plots the standard deviation (SD) of each model's forecast prediction value minus the radiosonde observation value (FCST-RAOB) for the atmosphere's pressure levels versus the temperature bias range. The second chart plots the root mean square (RMS) of each model's forecast prediction value minus the radiosonde observation value (FCST-RAOB) for the atmosphere's pressure levels versus the velocity bias range (in m/s).

Figure 6.6 has two charts showing the height forecast errors and the relative humidity forecast errors for the atmosphere using the RUC-2 and Eta model runs. The first chart plots the standard deviation of each model's forecast prediction value minus the radiosonde observation value (FCST-RAOB) for the atmosphere's pressure levels versus the height bias range (in meters). The second chart plots the root mean square (RMS) of each model's forecast prediction value minus the radiosonde observation value (FCST-RAOB) for the atmosphere's pressure levels versus the percentage bias range.

A third example of performance improvement is shown in Figure 6.7 for the use of the NWS Weather Surveillance Radar (WSR) - 1988 Doppler (also known as NEXRAD). Improvements in probabilities of detection (PODs) and declines in false alarm ratios (FARs) for the detection of severe local storms

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[32] Brooks, H. et. al., The Future of Weather Forecasting: The Eras of Revolution and Reconstruction, 15th AMS Conference on Weather Analysis and Forecasting, Norfolk, Virginia, 19-23 August 1996.

[33] Verification Statistics for 40-km RUC-2 Compared to 32-km Eta, http://maps.fsl.noaa.gov/RUCMAPS.stats.html.

with this system are shown for the time period of 1986 through 1996[34].

A fourth example, in Figure 6.8, of projected performance improvement in forecasting over time for detecting severe storms is given below for an individual NWS Weather Forecast Office (WFO) versus the NWS as a whole. In this case, the Tulsa WFO has published these detection statistics on their web site at: http://www.nwstulsa.noaa.gov.

6.4 ITS Context

The WIST-DSS is considered part of the Intelligent Transportation System (ITS), as defined by the National ITS Architecture. While the National ITS Architecture does not necessarily detail everything that will be deployed as part of the ITS, it is the framework for ITS standards, integration and regional architectures that will be required for federal-aid funding.

Weather information is one area that is not well detailed in the National ITS Architecture. However, it is important for the WIST-DSS to make use of information flows within ITS as interfaces to receive transportation-specific information and to disseminate information to decision makers within the transportation system. In order to define these information flows in a way that will be common to all ITS deployers, the National ITS Architecture should be referred to. ESS interfaces are more fully described in the ESS standard. The National ITS Architecture only superficially describes NWS interfaces and these will be described in the next subsection.

The National ITS Architecture evolved from competitive system concepts, and has been formalized to meet requirements for thirty-one (31) user services organized in six user service bundles[35]:

1 Travel And Traffic Management (User Service Bundle)
- User Services:
- 1.1 Pre-trip Travel Information
- 1.2 En-route Driver Information
- 1.3 Route Guidance
- 1.4 Ride Matching And Reservation
- 1.5 Traveler Services Information

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[34] Crum, T. et. al., An Update on the NEXRAD Program and Future WSR-88D Support to Operations, pp. 253-262, Journal of Weather and Forecasting, June 1998.

[35] Listed in the Hypertext Architecture Version 2.2, generation date 6/1/99 found at the URL http://www.odetics.com/itsarch/. The Archived Data User Service (ADUS) is being added after version 2.2.

1.6 Traffic Control
1.7 Incident Management
1.8 Travel Demand Management
1.9 Emissions Testing And Mitigation
1.10 Highway-rail Intersection

2 Public Transportation Management (User Service Bundle)
User Services:
2.1 Public Transportation Management
2.2 En-route Transit Information
2.3 Personalized Public Transit
2.4 Public Travel Security

3 Electronic Payment (User Service Bundle)
User Service:
3.1 Electronic Payment Services

4 Commercial Vehicle Operations (User Service Bundle)
User Services:
4.1 Commercial Vehicle Electronic Clearance
4.2 Automated Roadside Safety Inspection
4.3 On-board Safety Monitoring
4.4 Commercial Vehicle Administrative Processes
4.5 Hazardous Material Incident Response
4.6 Commercial Fleet Management

5 Emergency Management (User Service Bundle)
User Services:
5.1 Emergency Notification And Personal Security
5.2 Emergency Vehicle Management

6 Advanced Vehicle Safety Systems (User Service Bundle)
User Services:
6.1 Longitudinal Collision Avoidance
6.2 Lateral Collision Avoidance
6.3 Intersection Collision Avoidance
6.4 Vision Enhancement For Crash Avoidance
6.5 Safety Readiness
6.6 Pre-crash Restraint Deployment
6.7 Automated Vehicle Operation

7 Information Management (User Service Bundle)
User Service:
7.1 Archived Data

Each user service has a stakeholder group whose needs are articulated in a user service narrative. This needs narrative is then analyzed for requirements allocated to the architecture. The architecture is represented in both physical and logical forms. The physical representation defines subsystems as entities with physical communication connections. The logical representation defines process specifications (pspecs) as entities with data flows as connections. Either representation may be useful, but the pspecs and data flows should be used to determine interface details that will be embodied in deployments.

At present, the most comprehensive way to define weather information data flows within the National ITS architecture is to do word searches in the electronic version of the architecture. This obtains related pspecs and data flows. A more cursory version is obtained by consulting the physical architecture at its highest level. A terminator entity called Weather Service is defined, and is the ostensible source of weather information into ITS. The definition is:

> Weather Service Terminator
>
> This terminator provides weather, hydrologic, and climate information and warnings of hazardous weather including thunderstorms, flooding, hurricanes, tornadoes, winter weather, tsunamis, and climate events. It provides current and forecast weather data that is collected and derived by the National Weather Service, private sector providers, and various research organizations. The interface provides formatted weather data products suitable for on-line processing and integration with other ITS data products as well as doppler radar images, satellite images, severe storm warnings, and other products that are formatted for presentation to various ITS users.

The physical connectivity that can be traced from this terminator is shown in the figure below:

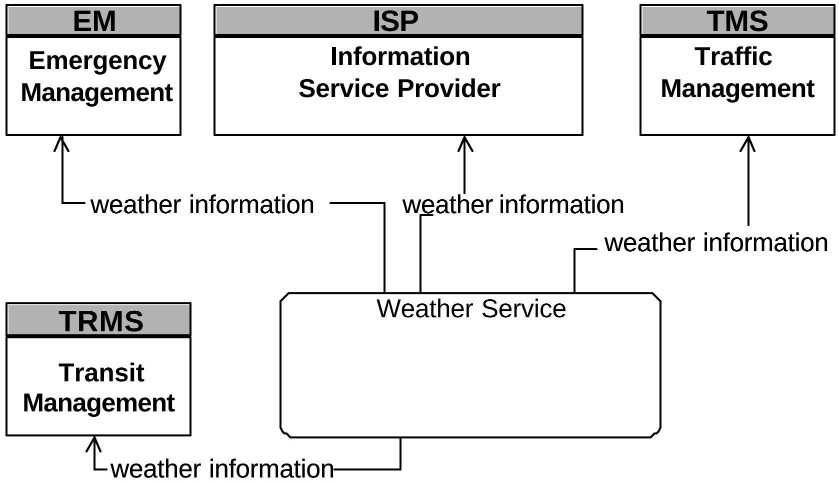

Figure 6.10: Immediate Connectivities to "Weather Service" Subsystem in the National ITS Architecture

The Weather Service provides current observations and forecasts to four first-layer subsystems: Emergency Management, Traffic Management, Transit Management and Information Service Provider (ISP). From there, decisions and weather information fan to many other subsystems. However, it is the role of the ISP specifically to be a disseminator of information, such as weather information to travelers. An operations and maintenance user service might result in an Operations and Maintenance subsystem that would also be an appropriate first-layer recipient of weather information. However, it is clear that there are other sources of weather information, and the flow is not necessarily only one-way from the terminator.

A more complete view of weather information in the ITS is obtained from searching the logical architecture. The online version of the architecture contains many cross-referencing matrices that are useful for tracing weather related information flows. The terms "weather", "environment", "snow" and "ice" were searched. The diagram below is a composite physical and logical diagram of all weather-related information flows in the National ITS Architecture.

In addition to the four subsystems connected to "Weather Service", the scan of the logical architecture also shows the roadway and vehicle subsystems. Both are fed by the Roadway Environment terminator. This terminator supplies the "environmental condition" data flow to the Process Environmental Sensor Data pspec in the roadway subsystem. It also supplies "roadside data" to the Vehicle subsystem, that can include weather-related conditions relevant to vehicle control such as iciness. The Roadway Environment-Roadway data flow to the Process Environmental Sensor Data pspec includes the structure that is addressed in the Environmental Sensor Station (ESS) standard. that has been developed with ITS sponsorship.

The Roadway Environment-Vehicle data flow to the Process Vehicle Onboard Data pspec represents an ESS-like data flow to vehicles as road-condition and surface-weather Smart Probes. These Smart Probe data are further processed through the Roadway subsystem in several steps before dissemination to several users, including back to the vehicle. This seems tortuous although it has the effect of concentrating surface-transportation specific weather observations in the one subsystem. The Smart Probe and Environmental Sensor data are then the other sources of current weather data besides the Weather Service. The Smart Probe and Environmental Sensor data and their originating subsystems are within the ITS rather than being terminators. This, including the ESS standard, stipulates coordination with surface observations standards within the NWS.

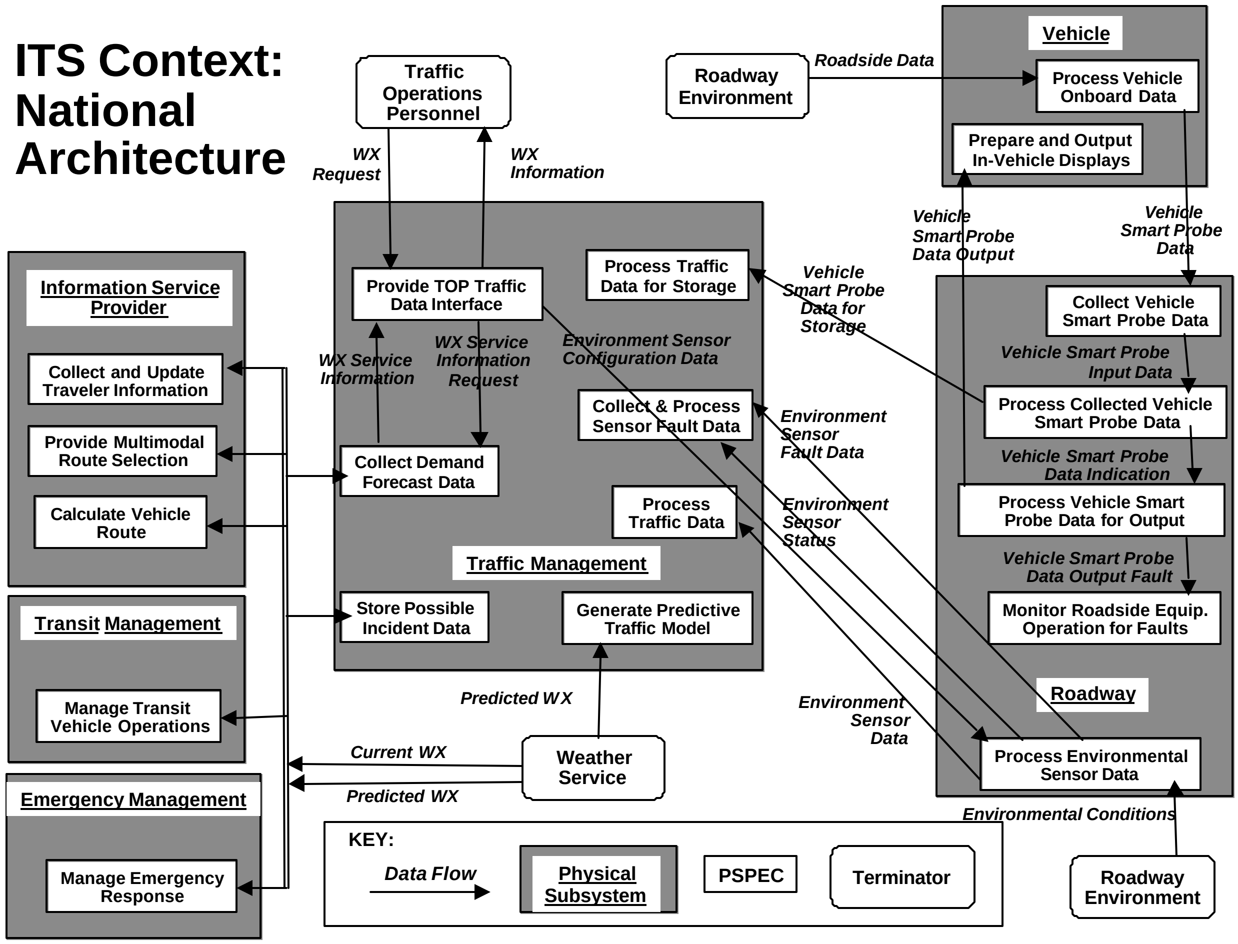

Figure 6.11: Logical Connectivities Concerning Weather Information From the National ITS Architecture

The TEA-21 legislation requires National ITS Architecture “conformity”. This stipulates the WIST-DSS through the critical standards, that include center-to-center and ATIS data dictionaries and message sets that include weather information. Also required will be integration strategies at the long-range plan level of federal-aid programming, and regional ITS architectures to accompany the Transportation Improvement Programs (TIPs) or short-range deployment plans. It is likely that the regulations will allow a degree of freedom to redraw systems within the regional ITS architectures as long as integration with other systems and standards use is maintained. If “Weather Service” is identified with the NWS (and functionally similar VAMS), then its interfaces into the ITS are largely determined by the NWS. The missing flow of information back to the NWS can include ESS observations for assimilation and requests for non-broadcast information (including manual communications with WFOs and ftp requests for NCEP products). In cases where a pspec has additional interfaces not directly involving weather information, the weather information has to support the functionality described for the pspec.

The Traffic Operations Personnel (TOP) terminator interface is the closest existing analog to the interface with a winter road maintenance manager. This interface is simply “weather request” and “weather information” data flows. The subsequent decisions are not shown in the diagram because they do not explicitly mention weather data. This is the case for almost all ITS decisions since they neither are decisions on weather nor use weather information exclusively. The WIST-DSS and context, defined to include all weather-related decision and performance feedback from the transportation system, is therefore larger than the weather-related part of the ITS shown in the architecture. However, a practical guideline is to draw the boundary of the WIST-DSS just outside of the pspecs that explicitly take weather information and that are concerned with its filtering, fusion and display. Clearly the TOP terminator and Traffic Management subsystem has to be defined broadly to include maintenance functions in this case. It could be argued that other subsystems and terminators use weather information only as filtered, fused and presented by the “central” set of subsystems and pspecs (e.g., ISPs to travelers generally, or Transit Management to Transit Users). However, as consideration of needs is expanded in the WIST-DSS, it may also be necessary to look more broadly for requirements. The bounding of the WIST-DSS within the ITS is therefore an open issue. This also bears on how a market package, if not a user service, might be defined for weather within the National ITS Architecture. These issues will be addressed, at least in part under development of the Environmental/Weather Information Management user service and the ITSA/WIATF weather architecture effort.

6.5 The National Weather Service (NWS) Context

The National Weather Service (NWS) disseminates hydrometeorological and other environmental data and information to protect life and property from natural hazards. To this end there are ten services they provide:

1. The NOAAPort broadcast system,
2. The National Oceanic and Atmospheric Administration (NOAA) Family of Services (FOS),
3. NOAA Weather Radio (NWR),
4. NOAA Weather Wire Service (NWWS),
5. The NOAA Emergency Managers Weather Information Network (EMWIN),
6. The NWS Advanced Interactive Processing System (AWIPS) Local Acquisition and Dissemination System (LDADS),
7. The NOAA Electronic Networks,
8. The NOAA Telephone Systems, and,
9. The NOAA WEATHERCOPY System.
10. The NEXRAD Information Dissemination Service (NIDS)

The figure below shows the various information services that are described subsequently in the text. The communications layers are shown separately, but are often bundled with the information service. Delivery into the RWIS or WIST-DSS is shown for three general recipients. Only the National Warning System (NAWAS) is strictly limited to emergency managers. Other official users may receive services as ISPs or as the general public. Channels that terminate within the communications layer suggest that access is now primarily within the NWS but could be extended.

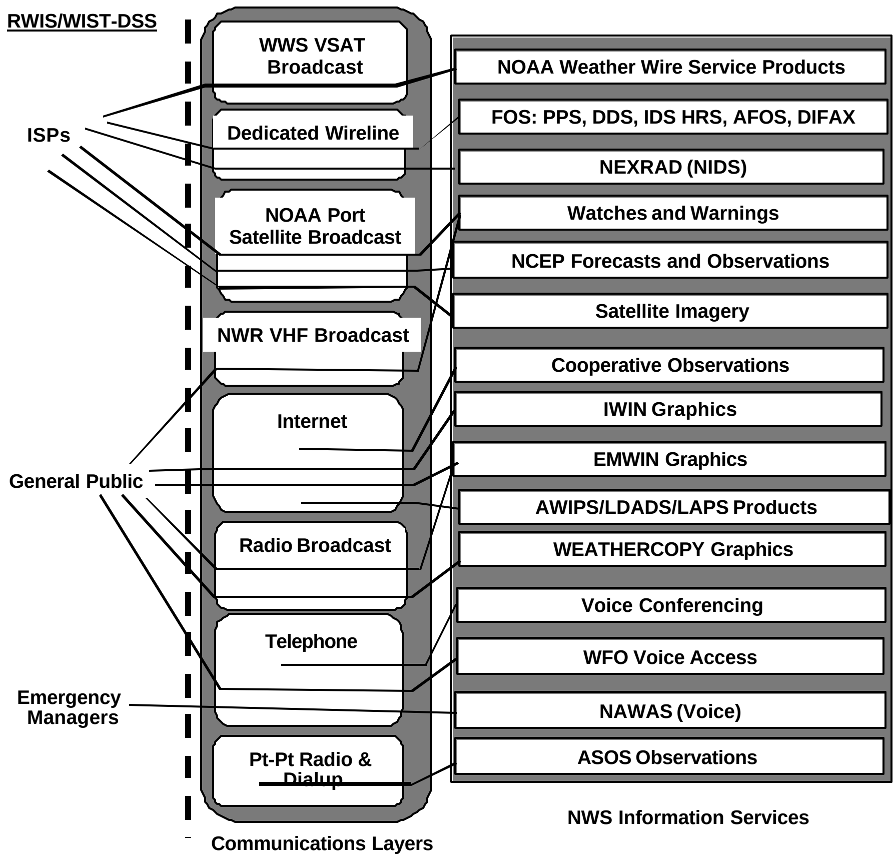

Figure 6.12: NWS Information Services and Dissemination Channels

6.5.1 The NOAAPORT Broadcast System

The NOAAPORT broadcast system provides a one-way broadcast communication of NOAA environmental data and information to NOAA and external users. This broadcast service is implemented by a commercial provider of satellite C-band communications. NOAAPORT data and products are formatted for transmission by the NWS and are currently provided in four individual signals, one for each of the four NOAAPORT data streams (channels). Each channel uses the same data format. The data characteristics of each channel are as follows:

- GOES East Channel - From the GOES East satellite, a data stream consisting of the following imagery products: visible, infrared, and water vapor for the Eastern Conterminous United States (CONUS), Puerto Rico, supernational composites, and Northern Hemisphere (NH) composites.

- GOES West Channel - From the GOES West satellite, a data stream consisting of the following imagery products: visible, infrared, water vapor for CONUS, Alaska, and Hawaii; supernational composites, and NH composites.

- NCEP/NWSTG Channel - From the NWS Telecommunications Gateway (NWSTG), a data stream consisting of model output from the National Centers for Environmental Prediction (NCEP); the observations, forecasts, watches and warnings produced by NWS Forecast Offices; and most observational data over North America.

- Non-GOES Imagery/DCP Data Channel This channel's data stream currently includes GOES Data Collection Platform (DCP) data, the Japan Geostationary Meteorological Satellite (GMS)/GOES - West/GOES - East/METEOSAT composites for visible, IR, and water vapor products (every 3 hours), and reserve capacity for selected other satellite imagery to be acquired by NESDIS for future field applications.

NOAAPORT products have the following characteristics:

- Every product has a World Meteorological Organization (WMO) header.

- Every product is transmitted in one of several code forms or formats depending on data type as identified in the header.

- The products appear on one of several NOAAPORT channels as earlier described.

- Although many products appear regularly, there is no product schedule. NOAAPORT is a data-driven system, not a time-driven system.

- The products available are determined by current weather patterns and available data are subject to change: NESDIS satellite products; NWSTG text, Redbook graphics (which are graphic products sent over the NOAAPORT satellite broadcast network (SBN)), and gridded binary (GRIB) products.

6.5.2 The NOAA Family of Services (FOS) System

The NOAA Family of Services (FOS) provides access to all NWS data and products at nominal cost recovery to private sector organizations, universities, and defense institutions who then repackage and tailor it for specific clients. The NWS makes available all of its data and products through systems such as the FOS to ensure that weather information providers have timely operational access to this resource. In the immediate and long term, an assessment will be made as to whether NOAAPORT can serve the FOS function. Unless otherwise directed by law, the NWS will continue to encourage the greatest participation by the private sector in adding value and serving specific client needs.

Since 1983, the NWS has provided external user access in the Washington, DC, area to the FOS via dedicated telecommunications access lines. All FOS data services are driven by the NWS Telecommunications Gateway (NWSTG) computer system at NWS headquarters in Silver Spring, MD.

Users may obtain the individual services from the NWS for a one-time connection charge and an annual user fee. Several private companies subscribe to the FOS and then resell the data as received and/or provide value-added information services for their customers. The FOS includes the following services:

- Public Product Service (PPS): Carries all public warnings and watches, and various hydrologic and miscellaneous forecasts and products.

- Domestic Data Service (DDS): Carries basic observations and various aviation, marine, and miscellaneous products.

- International Data Service (IDS): Carries worldwide surface and upper-air observations and other miscellaneous products.

- High Resolution Data Service (HRS): Carries global model-derived forecasts and analyses, most of which are in the GRIB format.

- AFOS Graphics Service (AGS): Carries centrally-produced weather products (charts) in the vector graphic format used in the NWS Automation of Field Operations and Services (AFOS) system.

- Digital Facsimile Service (DIFAX): Carries weather analysis and prognosis products related primarily to aviation.

The NWS plans no major changes for the FOS as a result of modernization, but as the program progresses, data currently transmitted on FOS circuits could also become available via NOAAPORT. This system will be a one-way broadcast of a comprehensive range of environmental data and products to both NOAA users and external users throughout the United States, and much of Canada and south to the Caribbean.

6.5.3 The NOAA Weather Radio (NWR) System

NOAA Weather Radio is the "Voice of the National Weather Service". NOAA Weather Radio broadcasts NWS warnings, watches, forecasts and other hazard information 24 hours a day. NOAA

Weather Radio is provided as a public service by NOAA. NWS field offices generate the data and send it directly to the public via a nationwide network of VHF-FM radio transmitter sites. The radio system broadcasts weather data from more than 480 transmitter sites across the nation, as well as Puerto Rico, the Virgin Islands, Guam and American Samoa. More than 73 percent of the population currently can receive broadcasts. The current network expansion program will increase this coverage to more than 95 percent. In many cases, cable TV weather channels rebroadcast this information as audio. In addition, the message is often rebroadcast on AM radio channels by local Traveler Information Services. Some states have low power transmitters at rest areas on Interstate roadways.

Weather radios equipped with a special alarm tone feature can sound an alert and give immediate information about a life-threatening situation. During an emergency, NWS forecasters will interrupt routine weather radio programming and send out the special tone that activates weather radios in the listening area.

NOAA Weather Radio now broadcasts warning and post-event information for all types of hazards both natural (such as severe weather, earthquakes and volcano activity) and technological (such as chemical releases or oil spills). Working with other Federal agencies and the Federal Communications Commission's (FCC's) new Emergency Alert System (EAS), NOAA Weather Radio is an "all hazards" radio network, making it the single source for the most comprehensive weather and emergency information available to the public. The receivers are especially valuable in places that are entrusted with public safety.

Additional NOAA Weather Radio transmitters will continue to expand the nationwide network coverage to more rural areas. Additional digital technology, called the NWS Console Replacement System (CRS), will provide automated broadcast capability for more timely service and also will allow messages to be received automatically by all the communications industries of the Internet, cable, satellites and other media through the FCC's EAS. The digital-to-voice technology automates the recording of the products, reducing the need for manual involvement. Messages flow directly from local NWS computers into the weather radio console, where they will be converted automatically to audio and sent to transmitter sites for broadcast to the public. The NWS expects automation to improve the timeliness of weather warnings and other critical messages.

The NWR product line includes a comprehensive set of weather and hydrologic products of public interest. These products are recorded as digitized messages at a program console. The console then controls the broadcast sequencing of the recorded messages and transmits the recorded audio to the transmitter site. In the modernized NWS, weather radio will remain a vital, direct communications link to the public. The NWS expects no change in the location of the existing transmitters; however, they plan to install many new transmitters as a result of network expansion. The NWS has reallocated the offices that generate weather radio messages for a transmitter site as modernized Weather Forecast Offices (WFOs) have opened.

6.5.4 The NOAA Weather Wire Service (NWWS) System

The existing NOAA Weather Wire Service (NWWS) is provided via a contracted Very Small Aperture Terminal (VSAT) network. VSAT is a sophisticated communications technology that allows for the use of small fixed satellite antennas in providing highly reliable communications between a central hub and almost any number – tens or thousands – of geographically dispersed sites. The DCE equipment (i.e., antennas, associated electronics, and controllers) are primarily Government - owned. The system currently collects and disseminates daily more than 7000 NWS weather messages (known as "products") to more than 1200 customers. From among all these products, each user may pre-select those which are of particular interest to them, by using message headers which are designed to identify each product available in terms of source of the product, category identifier, and specific product designator. These messages range from an Informational Climatological Outlook, or a River Recreation Statement, to an action oriented Tornado Warning. The system currently utilizes C-band spread spectrum satellite technology. The service is available in all 50 states plus Puerto Rico. Products originate at, and are uplinked from, a large number of locations, including many forecast offices, and several National Centers, and the Earthquake and Geomagnetic Center in Golden CO. Warning products are consistently delivered within 4-6 seconds. Traffic volume consists of a daily average of 11,179,403 characters with a monthly total of 345,561,509 characters.

The NWS intends to replace the existing NWWS with a new service that will meet or exceed the high level of performance provided by the current NWWS while delivering a larger and richer range of products to users. The service will meet high performance standards in a way that is attractive in technology and cost to end users. This new system will retain the designation NWWS, but will generally be referred to as the "replacement NWWS". The function of the replacement NWWS will be to provide the telecommunications facilities and infrastructure to provide for a data collection function for the NWS. Then, an enhanced (as compared to the basic text products) set of weather products created by WFOs and other data entry facilities will be collected and provided to a central location for broadcast by various vendors. The new system is envisioned as a multi-layered configuration. A major component would utilize packet radio compression techniques enabling the NWS to uplink the complete data stream via satellite, thereby avoiding monthly data charges to customers. Homes or businesses equipped with a small antenna, standard personal computer, and off the shelf software could receive gridded, graphical, and alphanumeric data from local offices and National Centers, as well as satellite imagery and observational data.

6.5.5 The NOAA Emergency Manager's Weather Information Network (EMWIN) System

EMWIN is a non-proprietary dissemination system developed by the NWS primarily for the emergency management community. It provides a continuous, dedicated low speed data broadcast of up to 5,000 pages per day using an audio signal. The EMWIN data stream consists of:

- Real-time weather warnings, watches, advisories, forecasts,

- A subset of alphanumeric products for each state,
- A limited suite of non value-added graphical products, and
- Some satellite imagery.

End user software provides a friendly environment to monitor the weather, set alarms, autoprint, etc., from a personal computer (PC). To receive and make use of the EMWIN data stream, a user must be in acceptable signal range (up to about 40 miles from a transmitter) and needs:

- At a minimum, a 80386 or 80486 personal computer with DOS 5.0 or greater and Windows 3.1 or greater;
- A relatively inexpensive portable receiver with antenna based on NOAA Weather Radio modified to receive the transmitted frequency; and
- A custom built, but inexpensive demodulator that receives the signal from the receiver and feeds it to the serial port of the user's computer system.

The EMWIN data stream was designed to run at minimal cost to the NWS and at no recurring costs to users in range of the signal. Basic software developed, but unsupported, by the NWS to meet minimum needs of users is available for free, and can be downloaded from the Internet. Low cost, supported commercial software with more features is available.

The EMWIN data stream can effectively meet the needs of public safety managers, schools, and special needs groups such as the deaf and hearing impaired for direct and timely access to large amounts of weather and warning information. The NWS has identified EMWIN as one of a number of dissemination technologies in a multilayered approach that the NWS must use to meet its goal of maximizing the dissemination of its warning and forecast information.

EMWIN is a suite of data access methods which make available a live stream of weather and other critical emergency information. Each method has unique advantages. EMWIN's present methods in use or under development for disseminating the basic data stream include radio, Internet, and satellite capability.

Radio broadcast transmits digital weather information using inexpensive radio broadcast and PC technologies. The NWS (and other public and private agencies) transmits selected text, graphics, and imagery products as an audio signal on a dedicated VHF or UHF radio frequency. This information can be received, by anyone within the 40-50 mile broadcast area, using an inexpensive radio receiver, a demodulator, and a PC. EMWIN software on a PC, running under Windows, receives the signal through a serial port, stores the received weather products onto disk, and simultaneously allows one to display this information.

Via the Internet, the Interactive Weather Information Network (IWIN) page uses HTML formatting and additional hyperlinks to an EMWIN server that ingests the data. Access to this data, as a linked series of clickable screens, is provided to clients operating web browsers such as Internet Explorer or Netscape. Graphics or text-only access is provided. FTP access is also available. While Internet access is convenient, there are times, especially during major weather events, that access may be difficult or impossible due to server overloads. The IWIN server has been online since September 1995, handling an average load of 1 million connections per day with peak loads of over 2 million connections per day during major weather events.

Via satellite broadcast, the NWS distributes EMWIN on the GOES 8 and GOES 10 satellites. GOES 8 is at 75 degrees West, elevation 45 degrees (from the latitude of Washington, DC). GOES 10 is at 135 degrees West. Data are uplinked to satellite from the NOAA Command and Data Acquisition (CDA) Station on Wallops Island, VA. The NWS GOES downlink frequency used for the 9600 baud EMWIN datastream is 1690.725 MHz, 275 KHz lower than the standard WEFAX 1691.0 MHz signal. The signal is passed through a down convertor, received as if a radio signal at 137.225 MHz, for example, and then demodulated to 9600 baud. The EMWIN data is also currently uplinked to the Satellite Broadcasting System (SBS) 6 satellite by Spacecom Systems of Tulsa, OK as a public service. SBS 6 is at 74 degrees West: Ku-band, Transponder 13, FM-FM, DFSK, 0.5425 MHz subcarrier.

6.5.6 The NWS AWIPS Local Data Acquisition and Dissemination System (LDADS)

The NWS Advanced Interactive Processing System (AWIPS) Local Acquisition and Dissemination System (LDADS) is the external interface for the modernized WFOs. It has always been deemed important that WFOs must be able to communicate advanced weather information to emergency preparedness agencies and other users. Otherwise, the full benefit of the NWS modernization will not be realized. Concurrent with the modernization, many state and local municipal governments, public utility companies, research organizations and private industries are installing meteorological observing systems suitable for their respective needs. This includes road-weather mesoscale observing networks (mesonets), public utility mesonets, boundary layer profilers from urban air pollution monitoring systems, hydrological observations from urban control districts, and airport windshear alert systems. Other datasets include severe weather spotter networks, cooperative observer networks, Automated Surface Observing Systems (ASOS), etc., using Intranet, Internet, and dedicated and dialup telephone connections. WFO acquisition of these local datasets for integration into AWIPS would significantly enhance existing NWS observing systems.

LDADS includes several important AWIPS elements including the ability to: 1) acquire and integrate a diverse set of local meteorological and hydrological observations; 2) perform quality control checks on locally acquired meteorological observations, and; 3) disseminate textual, graphical and image weather information to a wide variety of users, especially emergency managers. Essentially, LDADS facilitates two-way communication between WFOs and state and local government agencies, providing forecasters with "state-of-the community" information. The LDADS software architecture is very modular and generalized to accommodate a large degree of regional data variability between WFOs. The design also allows for future changes and upgrades as new local observations or AWIPS dissemination information becomes available. LDADS functionality will be integrated across two networks within the WFO. The first is the AWIPS internal network, consisting of communication systems, data processing systems, and forecaster workstations, and second, the external local area network (LAN), which consists of a terminal server, data servers, modem banks, a failover switch, facsimile server and dedicated and dialup communications lines to external user information systems.

6.5.7 NOAA Electronic Networks

Electronic networks such as the Internet and Intranet are an important way to share information by making all data and information available to interested parties. However, digital data, unlike printed data or analog information, is easily altered in a way that cannot be detected and it is difficult to guarantee the origin, timeliness, authenticity, or accuracy of network information. Therefore, the NWS will not consider electronic networks an operational system and will not depend on them to support forecast and warning operations. They will be used to solicit and collect cooperative and severe storm reports via e-mail.

In the near term, policy at the NWS will be developed to underscore the non-operational aspect of electronic networks as well as guidelines for consistent formats that will enhance the image of the NWS. For the intermediate and long terms, all NWS offices will be encouraged to use electronic networks to their fullest with minimal basic guidelines for its use. The intent is to encourage innovation and creativity.

6.5.8 NOAA Telephone Systems

The use of telephone systems falls into two broad categories: emergency operations and public service. For *emergency operations*, a national forecast and warning coordination hotline, called the National Warning System (NAWAS), was implemented with capabilities to conduct multiple coordination calls between NWS offices as well as between NWS offices and emergency management warning points and operations centers. The next generation NAWAS will provide such a voice communication capability. Among the most crucial elements of managing NWS's field operations in the NWS modernization era is coordination and communication. Having communications hardware that is intuitive and user friendly, flexible and powerful, is essential. Voice communications need to work in consonance with AWIPS inter-site coordination capabilities to enable field meteorologists and hydrologists to communicate and exchange both ideas and information. The structure and flexibility of a system like NAWAS is very important to the NWS. The need is especially prominent as the NWS changes how it prepares and issues watches for severe local storms. As the NWS migrates from the National Center concept, substantial coordination will be required, both internally within the NWS and externally between the NWS and the emergency management community.

Unlisted “1-800" numbers will be placed at each WFO to be used by emergency management officials and entities supporting the warning process who do not have drops on the forecast coordination hot line. Similarly, video teleconferencing capabilities will be implemented between the NCEPs, NWS Headquarters offices, and appropriate Federal agencies. In the intermediate and long terms, video teleconferencing will be extended to all NWS offices to support both internal and external forecast coordination. The NWS will work with FEMA to reduce the need for unlisted “1-800" numbers by the emergency management community.

For *public access*, the NWS will continue to support the ability of the public to call their local office and to receive weather information by phone. In the near term, options will be explored to provide menu options for various recorded messages as well as the ability to talk to a forecaster during normal business hours. Persons requesting repeated special forecast information will be advised to seek the services of the private meteorological community. Telephone service to the public will not be expanded in the intermediate and long terms since other options including NWR, the next generation of the NWWS, Internet, and the private sector offer better solutions.

6.5.9 NOAA WEATHERCOPY System

The NOAA WEATHERCOPY system uses VHF radio broadcast (associated with the NWR) and a relatively low cost receiver with no significant recurring costs that provides users up-to-date printed and graphic weather information. The receiver is easily programmed by the user to meet their specific needs. WEATHERCOPY has many applications to address current NWS dissemination needs. Primarily, the system can provide timely weather warnings and forecasts to the hearing impaired. The system can also be effectively used by emergency managers, as is now done in Canada. Another possible application of WEATHERCOPY is its ability to transmit a specific product to a particular user with minimal impact on other users. Future NWS applications for WEATHERCOPY, or a similar system, are without limit as the importance of dissemination increases. If NWR is to expand and become a true "All-Hazards" dissemination tool, WEATHERCOPY technology could greatly improve its usefulness.

6.5.10 NEXRAD Information Dissemination Service (NIDS)

The NIDS provides dedicated access ports to four competitively-selected ISPs who then process the data for end users and recover costs by subscription fee. End-user dissemination will be by various means, including the Internet. Low resolution products (especially reflectivity) are often available at free Internet sites. Additional access is also available to official state agencies (e.g., emergency management) but these privileges are not widely used. The NIDS program will be supplanted in the near future with a new open architecture. End users may then access data directly, but will more likely still depend on an ISP for products.

7.0 Operational Scenarios

Operational scenarios demonstrate the operational concept as sequences of time-correlated events. In iterative requirements development they are also the means of obtaining system requirements from a description of existing operations. The approach in this version of the STWDSR is to develop detailed weather and operational scenarios based on decision maker needs (decisions), to expose these to stakeholders for reaction, and thereby to refine the requirements on the WIST-DSS. A highway operational scenario is combined with a weather event and information scenario for this purpose.

7.1 Highway Operational Scenarios

7.1.1 Highway Maintenance Decisions and Weather Threats

A schematic of the winter highway maintenance decision process is shown below. This is the bottom half of a full scenario. The top half consists of the development of the weather event, its effects on the transportation system, and the intermediate information system that connects the weather events to decision making. In this case the information system is presently the ITS with RWIS and prescriptive requirements will lead to the WIST-DSS embedded in the ITS.

The figure shows the sets of decisions, from the needs list. These are coupled with types of resources controlled by the decisions. The states of the resources as controlled by decisions are the outputs. The scale at the bottom relates the decisions to space-time horizons that will correlate with information sources. Going from climatic to micro-scale implies increasingly localized domains of information at shorter time horizons. This generally means going from large datasets processed through formal models, to immediate observations, both electro-mechanical and human-sensory. Scale only generally indicates a time ordering. In some cases, decisions at a given scale may be before or after the prompting weather event (e.g., anti-icing versus deicing treatments).

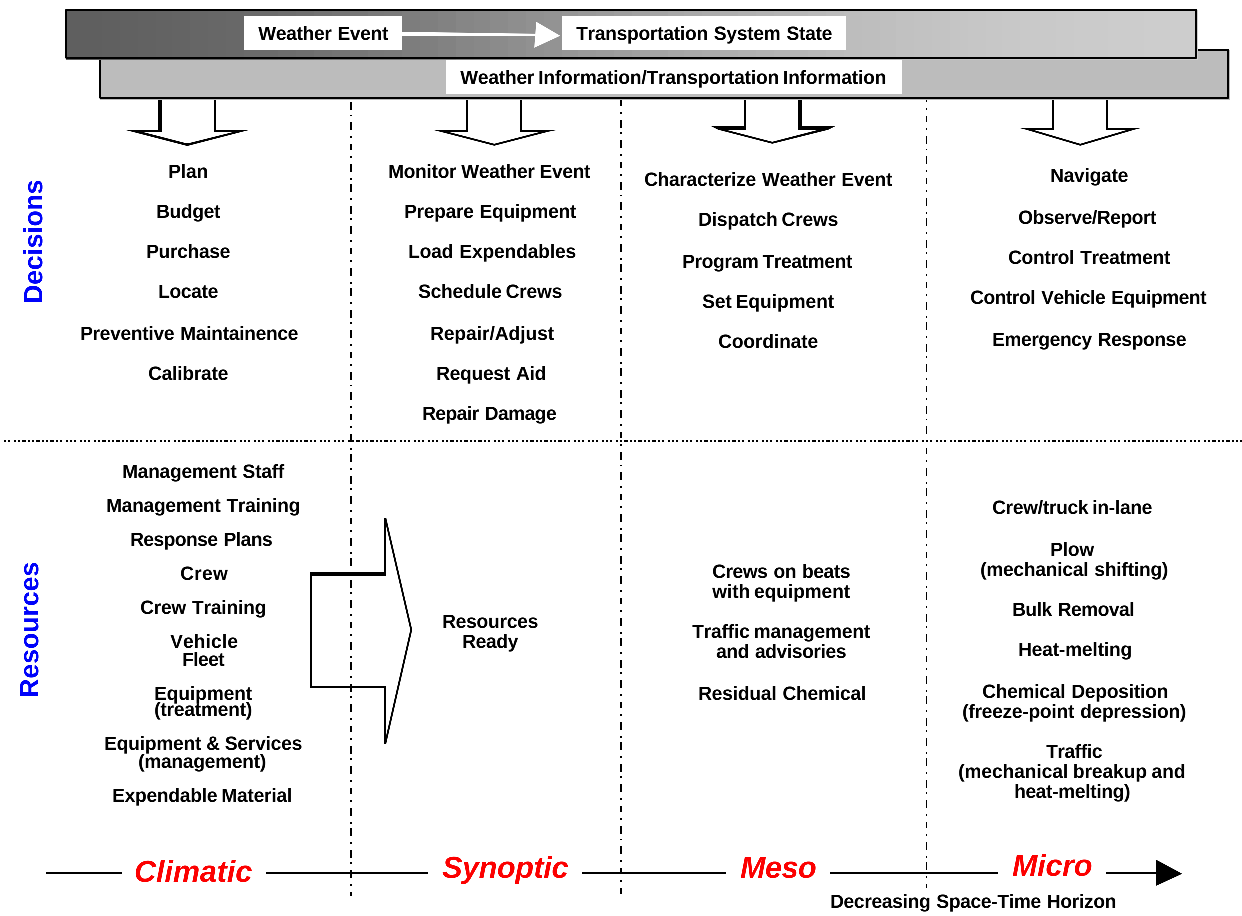

Figure 7.1: Winter Highway Maintenance Decision Schematic

The decisions (needs), are checked against the meteorological threats to highways and what can be done to mitigate threats by treatment or other responses within the responsibility of highway maintenance and other operating agencies. This threat analysis is shown in the table below.

Table 7.1: Decisions as Responses to Meteorological Threats

Meteorological Threat	Highway Transp. Impact	Treatment	Other Response
Visibility: fog, hydrometeors, smoke, dust	obscured visibility	dispersion	facility location, variable speed limit, road closure
Winds	vehicle instability, facility damage	none	facility design, advisory, road closure, damage repair
Hydrometeor impact (hail)	vehicle and facility damage	none	advisory to take shelter, damage repair
Flood from rain or meltoff	road obstruction, facility damage, vehicle trapping	flood control, pumping, mud removal	water level meters, road closure, rescue, damage repair
Mudslide, rockslide, avalanche	road obstruction, facility damage, vehicle trapping	obstruction removal	road closure, rescue, damage repair
Lightning	electrical and communication outage	none	facility design, backup facilities
Solar Flare	electrical and communication (HF, satcomm) disruption	none	facility design, circuit diversity
Precipitation, refraction layers	communication (VHF+) disruption	none	circuit diversity
Inversions/low winds, sunlight	air pollution episodes	none	traffic management
High temperature extremes	vehicle overheating, work disruption, equipment overheating, structural buckling	none	traffic management, breakdown rescue, facility design, work scheduling
Low temperature extremes	work disruption (labor and materials), vehicle freezing, equipment freezing	material/work-area heating	breakdown rescue, facility design, work scheduling
Snow/ice	friction reduction, obstruction	pretreatment (anti-icing), deicing, grit application, plowing, melting, bulk removal	traffic management, road closure, variable speed limits
Surface ice/frost	friction reduction	pretreatment (anti-icing), grit application, melting	variable speed limits
Wind+snow	snowdrift obstruction, visibility obscuration	plowing, bulk removal, snow fencing	facility design, advisories, road closure

The threats of most interest to winter highway maintenance are from surface freezing, snow/ice precipitation and winds associated with dry snow and drifting. The other threats are more or less related to winter maintenance or maintenance generally. Slides and flooding may be associated with the winter weather events. Visibility obstruction by blowing snow is a particular threat to safe treatment operations. Not to be overlooked are electrical phenomena that can effect the control and communications system vital to maintenance, or the winds and ice formation that can disrupt power and wireline communications. These are threats to both transportation system performance and treatment performance.

The small set of meteorological threats (at least when they are not finely quantified, or typed) and the small set of available treatments is what reduces the decision sets to manageable size. This allows a focus on building scenarios with the time and information dimensions. Of treatments, the entire set of direct interest to winter highway maintenance is listed in the table and consists of:

- Obstruction removal: This is defined as the removal of debris conducted by truck crews as part of other treatment operations. Disabled vehicle rescue, downed power line removal etc. are listed under "other responses" and requires coordinative information rather than direct treatment decision making.

- Material/work-area heating: This is applied to treatment preparation activities (e.g., engine starting) that are invoked by low temperatures.

- Pretreatment: Also known as anti-icing. The application of chemicals, sometimes mixed with grit, to depress road-surface freezing points prior to freezing, and to prevent bonding of frozen precipitation to the road surface. Done by truck-spreader units or by fixed sprayers, the latter usually on bridges or other frequently-freezing structures.

- Deicing: The application of chemicals, often mixed with grit, to ice that has already formed on the road surface, to accelerate melting and to facilitate mechanical breakup. Requires concentrations that may dictate application in tread-grooves only (zero-velocity spreading).

- Grit application: Spreading of sand/cinders on traveled way over ice or where freezing is threatened to enhance surface friction.

- Plowing: Mechanical displacement to roadside of frozen precipitation on road surface.

- Bulk removal: Loading and transportation of frozen precipitation off the road surface to remote locations. Usual only in urban settings with very heavy snowfall and sustained low temperatures.

- Melting: Application of heat to road surface to melt ice or snow.

- Snow fencing: Emplacement of snow fences, on a seasonal basis, to reduce drifting of snow onto road surfaces. (The planting of trees or design of grades to counter drifting is considered a construction activity subject to coordination).

Not listed are the decisions at long horizon (climatic scale) necessary to prepare for treatment and to operate the maintenance activity. However, these are as important to outcomes as the treatment activities. These preparation activities are best analyzed by working back from the treatment activities that depend on them, and forward to the outcome measures.

The "other responses" are coordinated actions that are necessary to improve transportation outcomes, but are not done by winter highway maintenance agencies. Traveler information is an example and, as part of traffic management, may have a critical role in treatment efficiency. In this group are also the long-horizon planning and facility design decisions.

7.1.2 Relating Decisions to Outcomes

Proceeding forward from the treatments leads to the outcome impacts that are the ultimate validation on any requirements to be met by the WIST-DSS. The diagram below suggests these causal relations.

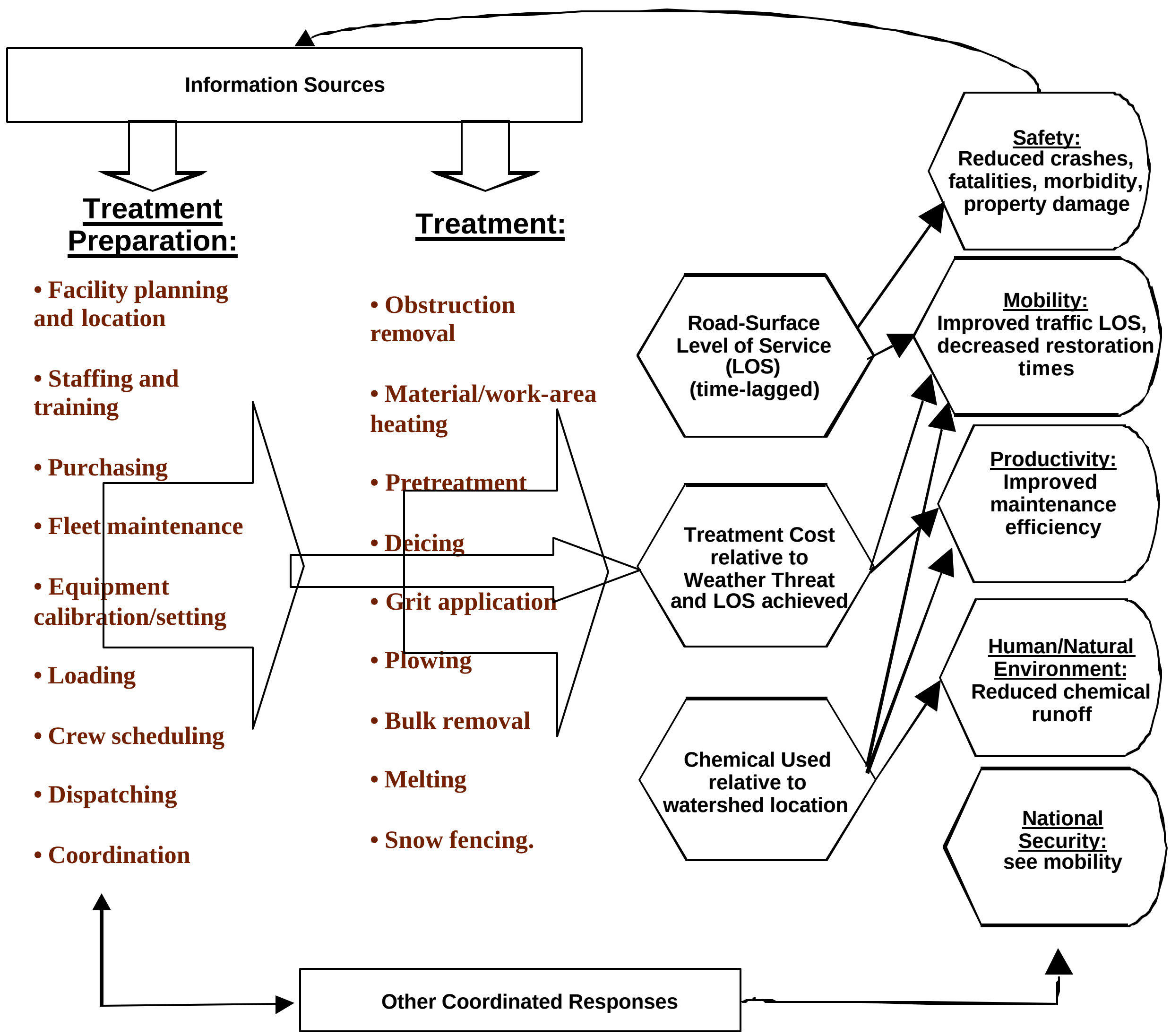

Figure 7.2: Treatment Output Relations to Outcomes

The outcomes are taken from the FHWA strategic goals. The outcomes are shown as a result of treatment operations and preparations for treatment, both of which are the outputs of decisions at different scales. Both the preparation and treatment affect three key outputs that can be related to all the outcomes. They are:

- A road-surface level of service (LOS), with time lags from onset of the weather threat.
- The treatment cost, with respect to LOS and chemical usage.
- The chemical usage, with respect to hydrological threat through runoff into biota and drinking water supplies.

These outputs are practical surrogates for the outcomes, but they cannot be maximized independently: More cost will generally provide better road LOS, as will more chemical application, but this worsens the cost outcome (efficiency) and the environmental consequences. Decisions come down to weighted evaluation of the three pre-outcomes. Information can play a role in the feasible "frontier" of outcomes, visualized as the best tradeoff in the four dimensional space of the outcomes (national security being taken as mostly correlated with the mobility outcome).

As pointed out in the Weather Team White Paper, there is a very sensitive relation between the road-surface condition (road LOS) and traffic LOS. Road LOS and other conditions (perhaps crashes related to road LOS) impact mobility (traffic LOS) more as the traffic LOS worsens toward traffic LOS F (congested flow). This relation will depend on road geometry and traffic volume as well as other conditions. In general, the most efficient treatment will involve prioritizing road LOS recovery according to some function of traffic LOS and total traffic volume affected. This probably is reflected in the observed higher costs for higher level roads. In most cases, a treatment prioritization based on an infrequently (e.g., annually) updated route list rather than immediate traffic and traffic LOS information is appropriate. This therefore becomes part of the climatic scale treatment preparation involving ESS placement and beat design for dispatching.

Definition of a road LOS index is a challenge and still under development. It is intended to be analogous to traffic LOS, in terms of a discrete set of measurable conditions highly correlated to highway-outcome performance, specifically safety and mobility. Since safety and traffic LOS are themselves not simply correlated, this is another complexity. It may well be that a high road LOS, but short of totally bare and dry, may be worse for safety than a worse road LOS because traffic will flow at higher speed. This is especially true for black ice versus snow cover. Therefore there may be more than one dimension to road LOS. Further, different kinds of vehicles can achieve different traffic LOS under specified road-surface LOS.

Highway maintenance operations may have a target for road-surface LOS, incorporating considerations of other outcome tradeoffs. This is often a “bare and dry pavement” since it is the easiest to verify and obviously maximizes safety and mobility outcomes. It does not account for costs nor is it relative to the severity and timing of a weather event. The policy indicates that mobility and safety costs from lesser road LOS dominate the treatment costs. If this is so, as is reasonable, then the problem of costs reduces to deciding what level of weather event can be totally treated in what time period. This involves preparation for a maximal event that must be known from climatology. Shorter scale information acts to determine the relation between the treatment resources provided and the time to clear the road network, by responding quickly to the exact route segments where weather threats exist.

The problem of picking the informational level relative to outcomes can be simplified if the acceptable time lag and the target road LOS are defined by policy. It is also necessary to define the acceptable environmental load from chemical application. In this case the critical relation to define is between information cost and treatment cost subject to a chemical application limit. The desired operating point is (subject to assumptions about the form of the treatment and information cost functions) where an incremental investment in information equals an incremental savings in treatment costs, or, if the chemical application constraint is binding, the information investment that meets the chemical constraint. This rule says that if current RWIS practice has very high benefit/cost ratios (treatment cost saved/information costs) it is likely that more information investment is justified, to where the *increments* of cost saved/added information cost = 1.

A road LOS index is still a useful measure of the shortfalls of treatment or for a network of roads, where not every route is subject to the bare and dry criterion, or where weather events over the maximal level are encountered and backup criteria are used. The basis of categories of road LOS is in vehicle performance relative to weather threats. A three-level categorization of vehicle performance (mobility model) has been developed as part of military mobility[36]:

- The vehicle can propel itself between two points (go/no-go)
- The vehicle can maneuver (tractive reserve).
- The vehicle can go at good speed.

The first and third criteria can be related readily to civilian traffic. The third criterion can be translated into speeds determined only by road geometry and traffic volumes, or divided into traffic LOS levels at or below the “normal” traffic LOS. The issue of safety in traffic is embedded in the second criterion. This is where problems of spot ice relative to traffic speed need to be considered. It is likely that a civilian road LOS index must consider more categories, and the dimensions of LOS and safety. In the

[36] Cold Regions Mobility Models, USACE Cold Region Research and Engineering Laboratory, CRREL Rpt. 95-1, February 1995.

project to evaluate treatment and information done by CRREL[37], several pavement condition attributes were used. These are shown in a table suggesting the two dimensions of traffic LOS and safety (spot skidding):

Table 7.2: Objective Factors for a Road Condition Index

} Less safety threat from skids

Less Movement Impedance f

Dry	Damp			
	Wet		Frost	
	Slush		Packed Snow	Black Ice
		Loose Snow		Glaze Ice

Any of these attributes can act on vehicle performance through tractability (or surface friction), which is also the most objectively measurable parameter. The evaluation specifically measured variations in a normalized friction value on control and treatment-test sections by pavement condition attributes (the tabulated list), temperature and precipitation. Typically there was a break in the friction ranges for dry/damp/wet and the forms of snow and ice. Slush had a large variance that overlapped the two extremes. Temperature ranges overlapped in their variance ranges, with the freezing point being the most distinct break for mean tractability. Precipitation forms showed overlapping spreads.

The attributes related to road-covering obstruction (rain, slush, loose snow) can also be quantified by depth. Further, coverage can be described in terms of road lanes and wheel tracks covered. All these will relate to the basic three-category vehicle capability.

The problem at this point is to choose the most meaningful road LOS measure, in relation to the outcomes and decisions. An objective measure, such as tractability (road friction) or traffic LOS can serve as an *ex post* evaluation of a decision, or as information where treatment (other than pre-treatment) must be applied remedially. Otherwise the information must be predictive, and that means sensible weather and road surface attributes analytically related to tractability or traffic LOS. Spot icing, critical to safety, can be measured objectively as road condition or variable tractability, or it can be predicted.

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[37] Test and Evaluation Project No.28: Anti-Icing technology, Field Evaluation Report, FHWA-RD-97-132, FHWA, March 1998.

If tractability is the key parameter for vehicle capability and traffic LOS, the evidence is that it needs to be measured directly and can be inferred only poorly from surface conditions. Traffic LOS and crash reports are ultimate outcome measures and can be measured objectively (LOS by traffic flow sensors), but need to be interpreted with knowledge of surface conditions. Obviously, only an analytical relation from vehicle capability to weather and road conditions will serve predictive decision making versus *ex post* evaluation. This is entirely analogous to the use of traffic LOS in highway design or ITS performance prediction. Traffic LOS is *measured* as traffic density (vehicles per mile) but the Highway Capacity Manual contains many predictive relations to road geometry, traffic type and signalization.

Relatively little work has been done on the analysis of road surface condition versus traffic LOS. It is known that some signalization control parameters respond to pavement surface conditions to account for altered queue clearing times. One report was found that used data from Ontario, in rain and winter conditions[38] characterized by observational data from the regional airport. As was found in an ITS analysis of the Seattle region, the relation of these observations to specific road segments can be poor. ESS data were available, but faulty for the period analyzed. Rain and clear days in August were analyzed and one snow day in November was compared. The study also chose relatively uncongested periods in order to discern weather effects more clearly (the objective being incident detection). The study did find significant differences in the density-volume relation for rain (above very low densities) and moreso for the snow day. At the maximum density considered (given as occupancy of 28%) the difference in flow on a freeway section was from about 3300 vehicles per hour (VPH) in clear weather, to 2950 in rain and 2800 in snow. This may be some combination of visibility and road surface effects.

7.1.3 Linking Outcomes to Information Requirements

Translation of outcome effects, or their surrogates back to information parameters is a critical step for DSS requirements. This can be reduced to finding the relations of costs, pavement LOS and chemical use to decision-support information.

Costs decided at larger scales (climatic and policy factors) are fixed at smaller, operational scales. This can be used to partition the problem of analyzing outcomes by scale. Operationally variable costs are a function of the intra-seasonal climatology (snowfall etc. as indicated by the Danish Weather Index), reliability of prediction for pretreatment, and the efficiency of dispatching to match resources to actual threats. The variable cost proportion will depend on the contracting and mutual-aid strategies. If variable costs are small, this outcome measure should be addressed mainly at climatic scales (planning). Variable costs, including vehicle operating costs, treatment materials and crew overtime, may be relatively small for direct agency operation. For contracted operations, it depends on the contracting terms–if providers use spare capacity (e.g., construction equipment) cost may be all variable. More

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[38] Hall, Fred L. and Deanna Barrow, The Effect of Weather on the Relationship Between Flow and Occupancy on Freeways, Preprint Paper No. 870526, TRB annual meeting, 1988.

variable costs make sub-climatic information more valuable for cost reduction. The other outcomes necessarily depend on adequate resources provided, mostly as fixed costs, but pavement LOS and chemical use depend directly on the operational and warning-scale decisions, and on the variable cost component.

The problem of variable cost minimization is to allocate variable assets where and when they are needed to avoid negative outcomes. Since all decisions are prospective, this depends on predictive information, of when some discrete event will happen (like freezing or start of precipitation), what accumulations will occur over what duration, or where crews should be sent to treat an adverse road condition (in which case the predictive information is an observation of where these conditions are). On the assumption that outcome costs dominate treatment costs, the informational requirement can often be reduced to a question of minimizing missed alarms (failure to treat when treatment needed). But especially for weather events distributed in time and space (e.g., snowfall) achieving low missed alarms by accepting false alarms can have high costs by using up assets (e.g., exceeding crew time limits and wasting chemical) and not having them available for true alarms. In an attempt to arrive at some decision support requirements, the table below examines critical parameters to avoid missed alarms, while considering false alarm consequences to be minimized for each treatment type. This is one way to reveal the critical information parameters, and the need for predictive reliability that is set jointly by the avoid-missed-alarm and false-alarm-cost risks.

Table 7.3: Critical Decisions and False Alarm Costs for Treatments

Meteorological Threat	Treatment (sub-climatic)	Critical Decision (avoid missed alarm)	False Alarm Cost
Flood from rain falling on ice or sudden meltoff	Clear drains	Dispatch crews (melting, mechanical clearing) with lead time to clear drains whose blockage will create critical water depths (>2 in.?)	Entire crew/vehicle time. Possible loss of crew capacity if meltoff event changes to one requiring other treatment (i.e.,sensitive to forecast temperature and precipitation)
Low temperature extremes	Material/equipment heating	Keep vehicles and materials heated to prevent freezing prior to long soak below coolant freezing/fuel gelling, material freezing. (Prior seasonal treatment assumed.) Note: it is rare that extreme low temperatures are accompanied by other precipitation or surface-liquid phase changes, so outcome-costs from failure	Minimal: power cost of providing extra heat or moving vehicles indoors.

		due mainly to vehicle outage if freezing causes mechanical failure.	
Snow/ice	Pretreatment (anti-icing)	Dispatch crews or activate remote sprayers to apply sufficient chemical concentration for expected temperature: In locations where T below freezing, and before freeze event, but not so long that chemical disperses. Since chemical will enter biota and watersheds, critical decision threshold may vary by location sensitivity.	Entire cost of application. May be mitigated if residual chemical still available for next critical event. (Environmental cost of chemical application same as true alarm).
	Plowing (snow)	Dispatch crews to follow threshold accumulations (>.5 in. snow?–dependent on liquid content and surface bonding possibility) where they occur. Must determine accumulation profile for timing or repeating of coverage.	Partial cost of treatment if crews layover or return when no accumulation found. May be cost of lost capacity if crews exceed time and event is only delayed or accumulation profile misjudged.. Note: If plowing anti-icing combined, do not double count cost against pretreatment.
	Plowing (deicing)	Dispatch crews to where ice has bonded.	Partial cost of treatment if crews layover or return when no accumulation found. May be cost of lost capacity if crews exceed time and event is only delayed.
	Grit application	(may be combined with other treatments that define critical decision) In many locations, accumulated grit must be mechanically removed (critical level variable).	Entire cost of treatment. Removal cost same as for true alarms)
	Deicing	Dispatch crews to where ice has bonded and spread chemical at rate depending on temperature and thickness. Determine extent of spread depending on ice-thickness (critical level =?) For track-breakup or lane-wide removal.	Entire cost of application. May be mitigated if residual chemical still available for next critical event. (Environmental cost of chemical application same as true alarm).

		Combined with plow scraping depending on ice thickness, temperature and existing bonding (critical levels =?) Since chemical will enter biota and watersheds, critical decision threshold may vary by location sensitivity.	
	Melting (rarely used except in runway applications or some sloped ramps).	(See entries for surface ice/frost).	
	Bulk Removal	Dispatch crews where plowing not feasible (critical level variable depending on wayside conditions). Timing may be critical if threat of meltoff flooding or refreezing exists (critical levels TBD).	Entire cost of removal if natural meltoff occurs, but not to cause flood/refreeze problem. These conditions relatively rare.
Surface ice/frost	Pretreatment (anti-icing)	Dispatch crews to apply sufficient chemical concentration for expected temperature: In locations where T below freezing, and before freeze event, but not so long that chemical disperses. Since chemical will enter biota and watersheds, critical decision threshold may vary by location sensitivity.	Entire cost of application. May be mitigated if residual chemical still available for next critical event. (Environmental cost of chemical application same as true-alarm).
	Grit application	(may be combined with other treatments that define critical decision) In many locations, accumulated grit must be mechanically removed (critical level variable).	Entire cost of treatment. Removal cost same as for true alarms)
	Melting	Sub-surface heating: Activate when surface reaches freezing. Super-surface heating: Activate when surface reaches freezing and treatment will not be thwarted by accumulated precipitation and rebonding (critical precip and temperature levels =?).	Cost of treatment (power or crews). Rarely accrued in limited applications where temperature can be measured accurately)
Wind+snow	Plowing	Dispatch crews to follow threshold accumulations (>.5	Total treatment cost only if no drifts found in search

		in. snow?) where they occur. Must repeat as a function of wind and residual snow. Since drifts are spotty, often depend on search-and-treat procedure.	areas.
	Snow fencing (only if a sub-climatic treatment)	Dispatch crews to locations where threshold accumulations (>12 in. snow?) will occur as function of wind, total snow and moisture content. Use only where frequent plowing would not occur for other reasons.	Total cost of treatment However, effect must be counted as seasonal once fences installed.
	Bulk Removal	Apply where threshold accumulations exist (>12 in. snow?), where conditions (dry snow, continued wind) do not favor plowing.	Rarely accrued since treatment responds to observed condition.

For false alarms, the cost function is different for pretreatment versus snow removal or deicing. Pretreatment costs are accrued nearly in full for a false event, although residual chemical for a subsequent event is a benefit if runoff and mechanical dispersion does not occur in the interim. This suggests that the acceptance of false alarms is itself a function of predicted weather–that temporary freeze followed by rain (probably where the freeze temperature is marginal anyway) should demand a lower false alarm rate because of chemical loss as well as other variable treatment costs. For snow removal, crew shift-splitting and truck dispatching generally will have no costs if nothing happens, and deicing will not occur if there is no ice. The issue of costs when crews are dispatched to segments where there is no ice or snow, while it is in other locations, is a more complex question of beat geography relative to road condition distribution.

The lead-time criterion for pretreatment under certainty of a freezing event would be simple: dispatch treatment to account for crew arrival onsite to occur just before the freeze. For a spatial distribution of freezing, this needs to be stipulated for arrival at any point no later than its predicted freeze time. This minimizes chemical dispersion, and reduces the lead-time to make temperature information more reliable. Uncertainty in the temperature prediction over time means variance in freeze onset, so that avoiding missed alarms would aim for an early-occurrence threshold (another parameter that is a probability that the freeze occurs no earlier), extending the lead time from the central parameter of freeze time[39], and therefore increasing the prediction variance. The problem of spatial variance can be

[39] The central parameter of the distribution may be taken as the most likely value or the average (expected) value, depending on how it is to be used. In skewed distributions, these values can differ substantially.

collapsed into the time variance if the time variance represents when any unmonitored spot might freeze. This variance then depends on how well climatology has identified the siting of ESS based on earliest-freeze points. It follows that treatment beats should be designed to hit such points first. Longer beats also introduce more spatial and lead-time variation, so dispersed geographies also need to be accounted for the dispatching decision risk. A larger beat should be dispatched earlier to minimize missed-alarm risks, but may accrue larger cost and chemical-waste risks from false alarms, while being associated with less dense traffic and therefore lower safety and mobility risks. Larger beats make micro scale information more important in this way.

As has been documented, predictive variance is low around local midnight, so that a longer-lead rule generally applies during day/evening freezes that are less reliably predictable, both in time and space. Unfortunately, these are also the cases when traffic will be heavier, risks of poor outcomes greater, and dispersion of chemical from traffic greatest. Therefore, critical performance should be focused on these day/evening freezing events.

It is intuitive that if a freeze prediction is made at noon for midnight, treatment will be dispatched only closer to midnight. A freeze prediction made at noon for a few hours later, when the sun is low, gains reliability from a near-horizon for the prediction, but is also in a period of large spatial variation and hence overall large predictive variance. Especially considering traffic flow peaking, treatment should then be dispatched close to noon. This is what supports the noon update cycle for freezing predictions. The worst case is then for morning freezing, that generally will occur only if there is rapid movement of a distinct cold air mass (a synoptic scale event). This indicates the criticality of a post-midnight predictive update. A meso scale prediction can sharpen the prediction, or even the micro scale tracking of temperature at discrete observation sites. NCEP forecasts (e.g., Eta or AVN) based on 0Z initialization also generate products about 4 or 5 hours later, so represent a midnight update for the eastern U.S.

Freezing may be treated as a discrete event, but storms usually are not. Modulating the response in a severe and lengthy storm (which is usually a synoptic and not a meso-event) is important. In these cases, total crew size and their work limits (e.g., 12 hours work maximum) are fixed resources that have to be managed with respect to the expected storm profile. It may be necessary to sacrifice early treatment for timing that will successfully deal with finished accumulation, or otherwise meet a desired time distribution of LOS. However, pretreatment also can reduce total treatment time through prevention of bonding. In these cases the predictive horizon is determined by the storm duration, and the critical attribute to predict is snow accumulation over the course of the storm. If the rate of precipitation over the network exceeds crew capacity, then a focus on particular routes may be decided, leaving others untreated. If the network will close down anyway, resources might be reserved for late in the storm. If the geography of the storm allows mutual-aid from districts not overloaded, this will affect capacity and so decisions on how to dispatch crews and their timing.

7.1.4 Empirical Data On Decision Making

Analysis such as above helps to identify critical risk parameters, on timing and weather attributes for defining the decision making scenarios and weather information needed. Stakeholder review will help to refine those parameters. In the meantime, some data are available from a small survey that was conducted for this project among four maintenance offices in Iowa and Missouri in the winter of 1999. Also, an "Anti-Icing Decision Chronology Log" had been collected in conjunction with the Test and Evaluation Project No. 28 (TEA-28) on Anti-Icing Technology [FHWA, March, 1998]. Copies of the logs were obtained and gave some treatment sequences, especially on test sections where pretreatment strategies were being tested. However, data on information consultation relative to actions was sparse and inconsistent. Additional work was ongoing for the project in Iowa in the winters of 1997 and 1998 that promised to document the decision making process further, but the results have not yet been obtained. Evaluation of the Foretell project, including Iowa, Missouri and Wisconsin, will commence for the winter of 2000 and may continue the preliminary survey described here.

The survey for this project sampled three sites in IA (Ames, Des Moines and Cedar Rapids) and one in MO (Kansas City). A total of 17 winter storm events were recorded in February and March of 1999. Survey diary forms asked the road treatment actions taken on each day (snow removal, residual ice treatment, frost pretreatment and pre-storm anti-icing) and whether a storm event was detected. If a storm event was detected, a log of information consultation and actions was solicited. The diaries were filled out contemporaneously with the events and the weather was monitored by Mitretek using Internet sources during the survey. This resulted in a few cases where information was independently collected on potential storm events for comparison with the diary logs. Parameters of the decision making are summarized here from a tabulation of the survey data.

The 17 cases occurred between 2/11/99 and 3/12/99. Only two cases were false alarms, of the storm being monitored but not occurring. However, special staff shifts and treatment did occur even in these two cases. The first three questions on the storm logs were:

1. Was weather monitoring increased before detection?

2. When did you heighten monitoring?

3. When did you detect storm was coming?

These were intended to establish monitoring as the first activity, leading to detection. In fact almost all responses listed detection (question 3) as the first event, even when the answer to question 1 was "yes". The interpretation by staff is therefore that monitoring is an activity triggered by awareness that a storm is coming. While it is obvious that some activity must be conducted to get information prior to storm detection, this apparently is so routine or implicit that it was not defined as the monitoring activity.

The diary data established the relative times of several events. Mean times and ranges were tabulated for the events defined as follows:

- T1, detection time
- T2, heighten monitoring time
- T3, storm start time
- T4, first treatment action time
- T5, storm monitoring end time

Table 7.4: Empirical Decision Event Time Intervals, IA and MO, 1999

Interval	Average	Minimum	Maximum
T1 Detect->T2 Monitor	6:10	0:00	28:00
T2 Monitor-> T3 Start	7:00	-7:00	18:15
T1 Detect-> T3 Start	13:33	0:30	34:00
T1 Detect-> T4 Action	12:03	-11:00	22:30
T4 Action-> T3 Start	03:31	-2:00	11:30
T1 Detect-> T5 End Monitor	28:24	8:00	52:00

The T2-T1 interval averaged 6:10 (six hours and ten minutes) with minimum 0:00 and maximum 28:00. Eight of the storm events had simultaneous detection and monitoring, meaning that they were actually the same event. The T3-T1 interval from detection time to storm start averaged 13:33 among 14 cases with valid times, minimum 0:30 and maximum 34:00. This represents the horizon of predictive weather information. There were three cases where this exceeded 24 hours, but more often it was substantially below that horizon. The T3-T2 interval from heighten monitoring to storm start averaged 7:00, the minimum -7:00 (monitoring after start, but 17 hours after detection) and the maximum 18:15.

The T4-T1 interval gives the time from storm detection to action. Actions were defined as calling special shifts, snow removal, salt/grit on residual ice, frost pretreatment and anti-icing pretreatment. One case of post-action (clearing blowing snow) was mentioned even though not included as a survey category. Of the 17 cases, 13 had special shifts, 16 snow removal, 10 post-salting/grit, 1 frost pretreatment and 8 anti-icing pretreatment. Time intervals from detection to action were given in only 9 storm cases. This averaged about 12:00, with minimum -11:00 (pretreatment before detection, another case had action 2:30 before detection and both cases were at site 2 with simultaneous detection and monitoring times). This suggests definitional problems or misinterpretation of the questionnaire. Maximum interval was 22:30. Looking at T3 versus T4, only one case showed action after storm start. Of the other 8 cases, action was taken 3:31 before storm start on average. For anti-icing, seven cases gave action times. These averaged about 9:00 after detection, the minimum -11:00 before detection and the maximum 22:30 after detection.

Comparing the T3-T2 results (monitor to storm start time) and the T3 versus T4 results, it appears that many actions were taken prior to heightened monitoring, although most after detection. This suggests that the relation between intensity of weather information consultation and action-taking is weak. The reasons why information would be looked at more intensely, and the definitional difference between heightened monitoring and detection need to be explored further. T5-T1 is the total interval of information use and decision making (with the exception of the two cases with action before detection). This interval averaged 28:24, with minimum 8:00 and maximum 52:00.

Information sources were noted for detection, monitoring and response initiation. These of course depend on the sources that the site has invested in. In all cases, subscription services were used. In three cases for detection, broadcast media were mentioned (TV, radio, Weather Channel) but only one case for monitoring (Weather Channel). The Internet was mentioned in 6 cases, all for monitoring. The differentiation between the subscription vendor sources and “RWIS” is not clear, but “RWIS” is taken to mean the ESS data. Surface observations and area observations are taken to mean the weather service reporting stations. There is only one mention of RWIS for monitoring, but eight for treatment information. In addition there are six mentions of a truck-probe temperature source for treatment information. It is likely that “radar” is one of the products provided in any subscription service. However, radar was specifically mentioned four times for detection, five times for monitoring and only three times for treatment information. Given that treatments were shown to precede monitoring in several cases (e.g., advanced pretreatment) this is consistent with using radar mostly as a near-horizon tool.

A question was asked on the frequency of monitoring consultations. Six responses stated “pager”, meaning a predictive event-prompted alerting, decided by the vendor. One response said “continuously”. Numerical responses ranged from 4 to 54 occasions. The maximum was associated with the one case where treatment was entirely after storm start, and may be an artifact.

During the survey period, Internet data sources were consulted at Mitretek to detect when a candidate storm might arrive. This was done sporadically during working hours of weekdays, so there was no serious intent to track each storm independently and only in a few cases were storms detected independently. The Internet sources used were the Unisys site (formerly the Purdue University site) at weather.unisys.com, and the subscription site Weathertap.com. Both provide a wide range of observational data and forecast products. The Weathertap site is advantageous mainly for access to the NEXRAD Information Dissemination System (NIDS) for high-resolution images and products (reflectivity, radial velocity, echo tops and precipitation). The monitoring procedure was to check the Unisys site daily for the national analysis composite map (fronts, satellite and low-resolution national radar reflectivity), then check forecasts to about 24 hours (NGM, Eta and AVN models from the NWS). Any apparent storm activity would prompt a closer look at the surface observations in the Unisys site, and the individual radars and local forecasts from the Weathertap site.

Only three storm events that were tracked independently matched the diary records: 3/5/99 recorded at two sites in Iowa, 3/8/99 recorded at one site in Iowa and 3/12/99 in Missouri. These three cases tended to confirm the value of the available Internet sources for storm detection, although forms of precipitation would be uncertain in advance of actual surface observation. In one case the Internet data seemed to indicate the threat well before detection was stated in the survey. With the small sample, it is not safe to conclude how much advantage in detection or monitoring additional "RWIS" sources gave to the surveyed sites.

The Anti-Icing Decision Chronology Log data associated with the TEA-28 project is very inconsistent in listing treatment decisions and information. There are scattered notations on RWIS use and some more extended textual descriptions of activities. The responses are mainly of interest regarding the respondents' reasoning for a treatment on control (no pretreatment) and test sections of roadway. There are 81 days recorded in the sheets obtained (with some multi-day weather events, and some no-event days), for respondents in CA, KS, NH, NV, NY, OH and WI. These are for the winter of 1995. A sample of 35 weather events was selected for tabulation, listing the treatment events, their times and reasons. The summary statistics are as follows:

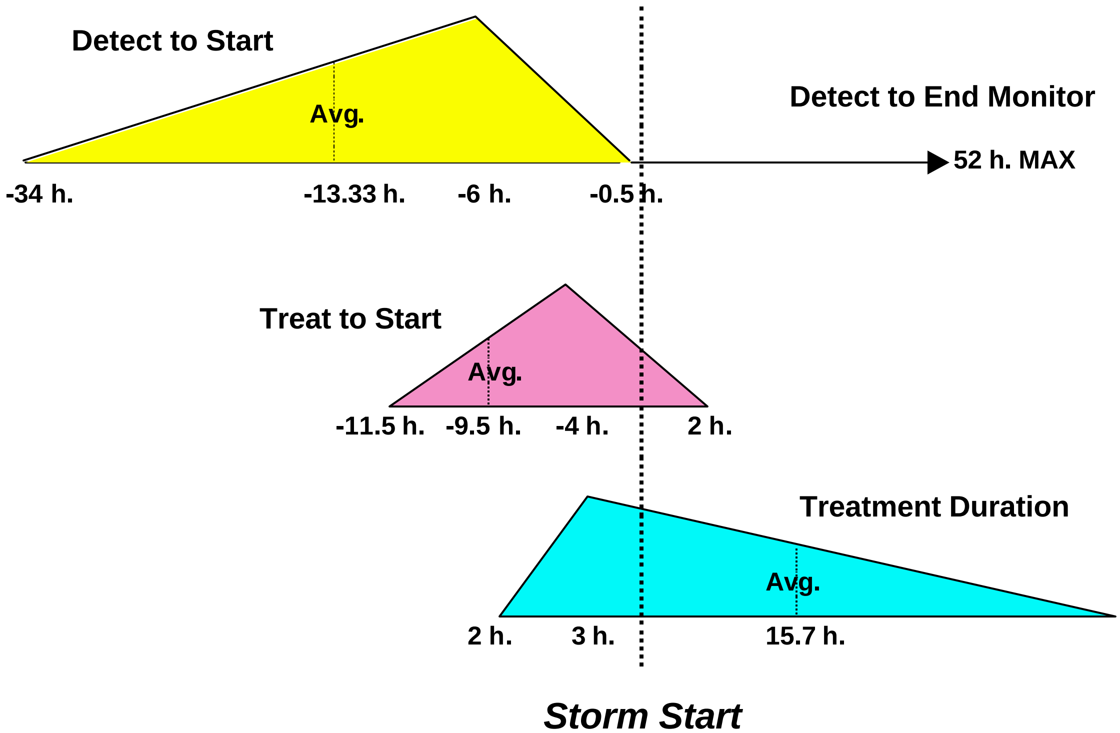
Statistic (N=35)	Number of Treatment Events	Duration (HH:MM)
Average	3.11	13:02
Multi-Event Avg.	3.55	15:44
MIN	1	0
MAX	5	42:00:00

Durations were derived from the time of first treatment event to last. Since single-treatment weather events could provide no duration, only the average duration for multi-event (treatments) cases is indicative. Since most of the treatments were directed as part of the test for anti-icing, they are not descriptive of normal practice. Some of the event sequences were aborted when the anti-icing test was dropped in favor of conventional treatment. However, most of the selected diary records showed an expected mix of anti-icing, plowing, salting and other deicing.

From one treatment event (generally the anti-icing pretreatment) to five events were recorded and there was an average of 3.11 treatment events per weather event. If the one-event cases are excluded, there is an average of 3.55 events per case and a 15:44 average duration with a maximum of 42 hours from first to last treatment. This averages about 4:26 between events. The data depend on the climatology of that winter and the areas selected. However, it is notable that most of the weather events are discrete over less than a 24 hour period. That is, there is usually a breather between major weather events and such events last less than a day. This is confirmed from other sources (a sample of national snowfalls). Any extended weather event typically consists of regular lake-effect type snow or freezing/snowing events with modulation of the precipitation. This is why crew-shift manipulation is such a successful strategy in dealing with weather events: If a 12-hour shift can be reserved for the onset of the storm, it likely will be able to cover the storm. Of course, pretreatment has the downside of extending the total duration of crew activity, in favor of a better LOS *if* the storm does not overwhelm the crew.

The repetitive treatment events for each weather event were typically a pretreatment for anti-icing, followed by re-treatment for deicing, including chemical application, grit and plowing. Re-treatment was often prompted by an accumulation of snow or ice that would send the trucks out in any case.

Figure 7.3: Distributions of Some Time Intervals for Treatment



Based on the empirical data some distributions for time intervals were deduced. The range from minimum to maximum values suggests that the averages are far from what might be recognized by operators as most likely (ML) values. This difference can be represented by triangular distributions as the simplest way of capturing how intuitive ML values (the peak in the traingle), that are likely to be stated in the scenario reviews by stakeholders, can differ from numerical averages. In a triangular distribution the average is one-third the sum of the minimum, most likely and maximum values, so the most-likely value can be retrieved from the tabulated data. Some distributions are shown in the figure above. The scenario review in the stakeholder meetings will be used to define how different kinds of storm events and treatment strategies create correlations between the different time distributions.

7.1.5 Preliminary Operational Scenarios

Operational scenarios will be created based on above analyses as the weather scenarios are defined fully. These are being documented in large-format MS Project schedule charts, and cannot be included in the text here.

7.2 Weather Scenarios

Operational decisions are made in response to weather events, and other information on the state of the transportation system. Therefore the operational scenarios are related to example scenarios of weather events.   The weather scenarios are constructed from archived data from the National Environmental, Satellite, Data and Information Service (NESDIS).   These will be presented in graphical (radar, satellite) and textual (watches, warnings) form for real storm events. The scenarios are summarized below along with the forecasting process and its terminology.

7.2.1 Selected Scenarios

The selected weather scenarios consist of winter events that affected large areas with varying densities of population and topography. The three events selected are:

1. A "surprise" snowstorm that developed over Washington, DC in the late winter of 1999;

2. A devastating ice storm that plagued portions of the deep south of the United States during the 1998 Christmas holiday season, and;

3. An early season blizzard in the western Great Plains of the United States in late October, 1997.

The scenarios were selected to give stakeholders a variety of weather hazards to think about as the events unfold. Issues of improved information, or decision making will then be assessed to contribute to the WIST-DSS.

Scenario 1: The Surprise Heavy Snow Event in a Metro Area (03/09 1999)

The first scenario deals with an unusual late winter snow event over the western suburbs of Washington, D.C. It was unusual in that the band of heaviest snowfall accumulation fell in a very narrow swath over a densely populated region of metro Washington (Figure 7.10). The population of Fairfax County alone (just west of D.C.) is almost 1 million people.

Initial forecasts indicated 2 to 4 inches of snow during a work day. Heavy snow on the order of 1 to 2 inch accumulations *per hour* developed during the morning and persisted into the afternoon. Accumulations of a foot of snow were reported by evening from the district, west across the suburbs and northern Shenandoah Valley of Virginia into the eastern West Virginia panhandle.

The rapid accumulation of snow made traveling treacherous. The Federal Government was forced to shut down at midday. As businesses and schools simultaneously released personnel, hundreds of accidents occurred. Short commutes turned into multi-hour adventures.

This scenario takes stakeholders into the fast paced process involved with attempting to stay ahead of rapidly changing and deteriorating conditions in a highly urbanized area.

Scenario 2: Ice Storm in the Deep South (12/23 - 12/25 1998)

The second scenario covers a weather phenomenon that is perhaps the most dreaded: Ice. A major ice storm struck a large portion of the deep south producing significant tree and power line damage and the closure of many major routes. The scenario will focus on how the storm affected central and northern Alabama from Birmingham to Huntsville where ice loading of one half to one inch was common. Emergency operations officials reported downed trees in every affected county with tens of thousands of customers without power.

This scenario takes stakeholders through the forecast process of a major ice storm in an area where widespread and long-lived winter weather is relatively rare.

Scenario 3: Western Plains Blizzard (10/24 - 10/26 1997)

The final scenario deals with the granddaddy of winter storms, the blizzard. While blizzards in the plains are not uncommon, this blizzard was called a ‘50 year’ storm. The focus of this event will range from the foothills to the eastern plains of Colorado, including the Denver/Boulder metro area.

This storm had all of the ingredients for a major winter event; arctic air, high winds, below zero wind chill values and heavy snow. Widespread accumulations of two to four feet of snow were observed with sustained winds of 40 mph frequently gusting to 60 mph. Wind-driven snow drifts ranged from 4 to 10 feet deep. Wind chill temperatures fell to 40 degrees below zero.

Thousands of people were reported stranded in eastern Colorado with hundreds requiring rescues from their snowbound vehicles. The Army, National Guard and Law Enforcement personnel were all called upon to perform rescues. Four thousand people were stranded at the Denver International Airport.

The combination of the high winds and heavy snow caused many power lines to come down. Many businesses and schools closed for part or all of the following week.

This scenario takes stakeholders through the forecast process of a major/widespread blizzard from detecting the first signs at the medium range to the nowcast.

7.2.2 Overview of NWS Weather Forecasting

This section introduces the winter storm forecasting process from the perspective of a National Weather Service (NWS) forecaster. This serves as the information-generation scenario from the NWS to transportation decision makers. Knowing the information that NWS forecasters use, and how it is used to produce products will also give insights on how to use the information within the WIST-DSS. In the stakeholder participation process, this information on the evolution of the weather events and the forecasting process will be combined with decision points required by transportation decision making. The simultaneous consideration of both types of scenarios will aid stakeholders in assessing when key decisions should be made and which types of data are most effectively utilized at a particular time in the forecast preparation process.

Weather forecasting continues to be a combination of both art and science. With the proliferation of new and more accurate remote sensing devices and faster and more capable computers, the ability to forecast weather events continues to improve. However, we are many years away from being able to accurately forecast many elements associated with adverse weather. These elements range not only from whether an event will occur at all to onset times, precipitation type, duration and amount.

Forecasters routinely struggle with deciding which data will be pertinent to a potential storm. For a summer thunderstorm, a key element may be the steering winds in the middle atmosphere which would determine if the slow movement could cause flooding, or the freezing level in winter which could determine the precipitation state (liquid, freezing or frozen). The amount of internal and external coordination required by forecasters also changes according to season and the expected severity of the storm.

In order to give stakeholders a better idea about the entire forecast preparation process, overviews of NWS data sets will be presented followed by a description of the NWS forecast preparation process from the meteorologist's point of view.

7.2.3 Overview of the NWS forecast data sets

The NWS currently has changed technology from the older computer communications systems to the new Advanced Weather Information Processing System (AWIPS). Through the 1980's and most of the 90's, NWS meteorologists used many different computer systems to acquire, process, interrogate and display the many different data sets that continuously arrive through dedicated terrestrial communications. Some computers were dedicated for satellite images, lightning data or remote platform access. Others were multifunction systems that were used to run programs to display upper air balloon information or look at gridded model data. It was not until the early 90's that many of these computers were linked internally via local area network (LAN) and the mid 90's when Internet access became the norm. One goal of the massive NWS modernization was to take the data on all of these separate platforms, and bring them together into one system which could exploit today's computing power and combine the different data sets into tools that would enhance and improve the forecast and warning process. This is a model for the WIST-DSS, subject to differentiating weather forecasters from transportation decision makers as users.

Today, the NWS has completed its modernization with AWIPS deployed at over 100 Weather Forecast Offices (WFOs). The transition from the old communications systems is underway and new advanced technologies such as Doppler radar, high resolution satellites and automated surface weather observing systems are in use. WFO communications have become more sophisticated using a combination of high speed terrestrial networks and satellite broadcast capability. With this higher bandwidth, much more information is available for the forecaster to peruse and include in the forecast preparation process. Examples of the different data sets available to NWS forecasters include:

- Gridded Model Data: Forecasters have much more control over the fields that are displayed from numerical models because the data are no longer transmitted from centralized sites as static images. Use of gridded data (the actual numerical output for different weather parameters) can be used to create images on-the-fly for virtually any level, slice or time section of the atmosphere. The data can be easily transformed to different map domains so that it can be overlaid on other information such as satellite or radar data (Figure 7.3).

- Satellite Data: The new generation of sophisticated weather satellites is in place offering forecasters new ways to observe the atmosphere remotely. With geostationary satellites in position over the east and west coasts, an almost continuous stream of images (ranging from visible to infrared and water vapor channels) are transmitted to ground stations (Figure 7.4). The satellites also act as remote data collection platforms which receive data from sensors such as oceanic buoys or solar powered rain gages in the mountains. These data are then transmitted to ground for dissemination.

- Radar Data: A new network of Doppler radars (NEXRAD, aka WSR-88D) has been created across the country which provides continuous surveillance of clouds, precipitation and potential severe weather. Doppler radars have the ability to sense the radial movement of airborne particles. This allows forecasters to look "inside" storms and sense the storm's structure (such as the development of cyclonic rotation which could be the precursor to tornadic development) before severe weather affects the population. The radar also includes a sophisticated package of algorithms that constantly estimate rainfall accumulation and scan the skies for hail storms, tornadoes and damaging down bursts (Figure 7.5).

- Upper Air Data: Twice per day, NWS personnel release weather balloons (aka rawinsondes) that are tracked by radar or GPS and send telemetry of a profile of temperatures, humidity and winds (Figure 7.6). These data are used as input into numerical models and as a key decision-making tool about the conditions in the atmosphere that could lead to severe weather locally.

- Surface Observations: One component of the NWS modernization is the proliferation of the Automated Surface Observing System (ASOS). ASOS is a tool that attempts to sense and report on current conditions such as sky cover, precipitation type, accumulation and duration, temperature, wind speed, direction and air pressure. ASOS sites are normally at airports and are capable of transmitting both routine and 'special' observations (reports that are issued at a greater frequency because of rapid changes or severity).

- Mesonet Data: Mesonets are local or regional networks of sensing platforms that can be placed and maintained by private companies, universities or state governments (such as a state Department of Transportation (DOT)). The data are valuable for giving forecasters much higher-resolution information for making fine changes to the forecast. These data sets become extremely important when forecasters have to determine the location of the rain/snow change line or whether localized storms have produced enough rainfall to induce flash flooding (Figure 7.7).

- Remote-area Data: Information from remote areas is important for initializing numerical models and for getting an advanced indication about weather changes upstream. Examples of the remotely sensed data includes anchored and drifting oceanic buoys or river and rain gage data in rugged terrain where conventional communications are not possible.

figures removed

7.2.4 The Timing of the NWS forecast process

The amount of data that is required to create a forecast varies from the time of the day to the season and weather event. Moreover, the type and amount of data that is (thought to be) needed to create a forecast package will vary from person-to-person based on personal temperament and experience. It will vary according to geographic area and location. Hence, no one forecast process can be listed as “official”. The following scenario describes one such process that could be used by a meteorologist in the continental U.S. faced with a potential winter storm. It covers a time frame from the “medium range” (3 to 5 days out) to the “short range” (1 to 2 days out) to the nowcast (within 6 hours).

Day 5 (before storm)

It is winter. Weather conditions have long periods of pause with occasional storms and frontal passages. The forecaster prepares his short range forecast relatively easily with dry high pressure stationary overhead for the next several days. To get a background as to what might be expected in the medium range, the forecaster begins to look at hemispheric models (models that have a domain over the northern hemisphere). First, at jet stream levels (often between 500 and 250 millibars (mb)), he looks at the meanderings of the river of air that steers the fronts and whose occasional sharp kinks could be the harbinger of developing winter storms (Figure 7.8). For this task, there are many models to choose from including the U.S. Medium Range Model (the MRF), the Navy NOGAPS Model, the European Community’s ECMWF, the United Kingdom’s UKMET and the Canadian SEF model. Each model uses different physics (ways to approximate atmospheric processes) to produce a prognosis. Some forecasters use the meandering waves of troughs and intermingled ridges as “teleconnections” to forecast the future movement of the stream. Others use an “ensemble” of forecasts where many different model runs are combined in an attempt to dampen individual model biases. Once the upper conditions have been studied, surface (actually Mean Sea Level (MSL)) forecasts from the same models are perused, looking for signs of cyclogenesis (the initiation of low pressure which could form into a cyclone or storm) and the storm’s computer generated evolution.

Once the numerical models have been studied, the forecaster would read the Prognostic Map Discussion (PMD)/Extended Forecast Discussion from the NWS’s National Centers for Environmental Prediction (NCEP). The PMD is produced by a unit whose mission also is to study all of the medium range forecast data and decide (using understanding of model biases, climatology and persistence) which models best represent what might happen in the future. This forecast is then encapsulated into a discussion which is widely disseminated to users around the world.

Along with the NCEP text discussions are graphics that include forecast positions of fronts and high and low pressure areas, probability of precipitation and maximum and minimum temperatures. The field forecaster would use these data along with raw numerical guidance to prepare the extended forecast.

If the models and NCEP indicate the possibility that a major storm could form during the extended forecast period, the forecaster could then issue a “special weather statement” (SPS) alerting users (such as emergency managers and the mass media) of the potential for storm development. This would allow organizations that require long lead times (such as a power companies or departments of transportation) to prepare staffing schedules or pre-place resources.

Day 4

With the previous day’s SPS still fresh on everyone’s mind, the forecaster again checks the same models for trends; to see if yesterday’s day 5 forecast looks like today’s day 4 forecast. Do the many medium range model solutions diverge at some time frame or do they converge into a consensus? Are there subtle hints that could change the potential intensification or track? The forecaster may want to coordinate directly with NCEP to get an better understanding of their storm positions on their graphics. With the extended forecast transmitted, the SPS must be updated to convey the latest thinking on the storm’s evolution. This causes an increase in phone traffic, calls from the media and perhaps a school system or DOT. Uncertainty in fine details cloud many of the questions; When will the storm begin? Will it be rain or snow? How much will accumulate?

Day 3

Some of the medium range models may still produce rogue solutions, but most unwaveringly indicate that a storm will form. NCEP agrees and holds an internal coordination call with all WFOs along the track of the forecast storm path. The neighboring stations collaborate on possible positions of the rain/snow change line and broad-brush accumulations. Some of the short range models reach into day 3 (such as the U.S. Aviation model) to give additional information on the parameters of the forecast storm. If the storm was expected to be large enough and effect a large segment of the population (such as the March 1993 “Storm of the Century” that affected most states east of the Mississippi River), the WFOs could issue strongly worded “winter storm potential outlooks” or long-fused winter storm watches. This issuance is the first official bulletin of the impending storm and begins to set the framework for indicating storm duration and broad-brush estimations of accumulations.

At this point, the pulse of the work load begins to quicken. Phone calls from the media become more frequent and ask questions that there are not yet answers to. Emergency managers begin to take heightened interest and call in for briefings. WFO staffing is checked to be sure that sufficient personnel will be on hand in the event that commuting becomes hazardous. Fuel stores for the emergency generators are topped off. HAM radio operators are briefed on the potential for communications disruptions and plans are set for having a troop of volunteers to staff the ‘base station’ within the office.

Day 2

Use of the medium range models has transitioned to the collection of short range models available to the forecasters. NCEP routinely generate models cryptically called ETA, MesoETA, NGM, and AVN which have time domains that range from 33 hours to 72 hours. Some universities also have mesoscale models available on the Internet, such as the MM5 or RAMS. In addition, the Navy and Canadian meteorological services have short range models available for perusing.

On this day, the phones are a constant buzz with questions ranging from the nervous commuter to school systems wanting to know the potential for disruptions. Forecasters begin routine collaboration sessions with neighboring WFOs and NCEP so that the upcoming winter storm warnings will be coordinated. Forecasters compare satellite loops with radar composites in an attempt to identify the upstream perturbation that will develop into the forecasted winter storm (Figure 7.9). Model data will be closely scrutinized looking at temperature profiles, quantitative precipitation forecasts and frontal structures that might aid in focusing either the path of the storm or the heaviest accumulation bands.

Beyond model data, surface observations from ASOS and mesonets are analyzed. Temperatures, dew points and wind trajectories will be very important in forecasting the upcoming storm. Roadway temperatures (available from state DOTs) are very important to the meteorologist as they indicate whether the subsoil layer is frozen, whether the precipitation will immediately freeze and begin to accumulate or whether the storm will pose a threat mostly to elevated highways.

After an hours' worth of coordination, the forecast package is ready for release. A winter storm warning has been prepared. This means that winter storm conditions are imminent within 24 hours. The text of the message contains the latest thinking as to precipitation onset time, its duration and forecast accumulations. Technicians send out alert tones on NOAA Weather Radio which turn on specially made receivers at many emergency management offices, school systems and government agencies.

Day 1

The stage is set. Phones ring continuously. Local TV stations have remote trucks in the parking lot. Forecasters lug in extra provisions. The conference room transforms into a makeshift dormitory. The air is filled with electricity and anticipation...

Within 24 hours of the event, forecasters study the many observational systems available to them. AWIPS contains an automated analysis system called LAPS that shows the change in parameters such as temperatures, pressure and wind updated every hour. NCEP generates a model that is continuously updated called the RUC (Rapid Update Cycle) that attempts to take model-initiated fields and modify them each hour with observations. In addition to visible, infrared and water vapor satellite pictures, and colorful composites of Doppler radars, forecasters can look at current lightning data from a nationwide array of sensors that detect the occurrence of cloud-to-ground lightning. The presence of lightning in developing winter storms can be very significant as it indicates the potential for rapid intensification and/or extremely heavy (white out) precipitation rates.

Roadway mesonet data are once again analyzed to see if the asphalt will absorb enough heat to melt the initial onset of precipitation. This is a good indication of whether commuters will immediately find slush or covered road surfaces.

The short range models are also analyzed for any changes of track, intensity or storm structure. Temperature fields are checked to make sure that the precipitation 'type' is still in line and that the onset and duration timing information hasn't radically changed. Once digested, this information is used to send out updates to the winter storm warning.

Day 0 / Storm Day

There is both excitement and relief as the storm begins close to when it was advertized. Most of the media has left to cover the story 'from the street'. The forecasters are hunkered down for the duration with emergency generators able to operate the facility for a week.

The main focus of the shift is to fine tune existing forecasts, issue frequent "nowcasts" (high detailed, short range forecasts for the next couple of hours) and rapidly relay storm reports in the form of public information statements.

Data will be flowing into the WFO from many sources. The HAM operators will be getting reports from short wave radio enthusiasts. Skywarn members (a group of citizens that have been trained in weather observing) will report accumulations, temperatures and trends. TV and radio stations with spotters throughout their viewing areas will phone in reports. Occasionally, the general public will get through to relay observations and storm totals. The ASOS platforms will be sending automated updates. People with email access will send in accumulation reports to the office using the WFO Internet homepage. These reports are supplemented by forecasters calling local fire and sheriff departments looking for reports in their jurisdictions. These data are used to create accurate post storm summaries (Figure 7.10).

The forecasters must be able to correlate the manual reports with the constantly updating radar, satellite and lightning loops, and the short range analyses and guidance provided by LAPS and the RUC.

The phone load begins to lighten as the population settles down for the storm and the media takes the focus away from the 'forecast' to the actual conditions outside. Routine coordination calls continue with affected WFOs and NCEP. Routine briefings continue with state emergency operations center officials, local jurisdictions and DOTs. The forecasters see the trailing end of the storm on radar and shift emphasis toward the precipitation tapering off. The forecaster's job is done with tired satisfaction...ready for the next hand that Mother Nature is willing to deal out.

8.0 Needed Improvements

This section will lead to requirements for the WIST-DSS based on stakeholder participation in review of the operational and weather scenarios. Preliminarily motivations for the WIST-DSS improvements are given and related to the information needs of treatment operations.

8.1 Justification for Improvements

The justification for improvements lies in the gap between existing and potential transportation outcomes due to winter road maintenance treatments decided with weather and other information through the ITS. The weather information component should complement advances that will occur elsewhere in the ITS. ITS advances will create the capability and demand for fusing more information into specific decision support, presented interactively in a variety of formats.

Indicators of adverse outcomes in the highway transportation system are[40]:

- In 1995, 6810 fatal crashes occurred in adverse weather conditions, and 453,000 injury crashes.
- A 1995 cost for winter highway treatment of $2.1 billion per year.
- Weather-related damage repair costs on highways of $5 billion per year.
- Up to 20 million tons of salt, and minor amounts of other chemicals used per year.
- Total economic costs (wages, sales and taxes) of a one-day shutdown that varies by state from $15 million (Iowa) to $76 million (Ohio).

For individual severe storms, impact data are available[41]:

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[40] As cited in the Weather Team White Paper, op. cit. The economic costs of storms has been added from the series of estimates on "The Economic Costs of Disruption from a Widespread Snowstorm in [state]", by Standard & Poors DRI, for the Salt Institute, Washington, DC, 1998.

[41] The data are from the online query system at www4.ncdc.noaa.gov/cgi-win/wwcgi.dll?wwevent~storms, provided by the National Climatological Data Center (NCDC).

Table 8.1 Tabulation of Severe Storms Data for 1995-98

Type	# storms	fatalities	injuries	Prop. Damage	Notes
Dust	1	10	20	--	All in one AZ hwy accident
Flood	258	455	2881	$2.7B	“some” vehicular fatalities
Fog	13	19	190	$4M	mostly chain collisions, 6 in CA
Hail	6	7	8	$100K	2 traffic fatalities
Hurricane	23	54	85	$1.7B	Mostly not traffic fatalities
Lightning	205	217	169	$241K	Mostly not traffic fatalities
Precipitation	20	31	9	$109K	Several traffic fatalities
Snow and Ice	161	250	963	$764M	Many traffic fatalities
Tornado	88	259	2355	$1B	Mostly not traffic fatalities
Temp. extremes	189	421	903	$4M	Some traffic fatalities (winter storms)
T’storm	147	195	298	$259M	Some traffic fatalities (vis, wind)
Total	1111	1918	7881	$6.4B	
Annual Avg.	278	480	1970	$1.6B	

Reasonable causal relations between weather information and the outcomes do not suggest that the negative outcomes can be eliminated entirely. For the most severe storms, treatment alone will not completely mitigate effects. Best outcomes will be from combinations of treatment, response to weather incidents and improved coping through transportation-user advisories. However, it is anticipated that efficiency gains from information system improvements could decrease costs by at least 5% and can have similar reductions in other outcomes. Based on the $2.1 billion dollar winter highway maintenance costs, this is worth at least $100 million per year in maintenance operating costs to public agencies, and much larger values to other public benefits. This conservative estimate is a strong motivation by itself for investment.

8.2 Descriptions of Needed Improvements

Improvements in outcomes can be achieved by improvements in treatment for snow and ice on highways coordinated with other response and coping actions. Treatment outcome improvements have been summarized as:

- Improving the road surface level of service (LOS) more promptly under threat from snow and ice.

- Minimizing chemical use consistent with LOS goals.

- Minimizing treatment costs consistent with LOS goals.

Information contributes to these improvements in the climatic scales in which resources are provided (facilities, staff, equipment and expendables stores), and in the synoptic- to micro-scales at which individual weather events are treated.

The climatic scale includes analysis of outcome effects to justify further investments. The climatic scale is therefore concerned with information on weather that can lead to annual (or longer period) adjustments of resources, and better spatial location of resources, as well as general benefit-cost arguments to motivate the public resources devoted to treatment. At the climatic scale the improvements needed, aimed at decision makers who are planners and policy makers, are:

- Better annual climatic predictions of the attributes relevant to highway treatments (temperature, cloud cover, precipitation amounts and forms), presented in probabilistic terms, with specificity to sub-state climatic zones.

- Climatic analyses of weather threat levels and frequencies (e.g., maximal storm return periods) related to transportation outcomes to set resource treatment levels[42]

- Evaluations that reliably infer the effects of information on treatment costs and transportation outcomes, with respect to climatic variables.

The climatic scale also includes statistical data aggregation that contributes to probabilistic (e.g., assimilation, ensembles, MOS) approaches to the generation of weather information, and the climatological extrapolation of point observations. The needed improvements in this area include:

- The thermal mapping data that relate continuous point-measurements of road conditions, as by ESS sensors, to conditions extensively over the road network.

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[42] Climatic data on snowfall and earliest freezes are compiled and available through NCDC. There is a CD set on Snow Climatology, including snow event recurrence times used by FEMA (Version 1.0, October 1998) from NCDC. What is needed is to relate these to treatment resources.

- Improved guidance on the appropriate level of investment in fixed and mobile road condition sensors (in terms of measurement accuracy, numbers and placement), with respect to the limits of climatological extrapolation and contribution to other decision support products.

- The assimilation of all observational data into a uniform and common database that applies quality-control checks to data, gives calibration indicators, provides the basis for initializing numerical models, and quantifies probabilistic parameters of the measurements.

- The production of model ensembles or MOS, to increase the reliability of model results and to quantify probabilistic parameters of the measurements. This should include ensembles at smaller numerical prediction scales as processing speed improves.

At the scales of managing the treatment of weather events from maintenance offices, it is clear that decisions are made at nearly a continuum of scales within the synoptic to micro scale range, so that scale distinctions for information should be reduced in favor of decision support that can fuse scales, and their associated information sources. If there is a discrete distinction, it tends to be between synoptic/meso scales (the operational scale range) that supports maintenance management decisions, and the micro scale (warning) of direct treatment control in vehicles or at the roadside. A needed improvement in the synoptic-through-meso scales is:

- Decision support for highway maintenance that fuses all information in a single graphical user interface (GUI) and that allows the user to select and combine space-, time- and attribute-specific information, primarily through a geographical information system (GIS). This implies the ability to fuse a variety of observational and modeled information, tailored to climatological and operational distinctions in each area and for each jurisdiction, based on probabilistic indicators of its relative reliability at a given location and time.

The information that should be provided by such a presentation will be linked to specific treatment decisions. Risk is inherent in all these decisions, and the need for probabilistic information relates both to the tradeoff between missed and false alarms, and the technical means for fusing disparate data. Needed improvements include:

- Improved distributional- and central-estimates of the total duration of crew activity, based on profiles of road conditions needing treatment, in order to determine <u>when</u> a shift should be initiated.

- Improved regional (multi-jurisdictional) distributional- and central-estimates of crew resources required over space and time, to support mutual aid between jurisdictions.

- Improved timing of crew dispatching based on distributional- and central-estimate values for the time when anti-icing applications should be made on specific segments of highway, relative to beats that will be operated by treatment crews. That is, treatment order and timing depends on feasible vehicle tours.

- Improved estimates of the anti-icing application amounts applicable to specific highway segments, based on risk assessments of future road conditions (temperature, residual chemical factors, traffic and precipitation).

- Improved timing of crew dispatching based on distributional- and central-estimate values for the time when deicing applications and plowing should be applied to specific segments of highway, relative to beats that will be operated by treatment crews. That is, treatment order and timing depends on feasible vehicle tours.

- Improved estimates of the deicing application amounts applicable to specific highway segments, based on risk assessments of future road conditions (temperature, residual chemical factors, traffic and ice cover).

- Improved estimates of when and where drain clearing is needed to treat potential flooding threats from meltoff or additional liquid precipitation.

- Improved estimates of when and where bulk removal of snow is needed to maintain road LOS or prevent runoff and re-freezing problems, with respect to other threats that crew resources are needed for.

These operational improvements will be translated into more specific informational requirements as part of the operational scenario review.

8.3 Prioritizing the Improvements

Priorities will be added through stakeholder participation in subsequent versions and further analysis of relations of treatment to outcomes.

9.0 Improvement Concepts

This section will contain requirements for the WIST-DSS based on stakeholder participation in review of the operational and weather scenarios, and contributions of system developers to the stat-of-the-art section. Preliminarily, high-level requirements are identified.

9.1 The WIST-DSS System Concept

9.1.2 System Vision

The development of the WIST-DSS as an improvement of the RWIS is guided by this Vision Statement[43]:

> *Transportation system operators and users have readily available weather information that is accurate, reliable, appropriate and sufficient for their needs. The resulting decisions effectively improve the safety, efficiency and customer satisfaction of the transportation system.*
>
> *Improved support for weather-related surface transportation decisions evolves through locally adapted applications that are integrated into a system with an information infrastructure that is national, and international. This evolutionary process occurs by decentralized, public-private action that is needs-driven and market-driven, but in a coordination framework that includes the National ITS Architecture. This framework allows decision makers to share an open system for obtaining weather information appropriate to each decision, and for coordinating the resulting decisions for maximum effectiveness. Decision makers measure their effectiveness in improving the performance of the transportation system, and use these measures to improve how decisions are supported, made and effected.*

9.1.3 The WIST-DSS Context

The WIST-DSS context consists of inputs, outputs, resources and constraints:

The WIST-DSS inputs shall be goals for surface-transportation system performance on the part of agencies and individuals making decisions based, in part on weather information. The WIST-DSS shall be adaptive in improving decision performance relative to measured goal performance.

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[43] From the Weather Team White Paper, 1998.

The WIST-DSS outputs are control of assets within the surface-transportation system. The WIST-DSS shall assure that all decision makers who control such assets are provided with necessary decision support information. Operational practices shall conform to best practices relative to the information provided by the WIST-DSS.

The WIST-DSS resources include the funding of the WIST-DSS, training of WIST-DSS users and information. The information is produced elsewhere in the Intelligent Transportation System (ITS) and by non-ITS processes, especially those of the National Weather Service or other meteorological services. The weather information shall represent the state of the art in meteorological observation and forecasting of all attributes of interest to surface transportation. Other ITS information shall be provided according to standards and specifications from the National ITS Architecture. Financial support of the WIST-DSS shall be consistent with the goal-performance improvements from investments in RWIS improvements. Training of WIST-DSS users shall be sufficient to use the information provided by the WIST-DSS.

The WIST-DSS constraints include several policy and organizational decisions. These are:

- Proprietariness: The WIST-DSS shall be an open system to facilitate communication and integration of information. The WIST-DSS shall maintain ownership rights to valuable WIST-DSS components and information in order to encourage innovation and financing of system evolution.

- Security: The WIST-DSS shall maintain security that allows control of access to information by the owners/originators of that information.

- Liability: The WIST-DSS shall facilitate a high level of practice in the provision of decision support information, including assessment of reliability of weather-related advisories and other information, and shall enable public agencies to be held harmless through the effective and efficient dissemination of such information for an overall improvement in outcomes.

- Performance: WIST-DSS performance shall be determined relative to goal performance, information resources used and information requirements of external agencies (e.g., for ESS data). Performance shall be maintained by adequate capital and operating investment.

- System Capacity Allocation: The WIST-DSS shall provide system capacity appropriate to goal performance, and shall allocate responsibilities between public and private agencies according to abilities to recover costs consistent with public benefits.

- Financing: The goal-performance benefits of the WIST-DSS shall be used to justify adequate system financing, and financing shall be divided between the public sector and the private sector where profitable pricing is feasible consistent with public goals. WIST-DSS performance benefits shall be used, as appropriate to justify additional funding to external agencies, e.g., the NWS.

- Allocation of Responsibility for Meteorological Information: The WIST-DSS shall respect limitations of the NWS regarding tailoring of products for users. The WIST-DSS shall use and encourage NWS products where they are necessary for an open system and performance goals, and shall otherwise use and encourage private sector provision of tailored products.

9.1.4 WIST-DSS Level 1 Structure and Requirements

As bounded by its context, the WIST-DSS includes three level 1 functions:

Decision Support tailors external information resources for the decision maker. This usually involves:
- Filtering as selection from a vast amount of external information, and also error reduction by "smoothing" the information.
- Fusion of disparate information to match the decision needs.
- Analysis, meaning some degree of information transformation into the decision.
- Information presentation, usually as display to a human, compatible with the decision maker's operating environment and information capacity.

Decision Making transforms the presented information into a prospective action. Therefore, predictions are inherent. Decision making can be automated, but in most cases it involves a human. Decision making under uncertainty involves risk (probabilities of outcomes via uncertainties in the information on the weather and the transportation system). Decision making interacts with Decision Support to select and be presented with information.

Decision Effecting transforms the decision into its output action. The action can be an information transfer, a control action, or the allocation of some physical assets. This is the link to assets in the surface transportation system. In the WIST-DSS this link is provided through interfaces with other ITS subsystems and processes.

Decision making is included since the output to the context is defined as asset control, and that must be effected through the "decision effecting" function. Ordinarily, the decision making will not be decomposed further in the WIST-DSS, especially when the decision maker is a human. However, the internal WIST-DSS interfaces will be intensive between decision maker and the DSS, and the interfaces will be intensive between Decision Effecting and the rest of the ITS. Therefore it is necessary to specify Decision Making and Decision Effecting to some degree here.
One of the principles that should be applied, to make the decision support and decision making compatible, is the use of risk decision making. This is an extension of some of the techniques used for fusing data within Decision Support itself. Also at issue here for requirements is how much the Decision

Support makes decisions, by producing go/no-go indications, versus how much processing is allocated to the decision maker . The mix and interface of human versus automated information processing is a major system requirements issue, and needs more information on human factors.

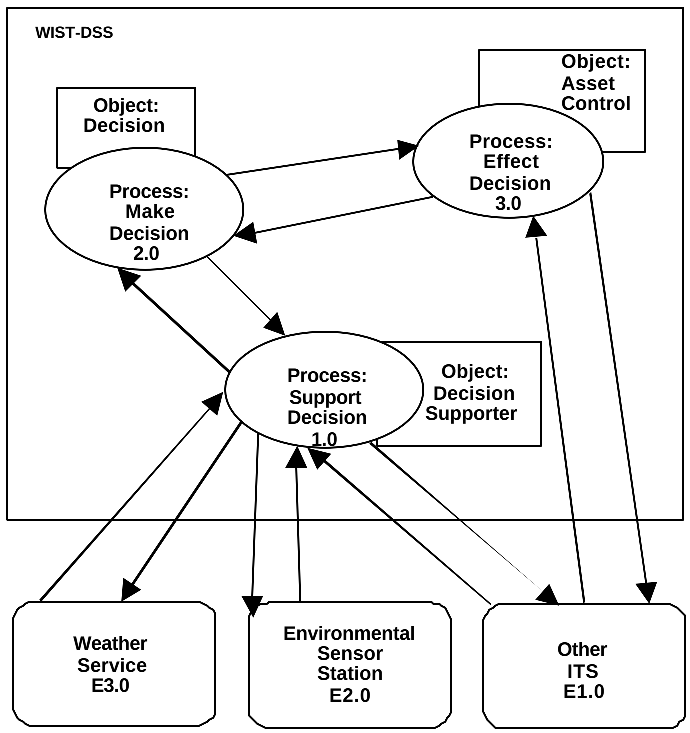

Figure 9.1: Level 1 WIST-DSS Diagram

The Figure above is the Level 1 WIST-DSS diagram. It shows the three Level 1 entities within the WIST-DSS and external interfaces with three identified terminators. The three WIST-DSS entities are shown as logical processes to match the logical National ITS Architecture representation, as well as by object-oriented forms of the same entities. The processes may be taken as verb-forms of activity while the objects are noun-forms and may be used to define the physical entities (subsystems) as well. The representation used here will be primarily logical processes and data flows, although contemporary system design might prefer the object-oriented form.

The three external entities will be subdivided at further levels of decomposition. At Level 1 it is decided to show “Weather Service” as generic, and this will contain both the NWS and other VAMS emulating NWS processes. This avoids a premature allocation of responsibility. However, it is the intent that most VAMS activity will be in the WIST-DSS and specifically in the Support Decision process.

The data flows are suggested by the arrows. Each entity is indexed for description at subsequent levels and for data flows. For instance, entity 1.0, Support Decision, will later be split into something like 1.2.3 Poll ESS Data with the indented index system. Data flow 1.0 to 2.0 is the flow from Support Decision to Make Decision. The external entities will be prefaced with E, so data flow E3.0 to 1.0 is Weather Service data to Support Decision. At Level 1, the following data flows are defined within the WIST-DSS:

1.0 to 2.0: decision support information to the decision
2.0 to 1.0: request presentation of decision support information

2.0 to 3.0: decided asset state to asset controller
3.0 to 2.0: receipt of decided asset state

It is not expected that there will be a 1.0 to 3.0 flow or the reverse. The 2.0 to 3.0 flows are included mainly to cover possible ambiguities between decision and control and to accommodate the interfaces with the ITS. The assets controlled are properly outside of the ITS in the Transportation Layer, and the external ITS is assumed to conduct all controls to the assets. The 3.0 to 2.0 flow is nominal, and information on compliance, as revised states of the transportation layer, will flow back from ITS to 1.0. Most of the WIST-DSS requirements will be on the 1.0 and 2.0 processes and their data flows, along with the data flows into 1.0 from externally. The external data flows are:

3.0 to E1.0: Forwarding of controls to assets via ITS
E1.0 to 3.0: Receipt of controls (generally a nominal flow)

E1.0 to 1.0: Information on state of the transportation layer (except ESS) to support decision
1.0 to E1.0: Request for information on state of the transportation layer (except ESS)

E2.0 to 1.0: Information on road conditions to support decision
1.0 to E2.0: Request for information on right-of-way (ROW) conditions and (possibly) remote adjustment of ESS parameters and controls.

E3.0 to 1.0: Information on weather to support decision
1.0 to E3.0: Request for information on weather *and optionally* information on road conditions.

These external flows have adopted the convention, along with defining the external entities, that ITS includes all information on the state of the transportation layer, except that provided on road conditions by the ESS, and further that road conditions are distinct from "weather" defined to be more general atmospheric conditions and meteors. In order to accommodate other surface modes, the term "ROW information" generally will be used in favor of "road information".

The 1.0 to E3.0 flow establishes the flow missing from the National ITS Architecture to "Weather Service". The primary function of this flow, besides request of non-broadcast information, will be to carry ESS ROW condition information into assimilation with other surface observations. The 1.0 to E3.0 option assumes that this is via the WIST-DSS. However, if a weather service (possibly a VAMS, possibly the NWS) performs the assimilation, the more direct flow is from E2.0 to E3.0. In that case, the WIST-DSS will receive assimilated observations of all types. Ordinarily an external-external flow would not be considered, but this choice makes it an issue.

Based on the Level 1 structure, appropriate requirements can now be allocated. These are made very generally, with the intent of specifying them in a meaningful way at lower levels and with stakeholder participation.

Table 9.1: Level 1 WIST-DSS Requirements

Data Flow or Process	Level 1 Requirement
1.0	Support Decision shall process all surface transportation and weather information necessary to support decisions that improve goal-performance of the surface transportation system.
2.0	Make Decision shall use all necessary information to improve goal-performance of the surface transportation system by controlling assets within the surface transportation system relative to road and weather conditions.
3.0	Effect Decision shall reliably convey all weather-related decisions for the control of assets within the surface transportation system to improve goal-performance of the surface transportation system.
1.0 to 2.0:	Decision support information shall consist of point values and statistics on the prospective state of the weather and the surface transportation system appropriate to control of surface transportation assets at specified locations and times, and appropriate to the comprehension of human decision makers who control the assets.
2.0 to 1.0:	Decision support information requests shall specify the attributes of information needed to support a decision including the spatial domain and time horizon of the decision.
2.0 to 3.0:	Decisions shall consist of a feasible and prospective specification of the state of assets in the surface transportation system.
3.0 to 2.0:	Decision receipt shall acknowledge the acceptance and further transmission of a control directive to an asset in the surface transportation system.
E1.0 to 3.0:	Control receipt shall acknowledge the acceptance and further transmission of a control directive to an asset in the surface transportation system.
3.0 to E1.0:	A control directive shall alter the state of a surface transportation asset consistent with a decision.

E1.0 to 1.0:	Surface transportation information shall consist of available point data and statistics on the past, current and future states of the surface transportation system.
1.0 to E1.0	Requests for surface transportation information shall specify the attributes of information needed to support decisions including the spatial domain and time horizon of the decision.
E2.0 to 1.0	ROW condition information shall consist of available point data and statistics on the past, current and future conditions of traveled ways in the surface transportation system.
1.0 to E2.0:	Requests for ROW condition information shall specify the attributes of information needed to support decisions including the spatial domain and time horizon of the decision. Settings of ESS parameters shall beneficially affect ESS performance.
E3.0 to 1.0:	Weather information shall consist of available point data and statistics on the past, current and future states of the atmosphere and meteors affecting the surface transportation system.
1.0 to E3.0	Requests for weather information shall specify the attributes of information needed to support decisions including the spatial domain and time horizon of the decision. ESS information shall consist of ROW condition observations specifying source information.

It should be appreciated how rapidly the volume and detail of these statements will increase at lower levels. The statements are the framework for what the lower levels will have to contain.

Further levels of WIST-DSS description and requirements will be provided as the project progresses. The next sections will also be completed in a later version of this document.

9.2 Operational and Deployment Policies

To be determined.

9.3 State of the Art Concepts

To be supplied by system development stakeholders.

9.4 Changes in Context and Interfaces

To be recommended in STWDSR V2.0.

9.5 Support Concept

To be recommended in STWDSR V2.0.

10.0 Expected Impacts

This section will be added pending further impacts analysis.

10.1 Output and Outcome Measures

10.2 Operational (Output) Impacts

10.3 Transportation System (Outcome) Impacts

10.4 Organizational Impacts

11.0 Deployment Programs

This section will be added in STWDSR V2.0.

11.1 The Federal Role

11.2 Federal-Local Partnership Role

11.3 The Local Public Role

11.4 The Private-Sector and Public-Private Partnership Role

Appendix material included in separate document