Surface Transportation Weather Decision Support Requirements

Draft Version 2.0

Operational Concept Description

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

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for

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STWDSR V2.0 Operational Concept Description

Introduction

This is a draft document for the Surface Transportation Weather Decision Support Requirements (STWDSR) project. The STWDSR project is being conducted for the FHWA's Office of Transportation Operations (HOTO) Road Weather Management Program by Mitretek Systems, Inc. The STWDSR V1.0 document was delivered in January, 2000, and gave background on the program and an initial needs analysis for decision support to winter road maintenance. Since then, two stakeholder meetings have refined the needs analysis and reviewed the initial operational concept for the Weather Information for Surface Transportation Decision Support System (WIST-DSS). The WIST-DSS is the conceptual system on which the STWDSR are levied, and the operation of which is described in this Operational Concept Description (OCD).

The STWDSR V1.0 should be referred to for full project background, that will be summarized in this introduction. The STWDSR through V2.0 is focusing on decision support requirements for winter road maintenance managers. Needs have been defined for all surface transportation decision makers and later phases of the project will develop their decision support requirements more fully. Therefore the WIST-DSS and its OCD should be considered expandable in user scope. The STWDSR project has two primary objectives:

- To provide requirements, at a high level, that can be allocated to lower levels, within a spiral evolutionary process of WIST-DSS deployment.
- To identify requirements on external information resources for the WIST-DSS that can be addressed by programs within the FHWA and by inter-agency programs with the meteorological community and others.

These objectives are met respectively in this OCD and a separate Preliminary Interface Requirements document. Both documents together constitute the STWDSR V2.0 deliverable.

The immediate objective of the OCD is to stipulate a prototype development project to be sponsored by the FHWA with FY 00 research funds. The baseline system for decision support to winter road maintenance managers is called the Road Weather Information System (RWIS) following colloquial terminology for the present system. The improved WIST-DSS will be deployed by road operating agencies, including state departments of transportation (DOTs) and generally supplied by private vendors who are here termed Value Added Meteorological Services (VAMS). The WIST-DSS will rely for its external information on the Intelligent Transportation System (ITS) that itself interfaces with a weather-information infrastructure, operated primarily by the National Weather Service (NWS). The FHWA role is to collect requirements and promote deployment by targeted research and operational test projects. The ITS program administered by the ITS Joint Program Office (ITS-JPO) under the FHWA has an important role in fostering open systems for surface transportation information through the National ITS Architecture and standards. The spiral cycle refers to many iterations between development projects, operational deployments, evaluations and requirements updating, over which the WIST-DSS concept will evolve. The OCD is just one step beyond the RWIS baseline that is embodied in many operational systems provided by VAMS, and some fostered by previous ITS funding.

The STWDSR V1.0 identifies decision support as the key bottleneck between environmental information and winter road maintenance on the way to improving the performance of the surface transportation system. This reflects the current difficulties in integrating “stovepiped” information sources on weather, road conditions and other transportation attributes. The focus on decision support strictly defines the information sources as external to processes that must filter, fuse, transform and present information to decision makers. The first-order assumption of the OCD is that the external sources of information exist adequately for further decision-support processing. However, the second STWDSR objective requires identifying where the end product of winter road maintenance might *effectively* require improvements in the external sources. This is the objective fulfilled in the Preliminary Interface Requirements document. *Effectively* in this case means that although everyone wants “better information”, the STWDSR must identify what is significant to surface transportation performance, technically feasible and not otherwise being developed. Being specific about what “better” means can only be achieved in the context of how the information will be used, so the OCD and interfaces document complement each other.

The WIST-DSS requirements documents are being developed according to system engineering standards. The WIST-DSS is primarily a software engineering development effort and the reference standard is IEEE/EIA std. 12207 for software life cycle processes. The OCD is specified as a Data Item Description (DID) by this standard. The OCD DID is identical with that specified by the earlier MIL-STD-498, which is the standard actually used here since it is more readily available.

The basic system engineering process consists of the analysis of operational needs, allocation of solutions to bounded systems, and a hierarchy of successively detailed specifications of systems to provide the solutions. The spiral evolution process puts this conventional development process within the larger context of needs and technology changes. For the moment, all that concerns the OCD is that needs have been identified, and they will be addressed at a high level by describing an operational concept for the WIST-DSS. Lower levels of the system and testing processes will be specified as a prototype is developed and as an operational test occurs. A DID, called the Interface Requirements Specification (IRS), accompanies the lower level specifications as development proceeds, and typically the IRS is created after the OCD. Within the STWDSR V2.0, it is not possible to develop a full IRS in parallel with the OCD. Therefore, the Preliminary Interface Requirements document accompanying the OCD is not a proper DID, but is more of a needs analysis for the external information resources. The interfaces document describes these external information resources in a formal taxonomy that is the basis for an eventual data dictionary for the WIST-DSS.

The remaining material in this document follows the content requirements of the OCD DID from MIL-STD-498.

1. Scope

1.1 Identification

This document describes the operational concept of the Weather Information for Surface Transportation Decision Support System (WIST-DSS). The WIST-DSS is an evolutionary improvement of current decision support systems for winter road maintenance managers, generally called Road Weather Information Systems (RWIS).

1.2 System Overview

The WIST-DSS shall support decisions at operational scale of winter road maintenance managers in order to improve performance of the surface transportation system through improved treatment of winter-weather threats to system performance. The performance measures correspond to Federal Highway Administration (FHWA) strategic goals and objectives[1]:

Table 1.2.1: WIST-DSS Goals and Objectives Derived from FHWA Strategic Goals and Objectives

FHWA Strategic Goal	
	FHWA Objective
1. Mobility	
	1a. Preserve and enhance the infrastructure...with emphasis on the National Highway System (NHS)
	1b. Improve the operation of the highway systems and intermodal linkages to increase access
	1c. Minimize the time needed to return highways to full service following disasters
2. Safety	
	2a. Reduce the number of fatalities and injuries
3. Productivity	
	3a. Improve the economic efficiency of highway transportation
	3b. Improve the return on investment of the highway system

[1] Federal Highway Administration 1998 National Strategic Plan at website http://www.fhwa.dot.gov/////////policy/fhplan.html

4. Human and natural environment	
	4a. Enhance community and social benefits of highway transportation
	4b. Improve the quality of the natural environment by reducing highway-related pollution and by protecting and enhancing ecosystems.
5. National security	
	5a. Improve the capacity and operation of the highway system to support mobilization

The WIST-DSS is a system that filters, fuses, and processes external information resources and presents decision support information to human winter road maintenance managers (optionally, automated treatment processes). The decisions regard operational allocation of treatment resources. The WIST-DSS tailors the presented information to the decision and the decision-making environment as defined by the organizational placement of the manager and the skill level of the manager. The decision-support information is presented through a computer-human interface (CHI) that contains a graphical user interface (GUI) also with keyboard or equivalent user inputs. Alerts of changes may also be presented through remote communications devices, such as pagers.

The WIST-DSS is an application and associated operating platform relying on open-system protocol layers for computer-to-computer communications of information. Human-to-human narrative interfaces are auxiliary to the CHI. The open-system protocols are specified in applicable standards, including data dictionaries and message sets of the Intelligent Transportation System (ITS). The WIST-DSS is an application within the ITS.

The WIST-DSS concept originated with research conducted by the FHWA under the rural ITS Program of the ITS Joint Program Office (ITS-JPO). The need for integrated decision support was first identified in a white paper in 1998[2]. The FHWA was reorganized in 1999 and the Office of Transportation Operations (office code HOTO) was formed. The HOTO consolidated winter road maintenance programs under a Weather and Winter Mobility Program, since renamed the Road Weather Management Program. This program sponsored the Surface Transportation Weather Decision Support Requirements (STWDSR) project in 1999 to address the problems and program recommendations cited in the 1998 white paper. The STWDSR project was conducted for the program by Mitretek Systems, Inc. The STWDSR project formed a stakeholder group consisting of winter road maintenance managers from 28 different states, six federal laboratories engaged in meteorological and decision-support system research, and representatives of Value Added Meteorological Services (VAMS) vendors. The National

[2] FHWA Weather Team, Weather Information for Surface Transportation: A White Paper on Needs, Issues and Action, Draft May 15, 1998.

Weather Service (NWS) and the Office of the Federal Coordinator for Meteorology (OFCM) were also represented. A STWDSR stakeholder meeting was held in February, 2000, to participate in refining the needs analysis. A second meeting was held in May, 2000, to review the initial contents of this OCD.

The baseline RWIS is currently operated by many road operation authorities and provided by VAMS. The RWIS relies on the national weather information infrastructure provided by the NWS, and specialized road-condition observations provided by Environmental Sensor Stations (ESS). There are approximately 1,200 ESS fixed sites in the United States[3]. There is some mobile ESS sensing, especially of road temperatures. The RWIS includes presentations of direct road-condition observations, NWS products, tailored weather products (including high resolution numerical weather prediction (NWP) products), and predictions of weather-related road conditions (especially road freezing). However, with the multiplicity of vendors, products and communications channels, the information remains “stovepiped”. Although the information has varying degrees of spatial specificity, down to major routes, the presentations generally are not decision-specific.

The FHWA will not deploy the WIST-DSS. The FHWA will sponsor research and operational tests to promote the WIST-DSS requirements. The FHWA will provide deployment guidance for the WIST-DSS within ITS deployments. Federal aid funding can be applied to ITS deployments according to programming, regional system engineering and architecture, and standards regulations[4]. WIST-DSS requirements do not constitute a standard or federal-aid requirement.

The WIST-DSS will be deployed as evolutionary improvements to the RWIS. WIST-DSS development may occur through FHWA-sponsored research or through VAMS investment. Operational systems will be provided by the VAMS. Systems will be acquired and operated by road-operating authorities. Systems will be operated at offices of winter road maintenance managers, that may be at district-level offices or in individual maintenance-area garages. It is possible that mobile versions of the WIST-DSS will operate in maintenance trucks or managers' vehicles. However, the operational-scale decision support of the WIST-DSS is different from the micro-, or warning-scale decision support associated with maintenance crews. It is also different from planning-scale decision support typically performed at central offices.

Background on the STWDSR project and some of the needs analysis for the WIST-DSS, and a needs analysis of the information resource requirements, will be found respectively in the following documents:

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[3] Count based on information from STWDSR stakeholders.

[4] Issued as Part V, Department of Transportation, Federal Highway Administration, 23 CFR Parts 655 and 940, Intelligent Transportation System Architecture and Standards; Proposed Rule. Federal Register, Thursday, May 25, 2000, pp. 33994-34000.

Surface Transportation Weather Decision Support Requirements, Draft version 1.0, Mitretek Systems, Inc., January 24, 2000. Available as document 12144 on the Electronic Documents Library, www.its.dot.gov/welcome.htm

Surface Transportation Weather Decision Support Requirements, Preliminary Interface Requirements, Draft version 2.0, Mitretek Systems, Inc., July, 2000.

1.3 Document Overview

The STWDSR V2.0 OCD will describe how the WIST-DSS will support winter road maintenance decisions. It will describe the baseline RWIS and its deficiencies that the WIST-DSS addresses. The OCD is the first in a series of specifications for the WIST-DSS, and it will stipulate FHWA-sponsored prototype research as well as other evolutionary improvements to the RWIS.

2. Referenced Documents

The major reference documents are listed below. Other documents are cited in the text.

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. IEEE Standards: *Software Engineering*, four volumes, 1999 Edition or updates.

3. *National ITS Architecture*. Listed in the Hypertext Architecture Version 2.2 (or update), 6/1/99 (or update) found at: http://www.odetics.com/itsarch/.

4. *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

5. *Surface Transportation Weather Decision Support Requirements*, Draft version 1.0, Mitretek Systems, Inc., January 24, 2000. Available as document 12144 on the Electronic Documents Library, http://www.its.dot.gov/welcome.htm

6. *Surface Transportation Weather Decision Support Requirements, Preliminary Interface Requirements*, Draft version 2.0, Mitretek Systems, Inc., July, 2000.

3. Current System (RWIS)

3.1 Background, Objectives and Scope

The Road Weather Information System (RWIS) is defined as the current system from which the WIST-DSS will evolve. However, the system objectives and scope are not identical. The WIST-DSS is, for each user, a single decision support system using external information resources to formulate decision criteria from the state of the environment, the road network and other relevant constraints and resources. Conversely, the RWIS is not a single system for each user, but a collection of road-condition and weather-information sources. These sources are external to the WIST-DSS, so the RWIS is mostly the subject of the interface requirements document, but it also serves as the baseline to define deficiencies in decision support. Two definitions are essential to differentiating the RWIS and WIST-DSS:

- "Stovepiping" describes the multiplicity of information sources and channels in the RWIS, with the sources and channels often being bundled, preventing integrated processing of the information. The information sources and channels generally use different structures and formats for data elements and communications. They are "proprietary" if the structures or formats are not published. This forces the user to consult many sources and to formulate decision criteria manually.

- An "open system" has uniform and published structures and standards for data elements and communications channels. For computer-to-computer communications, the channels are standardized by "protocols", and the data elements adhere to uniform data dictionary and message set standards.

The situation addressed by the WIST-DSS is shown in the figure below. The RWIS generally refers to the multiple *environmental* information sources, including weather and road conditions. Excluded, but also necessary to decision support anywhere in surface transportation are information sources on other attributes of the road network and of the operating agency. Stovepiping practically prevents the creation of a complete and integrated decision support system. Stovepiping is associated with proprietary information formats and communications protocols. This is often because property rights are asserted over both. Open systems make available formats and protocols to all system designers. Open systems do not affect property rights over the information, but enhance them through facilitating consumer access to the information. Decision support systems are applications using the information, and may be proprietary but with open interfaces. The WIST-DSS relies on an open system for *all* the information that operates from computer to computer, and on a single decision support processing application and display.

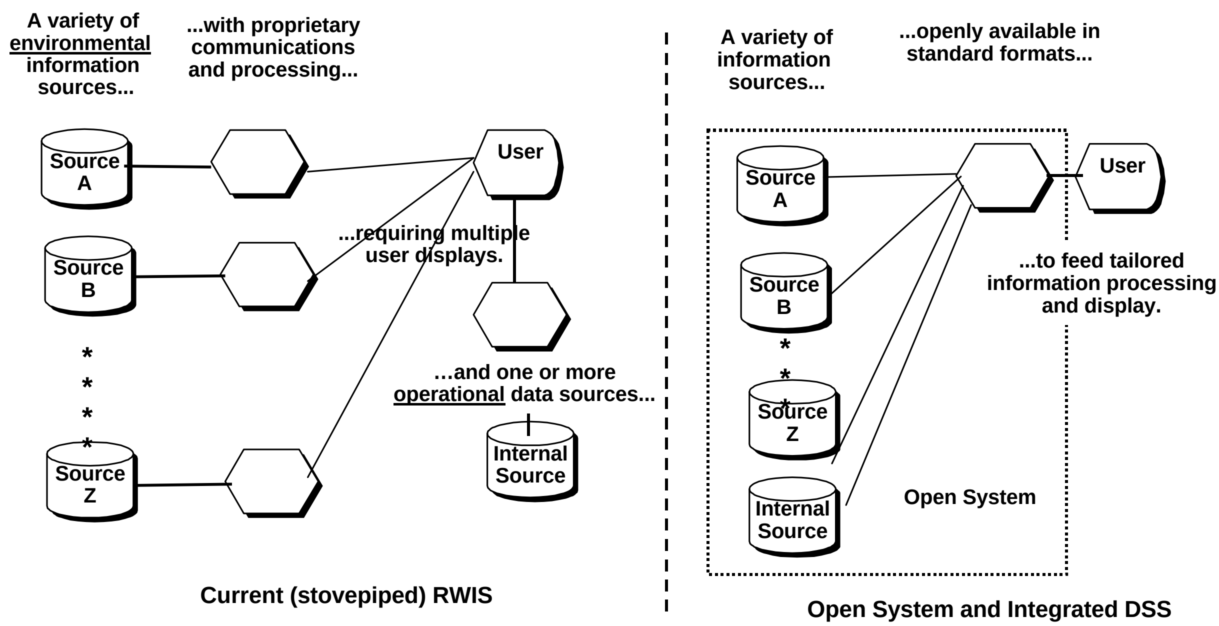

Figure 3.1.1: The RWIS and the WIST-DSS with External Information Resources

There is no strict definition of the RWIS or bounding of the included system. RWIS is defined here to include four kinds of services:

1. Supply of the Environmental Sensor Stations (ESS) for direct road-condition observation;

2. Further processing of ESS data for road-condition prediction;

3. Supply of general atmospheric condition forecasts and consulting by Value Added Meteorological Services (VAMS) vendors;

4. Dissemination of various road-condition and weather-information products by Information Service Providers (ISPs), including general atmospheric condition observations, forecasts, watches and warnings from the National Weather Service (NWS).

RWIS information is intended to support winter highway maintenance, traveler and other highway decisions. The services apply to all types of users. However, services (1) and (2) generally are purchased and may be used exclusively by winter road maintenance agencies.

The term RWIS was promoted through the title of a 1993 Strategic Highway Research Program (SHRP) report[5]. The term Environmental Sensor Station (ESS) is reserved for road-condition observation systems according to usage in the ITS standard[6]. ESS usually include near-surface weather observations (called "surface observations" in the meteorological community) and therefore provide some measurements equivalent to those of weather observing systems such as the Automated Surface Observing System (ASOS). ESS have been in use in the U.S. at least since the 1980's. At the time of the 1993 report, 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" who combined maintenance and traffic management responsibilities. Road-condition prediction, especially of road-surface temperature, is still developed in Europe and introduced into the U.S. by the VAMS. The RWIS complemented introduction of anti-icing practices in the United States, whereby freezing-point depressing chemicals are applied to roadways in advance of surface freezing to prevent loss of friction and bonding of snow to the pavement through an ice layer[7]. In colloquial use, the RWIS is often defined to be *only* the ESS information. Stovepiping has become a problem because the scope of the RWIS necessarily has expanded to a variety of information sources that are necessary, but not sufficient, for decision support.

Strictly defined, the VAMS *separately* tailor and process various ESS observations and weather information from the NWS into products that better serve decision makers. The ISPs (a term used in the National ITS Architecture) are disseminators of information that could originate from any source. Broadcast traffic reports, that may include weather, road conditions and incidents as well as traffic flows, are typical of ISPs. Increasingly, ISPs use the Internet[8]. Depending on how much value is added to the information by its processing, there is a spectrum of VAMS, most of whom have an ISP function, and some of whom have only an ISP function. ESS observations are transmitted to maintenance offices by dedicated wireline, switched wireline (telephone) or radio channel. This usually is not by an ISP but posting of ESS information to third parties

[5] *Road Weather Information Systems*, Volumes 1 and 2, Report SHRP-H-350, National Research Council, Washington, DC, 1993.

[6] *National Transportation Communications for ITS Protocol (NTCIP) Object definition for Environmental Sensor Stations (ESS)*, Draft Version 98.01.12, September 28, 1998, American Association of State Highway and Transportation Officials.

[7] Ketcham, Stephen A., L. David Minsk and Lawrence D. Danyluk, *Test and Evaluation Project No. 28: Anti-Icing Technology Field Evaluation Report*, FHWA-RD-97-132, March 1998.

[8] The conventional acronym ISP stands for Internet Service Provider. However, ISP in ITS use is an information dissemination service, that may use the Internet, and an Internet Service Provider, as a means of communications.

involves an ISP. Use of ESS data or weather information to produce road-condition predictions is a VAMS function. VAMS vendors usually control the data from the ESS equipment they provide and use the data for road-condition predictions. For simplicity, VAMS will be defined as the providers of RWIS.

Some VAMS products are provided by subscription, especially if consulting or ESS services are involved. Some ISP services are provided by subscription (e.g., satellite broadcast) but many terrestrial broadcast or Internet information services are free to the users with information originating from ESS, VAMS or the NWS. There are NWS subscription services but most NWS information is available for free over various NWS channels and other ISPs. In any case the important points are these:

- The RWIS is not a single source nor single communication channel to users. This is a reason why the current problem of stovepiping exists.

- The degree to which the RWIS can be said to provide decision support is the degree to which delivered information is sufficient and tailored to specific decisions. This is a function of VAMS, blurring into ISPs who provide important CHI tailoring functions, especially in client-server (Internet) communications.

As the RWIS became recognized, 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[9], the first national ITS program plan in 1995[10] and articulation of the Operation TimeSaver/Intelligent Transportation Infrastructure goals in 1996[11]. 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). The rural ITS program was initiated in late 1995, and emphasized highway maintenance and weather information as constituent needs[12]. The STWDSR project is funded by rural ITS research funds. ITS funds have supported significant operational tests of RWIS, including the Advanced Transportation Weather Information System (ATWIS) in the Dakotas and Minnesota, and the

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

[10] *National ITS Program Plan*, ITS America, March 1995.

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

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

Foretell™ program in Iowa, Missouri and Wisconsin. Weather information has been part of other ATIS and ATMS projects[13].

The National ITS Architecture is the structural framework of the ITS and the basis for the data dictionary, message set and equipment standards for surface transportation. The deployment role of the National ITS Architecture and standards are defined by proposed rule[14]. The National ITS Architecture reflects requirements of user services in a physical and logical structure of data flows and processes. The National ITS Architecture and standards are intended to promote open-systems interoperability of the external information flows of ITS applications. This document defines the RWIS and the WIST-DSS as being applications within the ITS. The ITS provides the logical, and sometimes physical, channels for all RWIS and WIST-DSS information. The ITS includes the ESS, and the ITS is the source of most of the surface transportation information other than weather.

The objective of the privately-provided RWIS is profitable service operation. This may involve bundling of services (e.g., equipment sales with information services), use of existing communications services (e.g., satellite broadcast) or specialized prediction services with customer value over free products. The objective of public weather information is contained in the authority of the NWS[15]:

> **Sec. 313. Duties of Secretary of Commerce**
>
> The Secretary of Commerce shall have charge of the forecasting of weather, the issue of storm warnings, the display of weather and flood signals for the benefit of agriculture, commerce, and navigation, the gauging and reporting of rivers, the maintenance and operation of seacoast telegraph lines and the collection and transmission of marine intelligence for the benefit of commerce and navigation, the reporting of temperature and rain-fall conditions for the cotton interests, the display of frost and cold-wave signals, the distribution of meteorological information in the interests of agriculture and commerce, and the taking of such meteorological observations as may be necessary to establish and record the climatic conditions of the United States, or as are essential for the proper execution of the foregoing duties.

Policy limits the "tailoring" of services by the NWS where such services can be provided by VAMS, but the definition of this limitation is not clear. It blurs because weather information is both necessary to and in parallel with road-condition information in the RWIS. The

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[13] See *ITS Projects Book* (annual), FHWA.

[14] Federal Register, op. cit.

[15] 15 USC 313, as of 1/26/98.

improvement of NWS products, or their formatting through ISPs, is a natural progression but can supplant what VAMS provide.

The *use* of the RWIS is according to objectives of the agencies and parties using the surface transportation system. For winter road maintenance managers, the ultimate objectives, in terms of surface transportation system performance are similar to the FHWA goals and objectives. Because of the decentralized operation of the road system, objectives are variously stated and interpreted. In most cases, the objectives are cost-effective and rapid achievement of level of service (LOS) standards established by states or other road operating authorities. The LOS standards generally are in terms of intensity of treatment (e.g., continuous, shift or part-time) or road-surface condition to be achieved (e.g., lanes or tracks with snow removal and ice treatment). The LOS standards are differentiated by functional road class, with freeways and primary highways generally having the highest standard.

The relation between RWIS supplier objectives and user objectives remains weak. This is because; 1) Users have not expected or demanded decision support apart from available information sources; 2) Predictive accuracy of RWIS information has been poorly validated and; 3) The causal relations between road-condition/weather information and transportation system performance have been poorly defined.

3.2 Operational Policies and Constraints

Since the RWIS is a mixed system of public and private suppliers, and public and private users, there are diverse operational policies and constraints. Operational policies on the user side are limited to winter road maintenance, and the group that can be best characterized are winter-road maintenance managers of state DOTs.

There are no national policies on RWIS services, and no state DOT stipulations on RWIS use amounting to “policy” are known. The only policies are on LOS, which is a maintenance output criterion, not an RWIS policy. There are no uniform ESS investment policies and the population of ESS sites is spotty across states. ESS is motivated primarily for observing road freezing and in conjunction with anti-icing. In the general sense, RWIS weather information can serve against flooding and hurricane threats, but it is safest to say that RWIS will be used by states where snow and ice threats are significant. State DOTs are beginning to share information on ESS purchase and maintenance requirements, as well as sharing the ESS observations. The state of the practice is for winter road maintenance organizations to have RWIS services, usually from multiple sources. The de facto policy is that “more sources are better” and this amounts to no decision support policy. There are varying degrees of autonomy for local offices to select RWIS services, as opposed to ESS buys that generally are at a state level. No standard operating procedures (SOPs) have been identified regarding operational use of RWIS. Information on how and when RWIS sources are used is part of the research for this OCD, and this confirms local discretion and multiplicity of sources. This also correlates with the absence of specific decision-support tailoring of most of the services.

There are several policies and constraints that affect the RWIS information resources and their delivery to the users. Most of these affect the external interfaces rather than decision support. However, stovepiping does affect the ability to perform decision support functions other than manually. The relevant constraints, on the information supply side are:

Proprietariness

Proprietariness has two aspects: ownership of the information and the lack of open-system protocols for computer-to-computer information communications. The two aspects have been, but need not be associated. Specifically:

- ESS data are subject to contractual agreements on data usage. In some 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 are stovepiped. Given a mix of standards and legacy stovepiped systems, it will not be possible to achieve an open system for some time, but in the interim special efforts to re-host or convert information sources can be done.

- 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.

Proprietary rights to develop self-sustaining ITS services and to encourage private sector participation in technical development are encouraged by federal policy. The National ITS Architecture and standards are intended to overcome proprietary <u>protocols</u> for communications and enhance both proprietary and public <u>values</u> of information.

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 can complicate information communications, but must be respected as an operational policy.

Liability

DOTs have expressed concern about the publication of information that may lead to decisions or actions for which the source of information is liable. This has inhibited some public dissemination of information, but should not affect management information. Case law increasingly points to provision of adequate warning information as necessary to escape liability. The liability of information suppliers for faulty predictions and warning is still present, but promotes competence.

Performance

Performance requirements for ESS are currently being bolstered in DOT contracts. These apply to both reliability of equipment and accuracy of observations. For RWIS generally, perceived performance plays some role in what services are purchased, but evidence shows use of RWIS services with low perceived performance. Performance generally is too poorly quantified to be a policy factor, and performance assessments remain largely subjective on the part of users. Performance in terms of the CHI, availability of human consultation, or cost are significant factors, but policy on these is lacking.

Information System-Capacity

This is an external interfaces issue, but it affects the RWIS and the WIST-DSS. Peak demands for information on weather events make information capacity an issue for some communications protocols (e.g., Internet but not broadcast). The various economic incentives by public and private ISPs to provide capacity is a policy issue because networks (road or communications) challenge usual market mechanisms. There are always technical means of overcoming the capacity constraints with sufficient investment.

Financing

Financing of RWIS for maintenance managers is constrained by public budgets, and responds to the perceived benefits to the using agencies. Since there are no performance policies for the RWIS, and generally poor benefits documentation, there is no uniform funding policy. Funding often follows state-of-the-practice of peer agencies. Documentation of direct cost and safety benefits to anti-icing mostly serves to motivate ESS investment.

The Division of Public and Private Sector Roles

Tailored decision support must be provided by the VAMS. However, the information resources in the RWIS depend largely on a public infrastructure of weather information. The users who are highway operators are mostly public agencies. This clouds the issue of how far the NWS should go in providing components of the RWIS services. The NWS modernization, that increases the NWS capacity for information dissemination, erodes some of the gap between general weather and specialized RWIS services. As a matter of policy, the NWS will not compete with viable VAMS markets. If this limits improved weather products necessary for improved road-condition prediction, this is a constraint. But so too if public products deter VAMS developments. The issue has to be divided more finely according to the place of the various sources of information in the processing thread to produce road-condition information as used in decision support. This belongs more fully to the interfaces document, but some topics where public-private allocation is pertinent are:

- Assimilating various point observations.
- Remote sensing observations (radar, satellite).
- Large-domain numerical prediction models.
- Local-domain numerical models.
- Watches and warnings of severe weather.
- Producing additional, sensible attributes from weather analysis and prediction.
- Dissemination of expanded NWS digital products.

3.3 Description of the Current RWIS

3.3.1 Operational Environment

The focus here will is on winter road maintenance. The RWIS operational environment concerns both the resources and the demand for winter road maintenance. From data collected from the STWDSR stakeholders, 38 state DOTs operate about 1,200 ESS sites, and there are additional operations by toll authorities. This ESS population is mapped below:

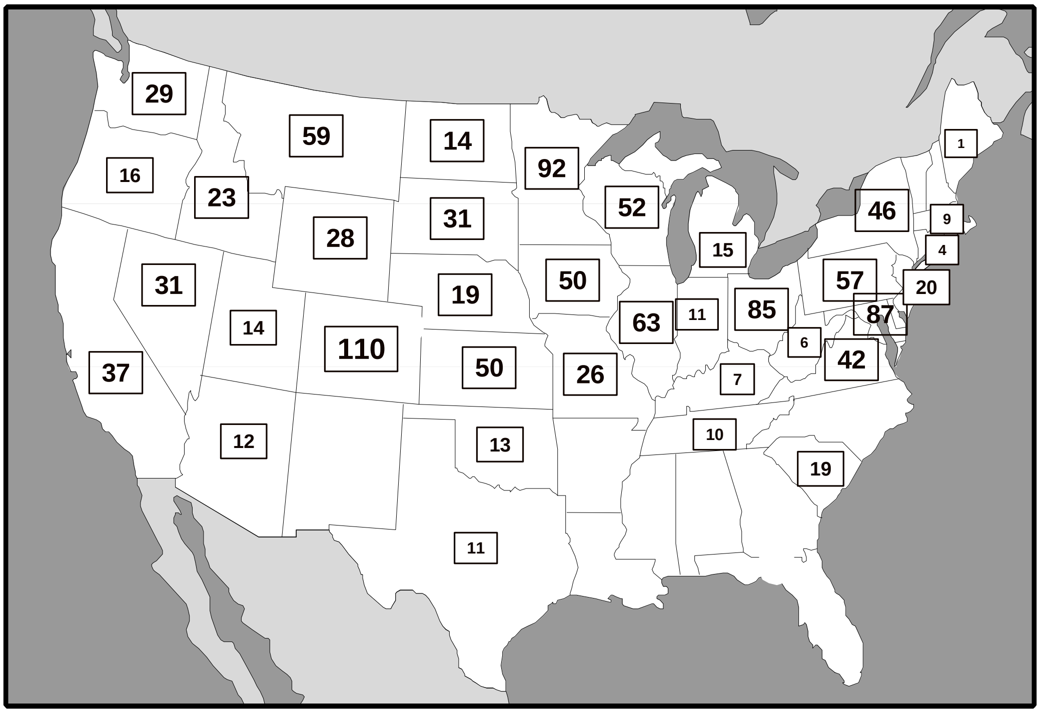

Figure 3.3.1: ESS RPU Counts by State

Sites are defined as ESS remote processing units (RPUs) that may have multiple pavement sensors homing to them, but usually one set of weather observation sensors. ESS installations are climatically regionalized, with most of the Gulf states lacking ESS but also New Hampshire and Vermont.

The winter weather threat, and therefore the user interest in RWIS, is partially indicated by snowfall. This overlooks icing events. European interest in RWIS and road temperature prediction is based very much on the icing threat associated with maritime humidity and marginally-freezing conditions that may be little associated with snow. However, mean annual snowfall[16] is mapped below for the U.S.:

[16] Doesken, Nolan J. and Arthur Judson, *The Snow Booklet*, fig. 26. Colorado State University, 1996.

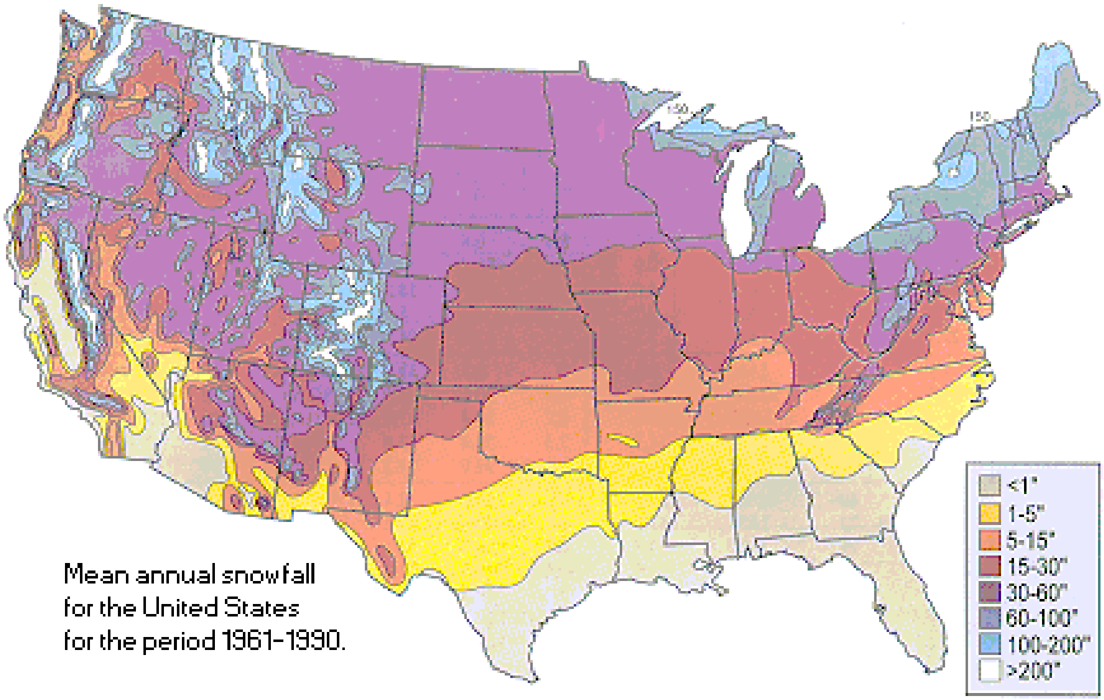

Figure 3.3.2: Mean Annual Snowfall Contours for the U.S.

The snowfall contours at least show that specifying the snow threat geographically is not simple. Depending on elevation and other terrestrial or meteorological factors, a state or even a maintenance jurisdiction can have many different climatic areas. Within one state, areas can range from 15 to over 200 inches average. Since climate is an important context factor for decision support, this affects RWIS performance. Mean snowfall also does not represent the extremes that are of significance to planning treatment resources and operational decisions. Greatest snowfall events[17] are mapped below:

[17] Tabulated from data in *United States Snow Climatology* (CD), Version 1.0, National Climatic Data Center, October 1998.

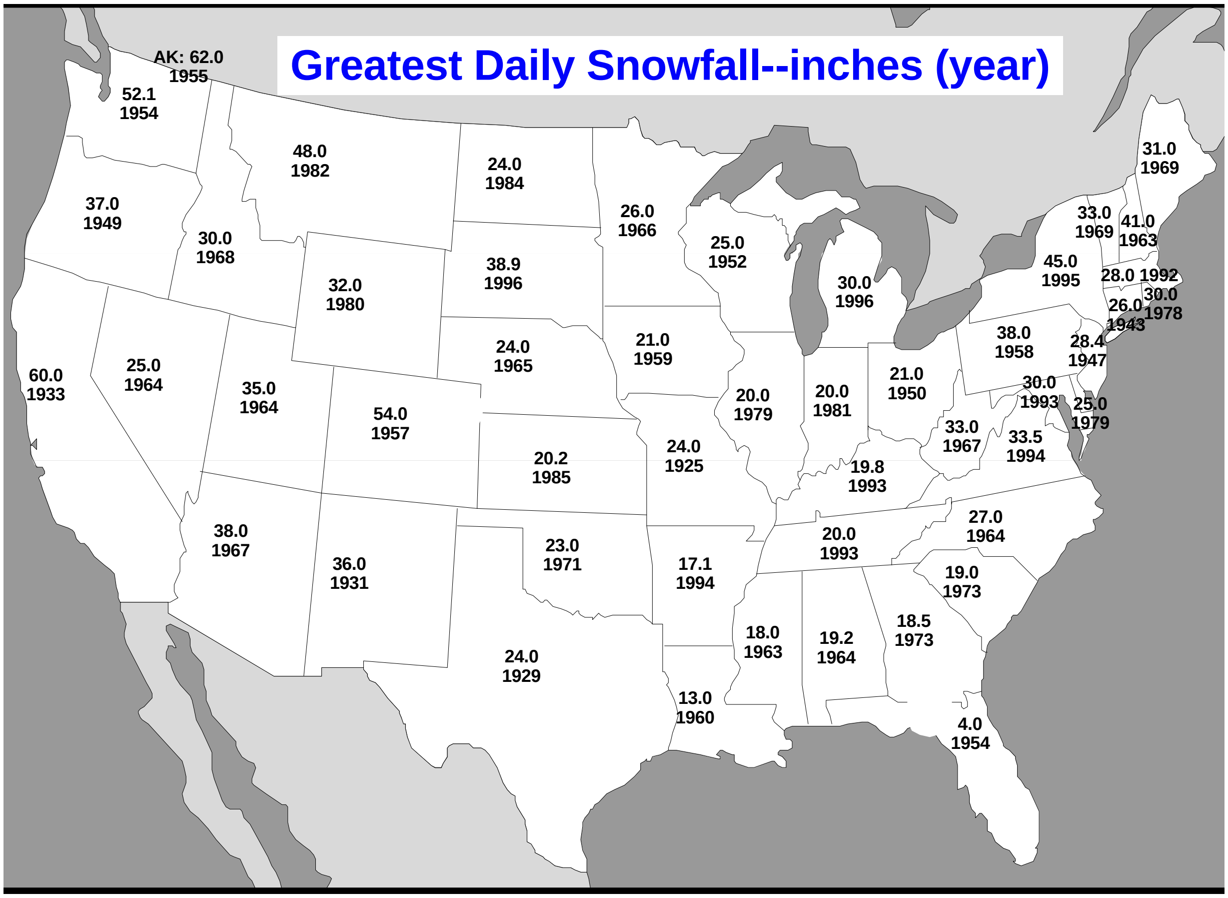

Figure 3.3.3: Greatest daily Snowfall Events, Inches and Year of Occurrence.

The range of mean snowfalls in areas across the states is from 1 inch to over 200. But the range of the maximums is only from 4 to 62 inches, and excluding Florida and Hawaii, the minimum is 13 inches. Comparing Louisiana to Maine, for instance, the range is only 13 to 31 inches. The RWIS may be particularly important to traveler information in the areas where severe snows occur infrequently, but then such areas may not invest in the treatment facilities for such rare events. In areas where snow is regular, the value of RWIS is in characterizing the timing of events to improve the efficiency of substantial treatment resources. Climatic factors of frequency, duration, and severity of snow or icing events will affect details of decision making. Information from the STWDSR group indicates that crew scheduling and anti-icing practices are different between cold areas with regular snow and more temperate areas with less frequent snow. For treatment decisions that are responsive to snow accumulations rather than for preparation for events, the type and value of predictive information will differ.

The RWIS specifies weather threats to the road network. Tailoring recognizes that the objects of interest to road treatment are road segments and treatment-beat routes, not the tracks, areas or volumes defined for weather. There are nearly 4 million miles of public roads in the U.S[18]. The highway system is categorized into functional classes: Interstate, other freeway, primary arterial, minor arterial, collector and local roads[19]. 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 (e.g., the LOS standards) and therefore the value of decision support information.

The functional classes also correlate with jurisdictional responsibility as shown in the table below. State DOTs generally control the Interstates, although Toll Road authorities have authority over some sections 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.

Table 3.3.1: 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

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

[19] 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.

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 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 (e.g., Wisconsin), and similarly for localities.

The costs of winter maintenance determine the direct economic leverage that decision support for treatment can have. Cost data are collected for state-administered highways[20] and local government disbursements[21]. These reflect both the road network extent and the climatic threat

[20] *Highway Statistics*, FHWA 1997. Table SF-4C, “snow and ice removal” column.

[21] *Highway Statistics*, FHWA 1998. Table LGF-2, “snow removal” column (data for 1997)

from winter weather. The 1997 total winter maintenance cost for public roads in the United States is $1.12 billion for the state-administered highways, and $1.14 billion from local funds. Cost per highway mile was derived for state or locally-controlled highway mileage[22].

Figure 3.3.4 compares state and local costs for 1997. Figure 3.3.5 shows just the state-jurisdiction costs, but compares 1997 and 1998. The horizontal categories on both charts are based on climate categories according to the mean number of days per year with one or more inches of snow on the ground[23]. The states in the climate groups are tabulated below. The climate categories are 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 data show that states have relatively higher per-mile costs compared to localities. Also, climatic differences, represented as two years with different snowfall, affect per-mile costs. In the second figure, 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.

[22] Ibid. Table HM-14.

[23] 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.

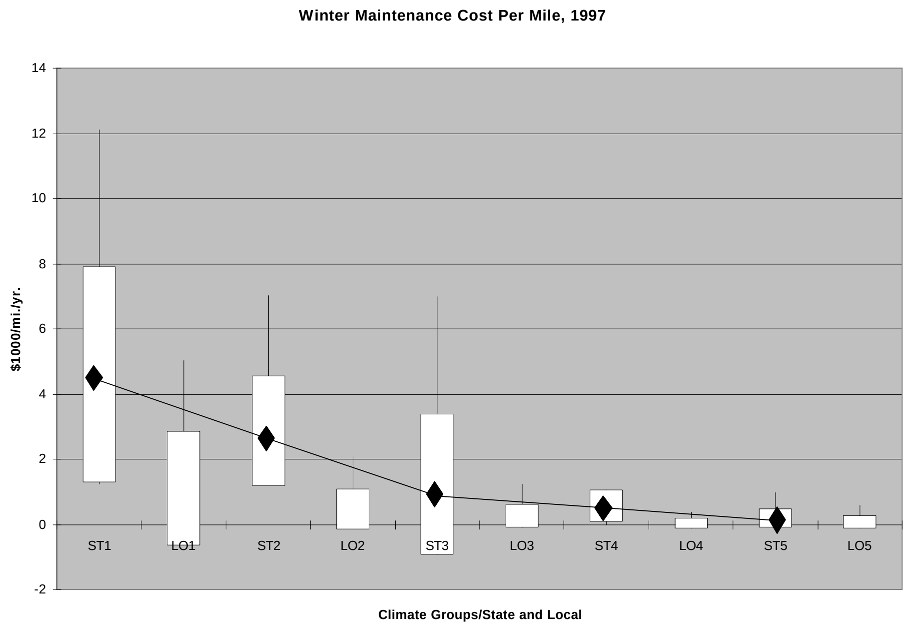

Figure 3.3.4: State and Local Snow and Ice Costs per Route Mile per Year (1997)

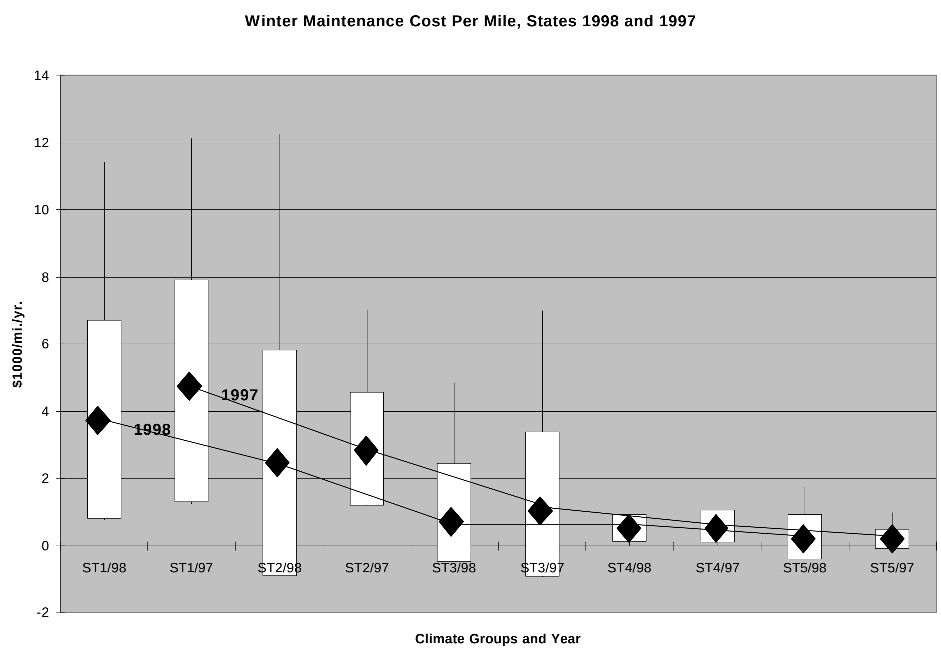

Figure 3.3.5: Comparison of State-Jurisdiction Snow and Ice Costs per Route Mile per Year, for 1997 and 1998

Table 3.3.2: 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

The higher state costs per route mile correlate with the higher functional class of roads under state jurisdiction and the greater vehicle-miles traveled (VMT) per route mile. The existence of snowfall and VMT components of costs is supported by an Ohio[24] study based on three years of data:

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 lack of a VMT component for the Interstates corresponds to high LOS standards for such roads, regardless of VMT. The VMT factor implies that denser states should also have higher unit costs. In climate groups 1-3, the highest 1997 costs were NY, MA and RI respectively. Northeast states also show the climatic variation from the January, 1996, snow northeaster, a heavy December, 1996, snowstorm, a heavy April, 1997, snowstorm, and the very damaging ice

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

storm of January, 1998[25].

A VMT factor to costs also explains the lower local costs per route mile. Localities have responsibility for the low-volume tail of the 4 million route miles. Costs probably are concentrated in roads with more use and aggregating over route classes in states lowers per-mile costs excessively. As far as leveraging costs through treatment efficiency, the RWIS should be aimed at the highest functional classes with the most VMT. This is typically in the state maintenance offices where RWIS is typically found. Overall, jurisdictions with high mileages of Interstates and other high-class routes, large VMT and large snowfall will have the higher winter road maintenance costs and are most likely to have RWIS services to reduce operating costs. VMT will also correlate with the other transportation outcome goal benefits. The exception will be environmental sensitivity, especially of watersheds and areas in violation of particulate matter (PM) air quality standards. RWIS can be effective in minimizing chemical application and particulate generation.

The concentration of costs and VMT on the NHS also has strong implications for ESS strategies. Distributed over the entire 4 million mile route network, the 1,200 ESS sites would average to one ESS per 3,333 route miles and is clearly inadequate. Over just the NHS, the coverage would be one ESS per 133 miles. This is far from adequate for characterizing each climatically-distinct road segment. However, thermal mapping techniques, or effective initialization of heat balance models, using sparse ESS puts road-temperature characterization of the whole NHS within economic reach. On the NHS, the amount of traffic and density of maintenance resources makes mobile ESS sensing most effective.

The RWIS operating environment should be stratified for economic, LOS and information-effectiveness reasons. On a jurisdictional basis, state and toll-authority jurisdictions with high NHS mileage, high VMT and high snowfall (or icing threat) form the most important group. On a route basis, the NHS may be distinguished from the rest of the road network. This points to urban areas as priorities as well as spatially extensive rural jurisdictions. This prioritization matters only where it affects design and cost of decision support. In general, relatively small costs of the RWIS, except for ESS investment, make it beneficial in all jurisdictions performing winter road maintenance.

3.3.2 Major System Components and Interconnections

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

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

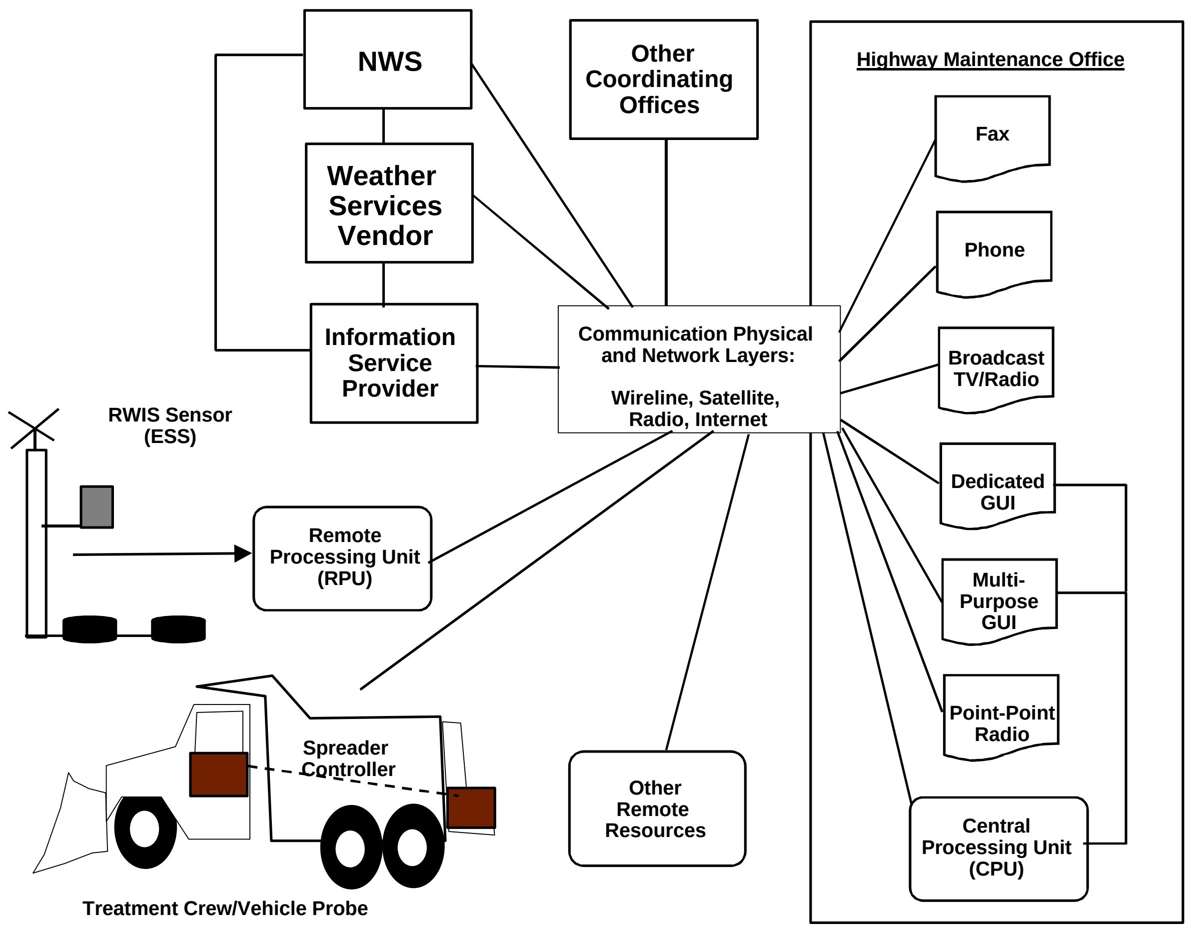

Figure 3.3.6: RWIS Components and Interconnections

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) platform. 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 NEXRAD Information Dissemination Service (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. Managers and crew frequently have paging devices, and these may advance to personal digital assistants (PDAs) with wireless connectivity. 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 information provided by these sources is described fully in the interfaces document. Typically, interactions with the public are via other offices (e.g., traffic advisories via a traffic management office) or the ISPs. The VAMS and ISPs also deliver weather and road-condition information directly to the public.

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.

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. The current emphasis on graphical displays and Hypertext Markup Language (HTML) for display formatting makes information integration difficult. The emerging Extended Markup Language (XML) standard allows data formatting on the Internet that can accommodate ITS standards for data objects and message sets, and for different display media. Otherwise, information displayed on the Internet or other media, whether textual or graphical, are not defined as data elements and so cannot be manipulated as discrete entities, except that text may be searched.

3.3.3 Interfaces to External Systems

Interfaces are covered in the Preliminary Interface Requirements document.

3.3.4 Capabilities/Functions of the RWIS

Capabilities of the RWIS ultimately must be measured by transportation system outcomes (goals). Because characterizing the causal links between information and outcomes is difficult, surrogates are used, closer to actions and perceptions of the decision makers. A valuable scheme for representing capability measures in this case was developed by Battelle for the Foretell evaluation[26]. This is represented in the table below:

Decision Support Thread Progression

Information ----->	Users ----->	Decisions ----->	Results
Information System Performance (output)	Users Acceptance (output)	Decision Effectiveness (output)	Operational Improvements (outcome)

Operational Goal Progression

In the upper row is a progression along the decision making thread, from information into, or within, the DSS to outcomes in the surface transportation system. In the lower row is an associated progression of capability measures. The output and outcome distinction is from the Government Performance and Results Act (GPRA), under which ITS program evaluation operates. Outcomes are goals, other measures are outputs from systems intended to enhance the goals.

The most reliable RWIS outcome measures are for cost and chemical reduction in winter road maintenance (goals of productivity increases and environmental impact reduction). In anti-icing applications, the RWIS has been successful in tailoring treatments to predicted road conditions. Safety and mobility benefits may therefore be imputed. These benefits are most directly related to ESS observations and the spatial (thermal mapping) and time predictions (ESS “filtering” or

[26] *Evaluation of the Foretell Consortium Operational Test: Weather Information for Surface Transportation*, Draft Evaluation Plan, March, 1999, Battelle, Columbus, OH.

time-series or heat-balance modeling) of road temperature[27]. In the Battelle scheme, these capabilities are at the level of “information” and “information system performance”, and primarily concern external information resources to the WIST-DSS. The extent to which RWIS performs decision support–to match the road temperature or other road-condition predictions to the decisions for treatment–is indicated by “typical” (state of the practice) and “emerging” (state of the art) capabilities that exist currently:

Table 3.3.3 Typical and Emerging RWIS Information Capabilities

Information Type	Typical Capability	Emerging Capability
Road temperature: ESS observation	GUI display: text and bar/line graphics of current and past data from fixed sites belonging to the jurisdiction.	Similar display, augmented by mobile ESS data from maintenance vehicles covering route segments. Sharing of point data files with other users (mesonets, NWS)
Road temperature prediction	GUI display: time series prediction for fixed site points, discrete time horizons. Static thermal mapping to infer other points from fixed reference points.	GUI display, GIS-based for route network segments. Based on thermal mapping and heat-balance modeling, discrete time horizons.
Other road condition: ESS observation	GUI display of other point measurements.	GUI display, GIS-based.

[27] McKeever, Benjamin, Carl Haas, Jose Weissmann and Richard Greer, *A Life Cycle Cost-Benefit Model for Road Weather Information Systems*, Transportation Research Board, 77th Annual Meeting, Washington, DC, January 1998.

Information Type	Typical Capability	Emerging Capability
Weather observation	"Current weather" (hourly or more frequently for changes) from NWS at surface-reporting stations (e.g., airports). Available as broadcast narrative text, NWS wireline or Internet ISP services. NEXRAD data via NIDS (dedicated terminal) or Internet (low resolution free, high resolution via subscription service). Satellite images via satellite broadcast ISPs or Internet (free and subscription services)	GIS-based GUIs. Access to cooperative observations and other specialized or private observation stations ("mesonets").
Weather prediction	NWS products: narrative watches and warnings by zone (county),over wireline or broadcast media including NOAA Weather Radio. Other graphical from broadcast media, Internet GUI (free or subscription) or satellite broadcast subscription. VAMS services: narrative by fax or phone, graphical products (including private synoptic NWP) by satellite or Internet GUI.	NWS: more regional digital products available via AWIPS and Internet. Based on regional (meso-scaled) NWP in some cases. VAMS: use of finer (meso) scaled NWP and interpolation to route segments via GIS GUI.
Other transportation information: ITS	Highly fragmented, stovepiped collection and distribution of static databases and road monitoring (volume and incidents). Often collected and disseminated by broadcast ISPs. Scattered regional efforts at integrated systems (HCRS in Arizona, CARS in west/midwest, I-95 Corridor, military IRRIS).	ITS standards and regional architectures just starting and will build on regional efforts including traffic management centers (TMCs) mainly in large urban areas. Some rural extension via "virtual" TMCs. Increased wireless (pager, GUI) ISP dissemination and integration of road monitoring data. Initial efforts at travel time prediction for traveler information.

Information Type	Typical Capability	Emerging Capability
Integrated (open system) decision support	Partial information sources. Often good GIS GUIs for representing geographical weather situation, but not specific decision criteria.	Increasing information source integration in GIS GUI, with route-specific access (at least of major routes). Support to decisions based on travel time criterion, but still very little for specific operational decisions.

These capabilities are at the level of information system performance (output) in the Battelle scheme, but even they are not a complete measure. Additional criteria for the information system performance include the coverage of observations and the validity of predictions, which were discussed in the STWDSR V1.0 document. Performance at each level of the Battelle scheme is summarized below:

Table 3.3.4 RWIS Performance Summary

Information/Information System Performance (output):	ESS observations: inadequate fixed sites and mobile systems to characterize NHS or larger road network. Road condition, temperature prediction: Good to 24 hours at ESS sites, other not well known. General weather and road-condition prediction: variable, generally lacking time and spatial specificity for road segments. See SHRP report[28] for comparison of one VAMS versus NWS prediction. Other (ITS): infrastructure deployment tracked by ITS-JPO. Incomplete in large urban areas, generally lacking in other areas. Interoperability (standards, regional architectures)generally lacking, soon to be required.

[28] Reiter, Elmar R., David K. Doyle, Luiz Teixeira, *Intelligent and Localized Weather Prediction*, SHRP-H-333, National Research Council, Washington, DC, 1993.

Users/Users Acceptance (output)	ESS and prediction: variable experience, extensive criticism of reliability and accuracy, issues of calibration and agreement on fixed versus mobile. Thermal mapping well accepted for general (climatic) differentiation of routes and treatment beats, but not universally deployed and depends on ESS deployment. General weather: widely criticized as unreliable and lacking resolution (specificity to route segments). Stovepiped sources. Appreciation of advanced GUI/GIS displays but still dissatisfaction with relevance of mostly synoptic-scale displays. Other (ITS). Wide consumer acceptance of improved traffic reporting. Little evaluation of acceptance by maintenance staff (Foretell evaluation still underway).
Decisions/Decision Effectiveness (output)	Little evaluation on this: Foretell evaluation still underway.
Results/Operational Improvements (outcome)	Some costs and chemical-use impact information for ESS. Favorable and significant benefits. Good results linking information to outcomes scarce[29]. Foretell evaluation to address this in 3-year study.

In summary, a careful distinction has to be made between information resources to the DSS and the DSS itself, whose capabilities can be measured in a progression of levels toward what matters to surface transportation. In this regard, the performance of the information (spatial coverage, time coverage, space-time scale and accuracy) is at least partly known. The key DSS measures, of user acceptance and impact on decision making, are not well documented for RWIS as yet. The best information is for ESS with respect to anti-icing, including outcome benefits. This is a small subset of the entire RWIS information.

3.3.5 RWIS Performance Parameters

This subsection addresses system parameters such as reliability, maintainability, availability (RMA), speed, safety, security, etc.

RMA parameters vary among the multiple communications channels and interfaces used in the RWIS. Data are not available for many of the private systems. For the ESS, RMA have been widely criticized and are being addressed by more stringent vendor requirements for maintenance and calibration. With greater DOT coordination on procurements, de facto standards are emerging. However, this is outside the scope of the DSS proper.

[29] For overview on ITS benefits analysis, see Proper, Allen T., *ITS Benefits: 1999 Update*, FHWA, Washington, DC, 28 May, 1999.

The RMA of the RWIS is allocated serially to the information source channels, PC platforms and user applications, and in parallel to the power supply to the user-end facilities. The WIST-DSS will affect mainly the user application, although open systems and fusion of the interfaces can result in some redundancy and backup of the information channels. However, the RMA of the RWIS is identified primarily with its individual information sources and channels. Choices exist for affecting RMA through the physical communications channels and other protocol layers. In this regard, dedicated radio, wireline, satellite broadcast, other broadcast and the Internet can be distinguished. Satellite broadcast is used because of cost and RMA advantages. Winter weather, when RWIS is most needed, is a threat to many wirelines, especially in remote areas. In remote areas, the costs of multiple homing of wirelines is prohibitive. In principle, terrestrial wireline channels can be made more secure than satellite, which necessarily depends on wireless and is susceptible to solar interference. However, the RMA tradeoff here is again one of economics, and dependent on the location of the user relative to all information sources.

While satellite links can be the physical layer for the Internet, the broadcast topology versus Internet protocols have fundamentally different channel capacity-effects on speed and reliability. Broadcast has a capacity limit in bandwidth and coding independent of recipient usage, while the client-server operation of the Internet creates server capacity bottlenecks that are sensitive to the information demand. This creates a tradeoff between sending all information that is possibly demanded by broadcast (for user-end filtering and display) versus determining selective transmissions via client-server interactions.

Since the Internet has choices in its physical channels (telephone wireline, high speed cable, terrestrial wireless, satellite wireless), the physical channel limitations should not be confused with the basic choice of broadcast versus client-server protocols for speed or RMA criteria. The Internet is becoming a de facto standard for many kinds of information the DSS needs. A user can choose a physical medium based on speed and RMA requirements, but this has to be coupled with server capacity and RMA of the supplier. The critical constraint is that for weather information, the performance is required most at times of peak usage. Server capacity can be guaranteed only by Internet services with restricted access and sufficient investment, meaning premium subscription services operating their own servers (as ISPs in both senses of the acronym). The only issue specifically for RWIS is whether the market will provide this as a viable, affordable choice. This problem argues for use of satellite broadcast instead, and therefore levies different information-filtering requirements on the DSS.

Security is another differentiation of the broadcast versus Internet services. Broadcast services can be jammed or tapped, as can any physical medium. At the physical level, Internet will have the same vulnerabilities as any other protocol. Internet adds the inherent problem that a client-server protocol requires network interaction and access that can be achieved by anyone remotely. Virus and hacking threats are the resultant security problems, that also touch on reliability. These are issues that have to be addressed systemically at the server and in the network. This is partly a matter of economic choices. Security issues also exist at remote sites for the information sources and at base sites for RWIS users.

No attempt will be made here to characterize system-parameter standards for the RWIS. The only issue relevant to the OCD is that high RMA and security are required for an operational system, and this can be bought, but the economic decisions are mostly joint in the market of users and suppliers. The OCD must include the concept that there will be investment and pricing sufficient to achieve decision support that is reliably available when needed.

3.4 RWIS Users

The RWIS users are defined to be winter road maintenance managers. However, the STWDSR research has shown that there are significant differences in organizational structure between RWIS users such that users must be better specified according to their skills, span of control, relation to other decision makers and decision making environment.

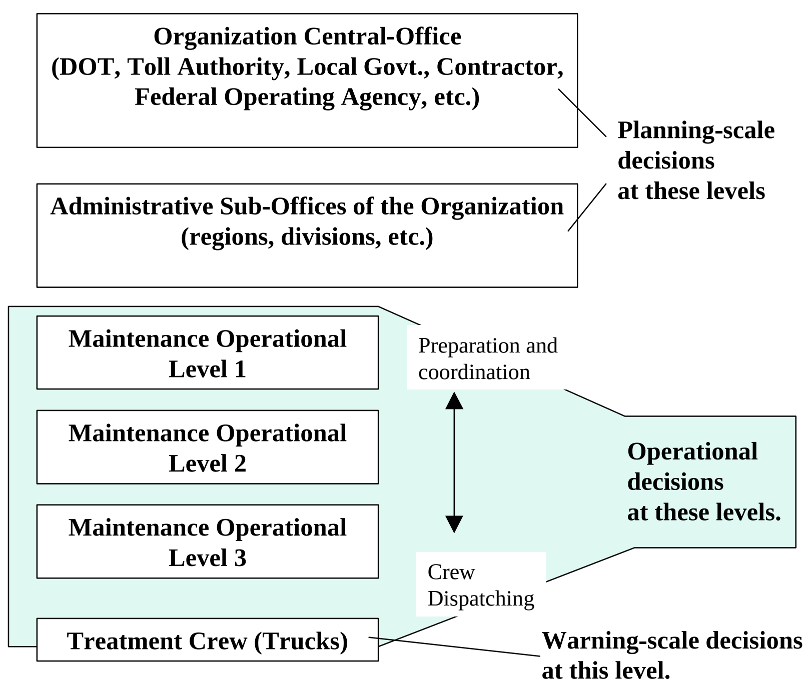

Figure 3.4.1: Synthetic and General Winter Road maintenance Organization

There are several different terms, across states, for the different organization levels and managers in maintenance organizations. Organizations other than state DOTs (toll authorities, local jurisdictions, contractors, operators of federal-domain roads) also have to be considered for winter road maintenance managers who are RWIS users. The generalized organization chart in figure 3.4.1 attempts to put a uniform terminology on all these cases.

Data from the state DOTs in the STWDSR group indicated that there are up to four organizational levels that make operational-scale decisions for winter road maintenance. It is assumed that there is some hierarchical allocation of responsibility corresponding to more general preparation and coordination decisions at level 1, down to individual crew dispatching at the lowest level, which is always the crew with truck (the only alternative means for treatment being fixed heating or chemical-spray systems). Higher levels cover more geographical territory, and tend to use longer time horizons. Crew dispatching is taken to mean proper equipment dressing, consumables loading and beat (treatment route) deployment. Overlap in the responsibilities is not excluded. Four of 25 sampled states explicitly stated some operational decision making responsibility for the crews. Otherwise, it is assumed that crews make only warning-scale decisions (immediate truck navigation and treatment control). Above the operational levels there is at least one central office, and usually more intermediate levels. These will be assumed to make only planning-scale decisions (resource availability, procedures) and are not further included in this OCD.

Smaller organizations will generally be flatter and have fewer levels. This is especially true for contractors. In some cases, contractors can be individuals so that the operational relation is essentially between callout in the office of a road-operating agency, and then the crew.

The critical differentiation in the DSS is based on decision types, that will be described with respect to the new system, regardless of the organizational level to which they are assigned. The decision-environment factors that are significant to DSS include:

- The skill of the decision maker, including familiarity with formal decision processes, experience with computer information systems, management experience, experience in the local environment, familiarity with meteorology and familiarity with environmental prediction.

- The physical facility for housing the decision maker and DSS, especially fixed versus mobile or portable facilities.

- The climatic characteristics of the operating area.

- The road-network characteristics and extent of the operating area.

- The organization of other highway operation functions (e.g., safety patrol, emergency management, traffic management, etc.).

- The facilities for public information from road operating authorities (ITS maturity).

Of these, the first two are likely to correlate with the organizational position of the decision maker. However, the DSS may need to be tailored in some way to all these factors.

The strongest assumption is that the DSS is devoted to winter road maintenance decisions. This flatly contradicts the need to integrate decision support when the decision maker has other responsibilities. This document has not analyzed such cases. The National ITS Architecture is depended on to describe requirements for other applications that may be integrated into one DSS. The most relevant case is the "roadmaster" integration of maintenance and traffic management. In the STWDSR state DOT sample, 8 of 25 states indicated that maintenance and traffic management were operationally coordinated. This is not necessarily the same as the roadmaster concept, but such a concept should be accommodated.

Even if a generic RWIS user could be defined, that is not what a DSS must serve. The most prevalent kind of user is probably a garage/district manager responsible for a county or multi-county area and several crews if not several garages. The user typically has minimal computer experience, but good managerial experience and environmental familiarity.

The baseline survey results from the Foretell evaluation are indicative[30]. The survey of current RWIS use sampled 85 highway maintenance operators in IA (36), MO (40), and WI (9) who completed 66 surveys. IA and MO are state staff while WI has contractor staff. Of these, 90% had access to computers, 73% had Internet access and 34% had an email address. RWIS sources were:

- Road and Pavement Sensors: IA (97%), MO (21%), WI (100%)
- Tailored - Site Specific: IA (60%), MO (31%), WI (43%)
- NWS (94%), Satellite (82%), Radar (76%)
- Other Sources: IA (93%), MO (48%), WI (41%)
- Do you obtain Weather-Related Information Daily?: IA (100%), MO (97%), WI (100%)

It is not assumed that any of the staff have more than lay knowledge of meteorology or the prediction techniques for road conditions and weather. The Wisconsin DOT has a meteorologist on staff, but generally no meteorological expertise resides in road-operating agencies. Most maintenance managers will rise through the ranks rather than being brought in with special training.

[30] From a presentation by Bradley Skarpness, Battelle May 5, 2000, to the STWDSR stakeholder meeting, Cambridge, MA.

3.5 Support Concept

No comprehensive data are available on support to the RWIS. The following are general statements:

- The ESS are purchased by road-operating agencies, with maintenance and support by the vendors. Power to RPUs is self-contained or from a utility. Communications is by dedicated radio (often operated by the road-operating agency) or wireline utility. The ESS CPU generally is provided by the vendor. The vendor often holds control of the data from third party use, and is responsible for its processing and predictions from it. There is little if any third-party road-condition prediction from the ESS data. Several states access ESS that are part of aviation observation networks. In one case (MN) the aviation network is state maintained and operated.

- Mobile ESS (mostly for road-temperature radiometry) generally are mounted on maintenance trucks or supervisor vehicles and maintained and operated by the maintenance agency.

- General RWIS services over dedicated dissemination channels are accessed by user subscription. They are operated and maintained end-to-end by the vendors, although there may be different VAMS and ISPs involved.

- NWS weather services are operated and maintained by the NWS, but the access is operated and maintained primarily by ISPs.

- General RWIS services over the Internet generally include user-operated and maintained terminals (PCs and modems), an ISP, and a utility communication carrier.

It is not possible to characterize system-maintenance policies further. These are split over maintenance contracts for the information services, user equipment and communications utilities.

4. Changes Needed

4.1 Justification for Change

4.1.1 New User Needs, Threats and Opportunities

The user needs are constant, for improved surface transportation system performance. New winter road maintenance practices may require new decision support. Anti-icing practices are in the baseline and no significant new practices are foreseen. A need for greater cross-jurisdictional collaboration, and between operational responsibilities (e.g., maintenance and traffic management) will emerge as they are facilitated by improved information systems.

There are no new threats. The interfaces document has more detail on threats for identification of information sources on the threats. The threat is winter weather to system performance via road conditions. The weather threats are any of the precursors to road blockage (snow and drifting, blown debris), loss of vehicle traction (snow and ice), loss of driving visibility (precipitation, blown dust or snow) or loss of vehicle stability (winds). The treatable threats are limited to snow accumulations (drifting prevention by snow fences not considered to be in operational scale), pavement-surface ice (treated by chemical, grit, and heating), and the bonding of snow to pavement through an ice layer (treated by chemical and heating). The impact of the threat increases with population and VMT. There is a secondary threat to the environment through treatment because of chemical and grit deposition.

There are numerous new opportunities to improve RWIS performance. Communications bandwidth and protocols, such as the Internet, can be used, in conjunction with steadily increasing PC power, to improve decision support through more information better tailored to user needs. The information resources, on weather, road-conditions and other transportation information, are increasing in kind, quantity and quality due to technical improvements and investment in all the sources. This includes sources multiplying within the ITS prior to integration. This makes information filtering, fusion, processing and presentation within a DSS all the more vital as the bottleneck to improved surface transportation system performance.

4.1.2 Deficiencies and Limitations of the RWIS

The decentralized and multiple nature of the RWIS make it adaptable to technical improvements, including the proliferation of information sources and improvement in their individual volume and quality. Such a decentralized and stovepiped system cannot achieve the integration needed to bring all relevant sources of information to bear on particular decisions in particular decision making environments. The single, user-tailored and decision-tailored DSS is lacking. There are two factors fundamental to this lack:

- Lack of a generally accepted architecture and open-system standards across all the information sources.

- Lack of operations research on the decision making process applied to DSS tailoring.

Neither of these deficiencies can be addressed by the multiplicity of RWIS providers, whether VAMS, the NWS or ISPs. Addressing deficiency (1) is in the domain of the ITS program. Deficiency (2) is in the domain of the STWDSR project. Both of these efforts reflect the need for some general coordination across RWIS providers, on behalf of users, and spanning both the public and private sectors. The RWIS by itself is limited in providing this because of its diverse and fragmented nature. The competitive and proprietary interest in improving individual information sources is in conflict with using all applicable sources to tailor complete decision support.

4.2 Description of Needed Changes

The needed changes are divided into two parts corresponding to the identified opportunities, deficiencies, and limitations of the RWIS. These changes will result in the improved systems called the WIST-DSS.

As surface-transportation applications, the RWIS and the WIST-DSS are within the open system framework of the National ITS Architecture and its standards. The ITS must interface with other architectures and their standards (e.g.,of the NWS) and the ITS will use many existing and emerging computer-to-computer communications protocols (e.g., TCP/IP for the Internet). The ITS is establishing data dictionary and message set standards at the application layer. This will facilitate the integration of information within the WIST-DSS to overcome the stovepiping of RWIS information channels that can be only manually integrated and that have deterred automated decision support.

The National ITS Architecture and standards are not complete nor fully adopted at this time. This will be part of the evolution of the WIST-DSS. The Operations and Maintenance user service is being forwarded to the National ITS Architecture. An Environmental/Weather Information Management users service has been proposed, but the issue is probably a better incorporation of environmental information into the ITS for all user services. This can be promoted by WIST-DSS application development. Enhancement of data dictionaries and message sets for weather and road-condition information is ongoing under the leadership of Foretell and other RWIS programs.

The National ITS Architecture is complemented by the NWS modernization program. The NWS and the World Meteorological Organization (WMO) establish standards for weather information, and these are adopted at the ITS interface or adapted into ITS data dictionaries and message sets (e.g., the ESS data objects). NWS information communication, of improved resolution and timeliness necessary to winter road maintenance, is facilitated by enhancements to the NWS Weather Forecast Offices (WFOs) including the Advanced Weather Interactive Processing System (AWIPS), the Local Analysis and Prediction System (LAPS) that is important for assimilation of ESS data and support of regional numerical weather prediction (NWP), and the Local Data Acquisition and Dissemination (LDAD) system that will support both data ingest and product distribution over the Internet.

The information resources of the VAMS and various channels of the ISPs need to be included in an open system. The ITS program represents the effort to organize a critical mass for standards of interest to surface transportation, that is otherwise a fragmentary market. However, standards and architectures cannot be dictated and the competition of private interests in conjunction with public research and user markets create important de facto standards (e.g., the Internet). This is a necessary part of system evolution in response to technology and other changes. However, applications expecting open systems standards, and programmatic efforts to enhance the market attractiveness of these to vendors, are needed. Necessarily, such applications focus on the integration of information for specific purposes such as decision support.

Proprietary interests legitimately price the use of information. The issue of pricing and cost recovery is complicated when public agencies are involved. This particularly affects third party use of ESS data and road-condition forecasts, where there are interests of the DOTs and other agencies to disseminate the information to the public and other public agencies. Open systems by themselves do not resolve the issue of information access rights and the contractual means for information access. However, neither should stovepiped systems be an excuse for failing to deal with this issue. It is programmatically necessary for the state DOTs and other DSS users to assess what their information-sharing needs are and to contract for services accordingly. Progress is being made with respect to ESS data dissemination to mesonets, to the NWS, and to the public. Projects like ATWIS and Foretell reflect the public sector interest in funding RWIS services for general dissemination.

Creating the DSS application requires user-centered operations research to characterize the decision making process and the specification of processes to support the decisions. That is the role filled initially by the STWDSR project, in conjunction with other winter road maintenance research, and this OCD. Programmatic efforts are needed to promote responses to the OCD. By the nature of highway operations in the U.S., deployment must be a joint partnership between the FHWA, road operating authorities, system developers and the VAMS. This is facilitated initially by the STWDSR stakeholder group, which is only a fragment of all the necessary parties. The OCD should serve to broaden and deepen the affiliations of all parties. It is expected that initial WIST-DSS development steps, sponsored by the FHWA, are also necessary to attract this interest, and these are being undertaken. In short, the WIST-DSS needs not just a technical development effort, but the institutional development to appreciate and exploit the advantages of improved DSS. This is necessary to initiate the spiral-cycle dynamics that fuse the presently diverse information channels of the RWIS into integrated DSS applications, that in turn selfreinforce the open system standards and information access. In this sense, the system is not just the WIST-DSS but the whole process of open system integration whose ultimate motivation is benefit at the application end.

4.3 Priorities Among the Changes

Because of the interactive nature among the open systems standards, information access, and DSS application development, all the changes have equal priority and are being pursued simultaneously.

Priorities can be sub-allocated to the components of the WIST-DSS. This can be done only when the WIST-DSS is further defined, and if it is decomposable into parts that can be sequentially deployed. It is expected that since decision support requires an integral thread of information processing, the priorities will be on the basis of decision type. The focus on supporting operational-scale treatment decisions for winter road maintenance already reflects a prioritization. This was explicitly chosen by the FHWA Road Weather Management Program because the market for improved DSS is mature, direct cost-benefits to the operating agencies are likely, and improved winter-weather treatment has plausible, direct benefits on all of the outcome goals.

4.4 Changes Considered but not Included

Changes considered but left to later or other programmatic attention include:

- Planning-scale and warning-scale decision support to winter road maintenance.

- Decision support to other surface transportation decisions (whose needs have been defined initially by the STWDSR and will be further defined by the OFCM WIST-JAG).

- Operational-practice changes in winter road maintenance. These will be addressed by other Road Weather Management Program activities, and will evolve with improved DSS.

- Incorporation of evaluation-scale learning in the WIST-DSS (i.e., performance improvement based directly on outcome impacts). This can also be considered a planning-scale function, and it is conducted by the ITS and other evaluation programs.

4.5 Assumptions and Constraints

The assumptions and constraints regarding WIST-DSS development and deployment are:

- The FHWA does not operate the highway system. It does not directly determine what deployments federal-aid funds will support. Therefore the FHWA role is promotion of the WIST-DSS concept and the partnerships to deploy it.

- Value can be added by focusing on decision support that uses existing weather, road-condition and other information resources. Information resources are strictly defined as external to the DSS, but addressed in the interfaces document that accompanies this OCD.

- The DSS performance depends on the quality of its external information resources and the ability to access them easily. The external information resources should be made available through open system standards. The quality of the resources is adequate for DSS deployment but should be improved. Development of the WIST-DSS is expected to leverage these improvements, but generally is a small part of the market and motivation for such improvements. In many cases, identifying specific information-resource deficiencies will uncover institutional, technical and investment issues that the WIST-DSS by itself cannot address. Therefore, while identifying information-resource deficiencies is a purpose of the STWDSR project, and addressed in the interfaces document, they are not the focus of this OCD.

- The production of weather and road-condition information is joint between the NWS, VAMS and the highway operating agencies. These need to be addressed through FHWA Road Weather Management Program activities other than the WIST-DSS, including inter-agency coordination through the OFCM.

- The amount of research funding controlled directly by the FHWA is small compared to the total resources, including designated federal-aid research funds, of the highway operating agencies. The FHWA efforts must leverage the state and local research funds. This includes the FHWA sponsorship of cooperative projects and promotion of projects to pooled fund consortiums (e.g., AURORA) and through AASHTO.

5. Concept for a New System

5.1 Background, Objectives and Scope

The new system to evolve from the RWIS is called the Weather Information for Surface Transportation Decision Support System (WIST-DSS). The background of this system is the same as described for the RWIS.

The objectives of the WIST-DSS are to improve surface-transportation system performance (outcome improvement, goal attainment). In this phase, the objective is limited to enhanced decision support to winter road maintenance managers in the treatment of winter-weather threats at the operational scale. The objectives are elaborated in the WIST-DSS Vision Statement[31]:

> *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.*

The scope of the WIST-DSS is defined by its context diagram:

[31] From the *Weather Information for Surface Transportation, A White Paper on Needs, Issues and Actions*, The FHWA Weather Team, May, 1998.

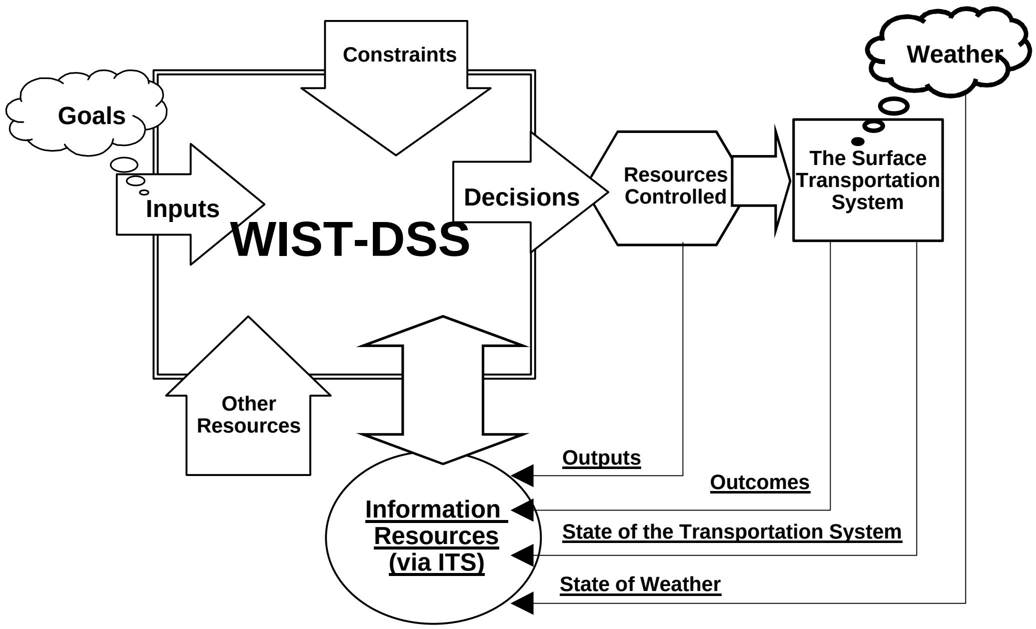

Figure 5.1.1: Context of the WIST-DSS

System scope is defined jointly by what is inside the system and by what it excludes as external and therefore in its context. The external interfaces of a system are defined (in the IDEF level 0 context diagram format) as input, output, resources and constraints:

- The WIST-DSS inputs are the surface transportation performance goals. These inputs are either embedded in the system or entered (as system queries and adjustments) by the user, the winter road maintenance manager.

- The WIST-DSS outputs are decisions that control resources for treatment of winter-weather threats to the road system. In some cases, the control may involve other agencies and the traveling public.

- The WIST-DSS resources and constraints include institutional procedures, responsibility boundaries, funding, physical resources (staff, equipment, consumables, etc.) and information.

The context, especially the information resources, is described in detail in the interfaces document. The information resources generally are categorized to include outputs, outcomes, the state of the transportation system (including ESS data and road-conditions) and weather information. The ITS is in the WIST-DSS context, mediates all WIST-DSS information resources, and generates some of them.

The decision maker is defined to be a human winter road maintenance manager, and therefore mediates between the WIST-DSS proper and the output. There are ambiguities in this scoping that will be addressed in detail at a lower level. In particular, there is a spectrum from decision support as piping of the information resources to the decision maker, through value-added processing of the information for the human, to automatic definition of the output. The latter constitutes automatic control. Therefore, there may or may not be an external intermediary between the WIST-DSS and the output as defined. In any case, there are aspects of the decision making process (e.g., formal risk decision processes, or analytical process that define "optimal" decisions) that should be automated within the WIST-DSS but cannot clearly be separated from the manual decision making component.

The scale of decision making is an important scoping attribute. Scale is defined as a physical space-time domain of the decided control actions and the corresponding information resources. On the decision making side, the operational scale is defined as the space-time domain for readying and dispatching the resources provided for winter road maintenance activities. On the information side, the scale corresponds to synoptic and meso scales of weather information. The time horizon is up to days and down to sub-hours. The spatial domain is sub-continental down to treatment beats. This scale is bounded above by the planning scale that provides the physical resources and institutional context (climatic scale of information) and below by the warning scale of direct maintenance activity such as truck driving, plowing, and spreading of chemicals. The scale will be defined strictly by the types of decision supported.

The WIST-DSS uses external information resources and it does not produce environmental information. It generally does not process such environmental information into predictions of weather or road conditions, except when road conditions are affected by treatment resources. It does transform environmental information into the direct decision maker information displays and measures that relate to decision making criteria. This scope will be defined strictly by the processes within the system.

5.2 Operational Policies and Constraints

The WIST-DSS shall be operated by winter road maintenance managers according to the policies of the winter road maintenance organization. These operational policies shall either be known to the manager or included in decision support information by the WIST-DSS from external information resources. Important policies include:

- The geographical boundaries over which treatment may be dispatched for individual maintenance sub-units.
- Operational agreements with adjacent maintenance organizations or organizations responsible for other portions of the road network, including contractors.
- Crew and staff notification, pay, safety and work hour regulations.
- Crew splitting (treatment-event schedule adjustment) procedures.
- Equipment operation and maintenance requirements and limitations.
- Operational agreements with other organizations impacting, or impacted by the maintenance organization.
- Restrictions on treatment operations (chemicals used, plowing, hours of operation, etc.).
- Road level of service (LOS) goals.
- Other standard operating procedures (SOPs) and best maintenance practices (BMPs).

Policy information is defined in the information taxonomy in the interfaces document. Policy on use of the WIST-DSS is assumed to be embedded in any SOPs and BMPs. The constraints on decision making are also embedded in the policies enumerated. The constraints on WIST-DSS design and use include:

- Physical capabilities of the decision maker concerning the CHI. The WIST-DSS shall conform to requirements for use by persons with physical disabilities. These and ergonomic requirements generally are included in the computer platform hosting the WIST-DSS.
- The user is assumed to be trained on use of the deployed computer platform. Training must be provided for the WIST-DSS application.
- Decision-making training of the user. The decision maker is assumed to be trained in the normal management of winter road maintenance treatment resources. The decision maker is not assumed to be trained in formal risk or optimal decision-making procedures.
- Environmental prediction training of the user. The decision maker is not assumed to be trained in meteorology, weather analysis or road-condition prediction.

- The WIST-DSS shall be used in fixed maintenance management facilities and shall have the capability to be ported to mobile or portable platforms. The WIST-DSS shall be used in ambient office and vehicle noise and lighting.

5.3 Description of the WIST-DSS

5.3.1 The Operational Environment

This is the same as described for the RWIS.

5.3.2 Major System Components and Interconnections

The level 1 logical system diagram with interfaces of the WIST-DSS is given below:

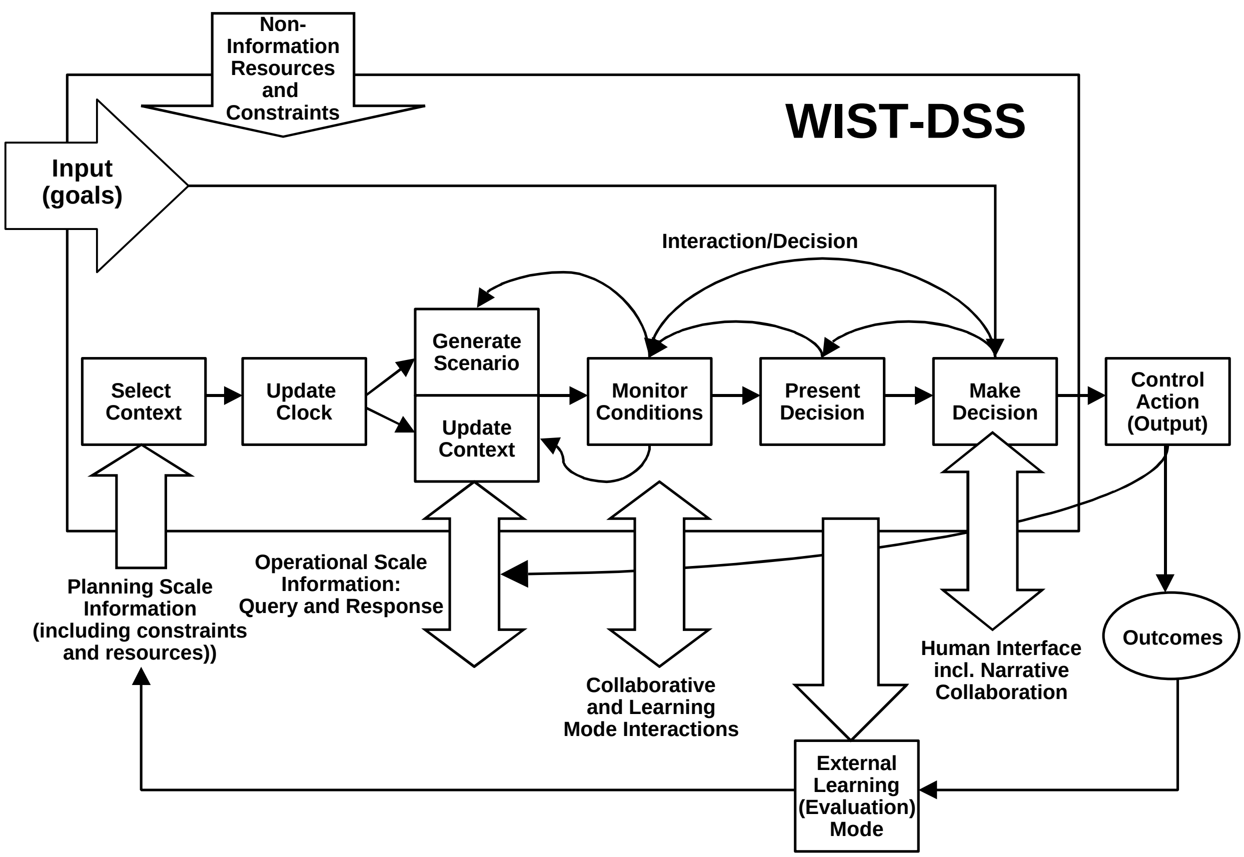

Figure 5.3.1: Level 1 WIST-DSS and Interfaces

The WIST-DSS has three operational modes that affect the system structure:

- Decision mode. This is the normal operating mode. A single user is supported for making prospective decisions based on available information resources.

- Learning mode. The system and context observe ensembles of system states, inputs, and information resources to adjust system parameters toward improved performance. This mode may occur at different scales. Evaluation, meaning observation of outcomes, is at planning scale. Operational scale learning may be confined to adaptation to direct user inputs (i.e., self-tailoring of the system relative to the human interface).

- Collaborative mode. Multiple decision makers, making interactive decisions, are supported for prospective decisions based on available information resources and additional information between the decision makers and decision support systems (possibly multiple WIST-DSS, possibly different DSS).

These modes affect interface descriptions, processes, and an important part of the operational concept concerning contextual versus interactive information. Schematics for the latter two modes are shown below, but all contain the decision mode processes.

The basic operation of decision making can be represented as a sequential and causal process. A purpose (desired outcome) is given. Examination of the environmental state results in a set of control actions to change the state to satisfy the purpose. The impact of the alternative control actions is predicted, and the one best satisfying the purpose is selected and executed.

In practice, the process is not so simple or sequential. How the process can be simplified is the essence of whether decision support or automated decision making can be done. However, a reasonable challenge is to determine alternative actions *based on external information that is not affected by the choice or execution of the alternatives*, and then to select among the alternatives in such a way that *a selection does not alter what should have been selected*. These conditions are not always fulfilled, but when they are they result in a sequential process. Counter examples can occur in collaborative cases (gaming) and this includes between the human user and the system. The collaborative cases require special processes to prevent “thrashing” (repeating loops of process sequences). In the decision mode, the human user is applying such processes intuitively to converge toward a decision. However this may require going back and forth between the processes represented in the system. A simple case is in asking for different types of information as part of both formulating what decision should be made and the alternatives to choose from.

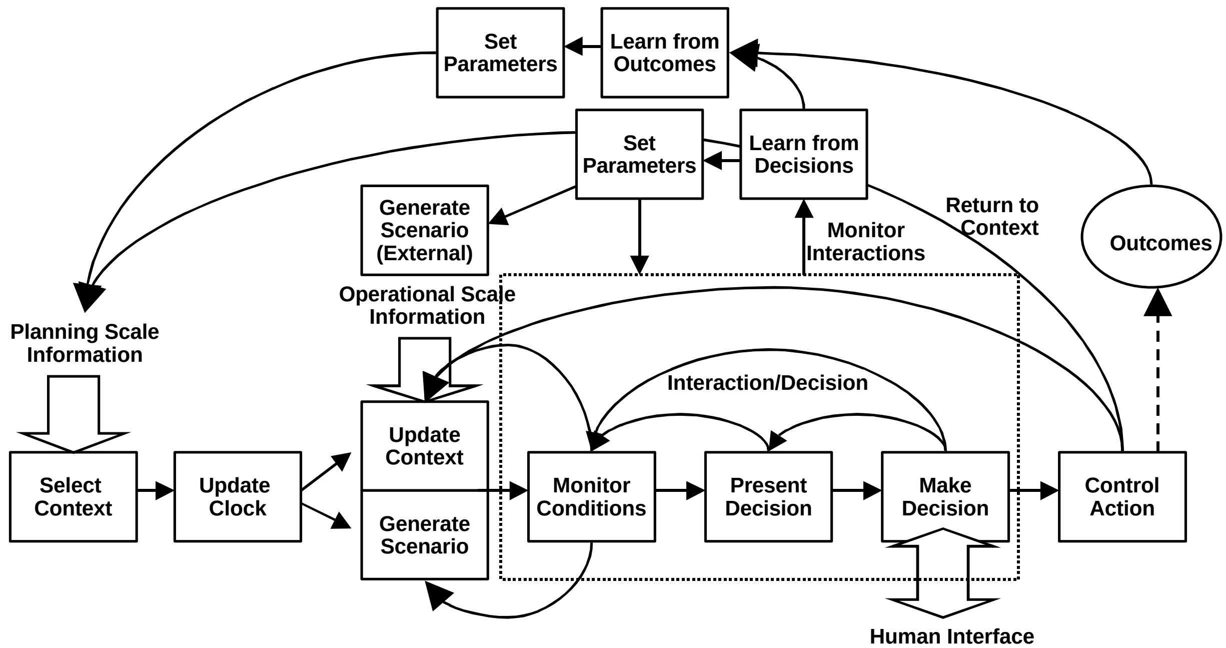

Figure 5.3.2: Level 1 Learning Mode Schematic for the WIST-DSS

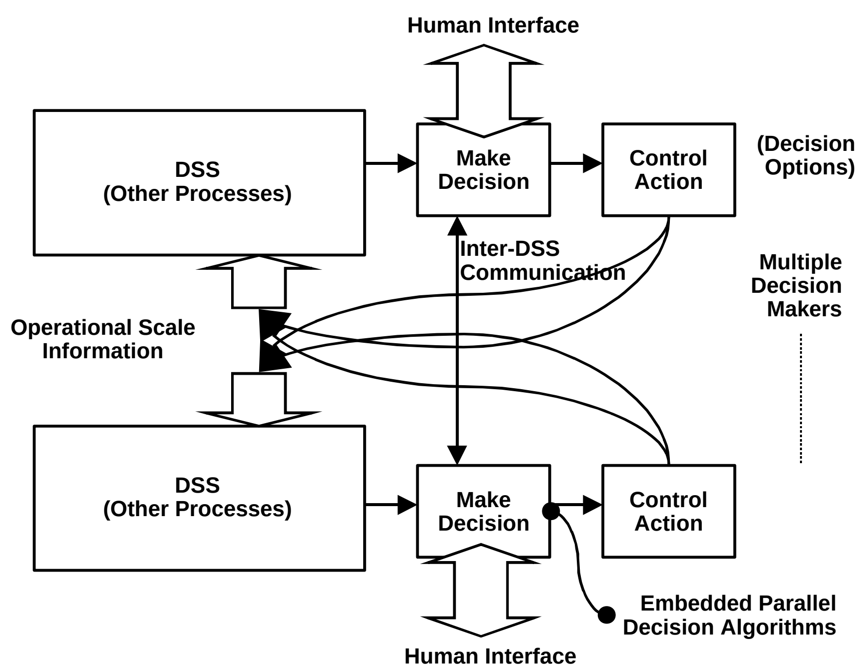

Figure 5.3.3: Collaborative Mode Schematic for the WIST-DSS

The text of the OCD is limited to describing sequential processes. In some cases this is sufficient to describe the system, and in other cases not. Looping and branching processes can be built into system software of course, but these would have to be described in lower level specifications.

The WIST-DSS processes can be separated broadly into those that are highly interactive, and those that respond to a quasi-static context, i.e., conditions that can be taken as fixed relative to the time it takes to make a decision. The ideas of system context and decision scale define this distinction.

Contextual information includes weather information, since no maintenance action controls weather. It does not strictly include the road LOS as affected by weather, since this is road-condition to be treated. What puts the road condition in the context of the decisions as a quasi-static state is the causal, sequential separation of the current from future road condition by the time interval of decision, action and result. Therefore, although there is a definitely a feedback from decision choice and system output to information resource, it is still sequential in discrete time and decision steps. This condition does not hold say, for collaborative decisions between two managers who may choose to treat the same beats or between a maintenance manager and a traffic manager mutually deciding on treatment beats and traffic control.

Scale separations of decisions also accomplish the appropriate contextual sequencing. For instance, there are budget decisions at the planning scale. Every operational decision accrues costs and therefore affects the budget. However, the interaction of these is separated because budgeting is only updated annually based on ensembles of historical information. The statistical aggregation cuts the direct causal feedback, and this generally is what happens between any decisions at different scales. This is part of the principle of any adaptive or evolutionary systems, and so is relevant to the learning mode as well. The learning mode is relevant mostly at the planning scale rather than the operational scale. This generally eliminates adaptive (or self-organizing) system issues from the decision mode.

In the level 1 system description, the processes can be separated by whether they are mostly contextual and sequential, or whether they have to be considered more interactively, as follows:

- Contextual Processes
  - Select Context
  - Update Clock
  - Update Context (in part)
- Interactive Processes
  - Update Context (in part)
  - Generate Scenario
  - Monitor Conditions
  - Present Decision
  - Make Decision

These processes will be described in turn. The interface information is described fully in the interfaces document. The level 1 process description includes the major data objects between processes. These are shown in the figure below and will be described with the appropriate processes.

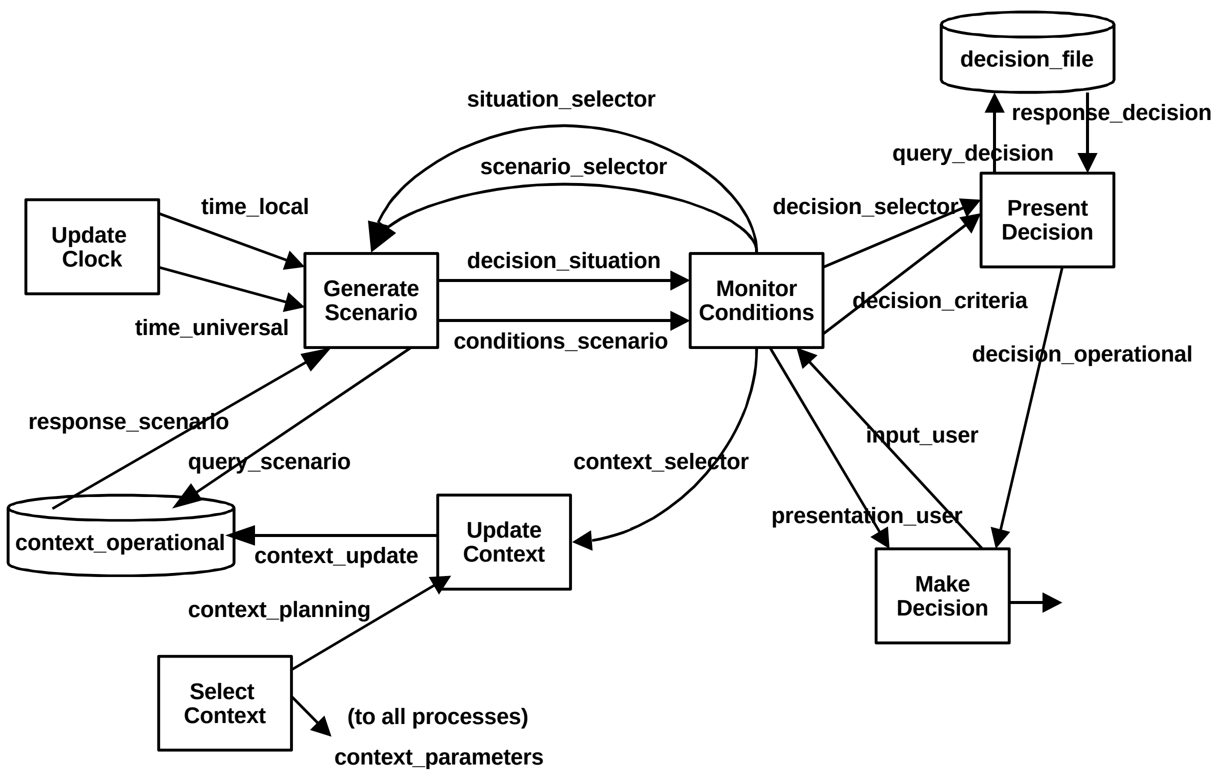

Figure 5.3.4: Processes and Data Objects for the WIST-DSS

Select Context

Select Context is a contextual process, meaning that it is scale-separated from interaction with the operational decision making processes. Select Context receives external planning-scale information and distributes it to the WIST-DSS. Select Context is activated by external information update cycles and not in response to internal queries. The planning-scale information concerns resources, constraints and climatic-scale environmental information for the operational decisions and is distributed to the decision-making process. Some of this information, including results of learning mode processes, is distributed generally to processes as parameters. This information is represented in the two data flows from Select Context:

context_planning contains all resource, constraint and climatic-scale environmental information relevant to operational decisions.

context_parameters contains all algorithmic parameters, addresses, constants, settings and other variables that are quasi-static at the operational scale but that are necessary to the operation of the WIST-DSS.

Update Clock

Update Clock is strictly contextual. Update Clock receives external time synchronization data for distribution to the time-dependent processes in the WIST-DSS. In general, these are within Generate Scenario that creates the time-relative context for all other processes, and the time information is considered to be passed through the data flows from Generate Scenario. Two times are used:

time_local is the clock time used in jurisdictional activities, reflecting the local time zone and daylight savings etc. The option exists to serve jurisdictions containing more than one local time zone. The time includes calendar (day, date, year) information.

time_universal is Z (zulu), Greenwich mean, or UTC time. The time includes calendar (day, date, year) information.

Update Context

Update Context is generally contextual, but an optional exception is allowed for user-initiated parameter changes that may involve limited operational-scale interactions. Queries to Update Context are not strictly interactional, but are requests for additional information that still is contextual.

Update Context queries, receives and processes external, operational-scale, context information as required by Generate Scenario and Monitor Conditions. It filters, fuses and processes the external operational-scale information and information from Select Context into a database, that is updated in response to external information pushes or cycles triggered by Update Clock[32]. The filtering done by Update Context selects the external information for inclusion in the internal data store according to parameters set by Select Context (including initial settings on available information and learned parameters of useful information). The filtering is time-dependent, including forgetting of old information past relevance and obtaining information that comes within the relevant time horizon. The adaptive filtering performed by Update Context includes the structuring of the database (e.g., variable definitions). Update Context creates information by the fusion and processing external information. This includes creation of statistical information from external ensembles and road-condition inferences from external weather information and road-condition observations. These fusion and processing functions are re-allocatable to external processes, if the latter are available.

Update Context is primarily responsible for coping with loss of the external, operational-scale interfaces by maintaining the database that defines the operational context of decisions. This is necessary to achieve good availability of decision support even when the external information sources are probably the limiting factor in availability. Update Context shall incorporate provisions for maintaining data that are otherwise externally provided by internal prediction when updates are cut off. It also shall be able to restart within reasonable time, and without DSS interruption, when external data sources are restored. The data flows and stores associated with Update Context are:

context_operational is a data store and the database of operational conditions. It includes all types of information required by the decision making and retrieved or constructed by Update Context (including statistics needed for risk decision-making in Make Decision), contextual triggers for Present Decision, and information requests from Generate Scenario. All information types include meta data (source, format, reliability, etc.) with physical space-time coordinates for all environmental data.

context_update is the information sent by Update Context to structure, populate and update the context_operational data store.

[32] Update Context queries can operate in a client-server architecture, either automatically scripted or under user query. In this case, parts of the database may be physically external to the system, and Update Context may be interactive with the decision process. Logically however, it is sufficient to represent the process and database as contextual and internal. There will be physical variations in the data flows and process allocations according to the capabilities of external information resources and communications protocols.

Generate Scenario

Generate Scenario is interactive with the decision making. Prompted either by clock updates or queries from Monitor Conditions, Generate Scenario queries the context_operational database to extract and format the subset of operational information needed for particular decisions or user queries. This information is made relative to the time perspective of the decision or query, that may be current time or an arbitrarily selected time. This information is also made relative to the spatial perspective of the decision or query.

Filtering, fusion and processing are allocated to Generate Scenario as well as to Update Context according to how dependent the results are on the particular decision to be made or other user query. This allocation should also consider how readily the processes may be allocated to external sources: If they are likely to evolve to external processing, they are more likely to be internally allocated to Update Context. Making information time-and-space relative to a decision is clearly for Generate Scenario. Since time or space weights statistics of predictions or estimation, there is more of an issue as to what statistics are external (e.g., NWP or MOS ensemble statistics), versus in Update Context (e.g., modifying statistics by cross-comparing observations or predictions with observations), versus how the statistics may be altered simply by a formula with a time or space weighting parameter. The data flows associated with Generate Scenario are:

query_scenario requests information from the context_operational database.

response_scenario supplies information from the context_operational database in response to query_scenario.

decision_situation is a specification of all operational-scale contextual information that is relevant to supporting a particular decision, other than that contained in conditions_scenario. That is, decision_situation contains information that is not inherently dimensioned by time and will be formatted other than in a scenario. An example is a staffing roster where individuals may have a skills attribute (e.g., able to program spreader-controllers) that is relevant to certain weather conditions or equipment changes. This could be presented to a crew splitting decision that may be selective among staff. Other examples (e.g., treatment stocks) may or may not be considered time varying over the horizon of particular decisions and may be included in this data flow or as part of the time-relative scenario.

conditions_scenario is a specification of all operational-scale contextual information that is relevant to supporting a particular decision, and that is inherently dimensioned by time relative to a reference time established by Make Decision. The information in conditions_scenario is assumed to be relative to a chosen spatial perspective. The conditions_scenario extends backward and forward from the decision reference time, that may be current clock time, an offset from current clock time based on some decision or action lag, or an arbitrary time for “what if” queries. Some attributes may be specified by time_local (e.g., crew activities) and others by time_universal (e.g., weather) and some may have to consider both (e.g., road condition, affected both by the universal diurnal cycle and local-time dependent traffic). All information in condition_scenario is weighted by statistics according to the time and place of the information relative to the decision.

Because the contents of conditions_scenario is central to the decision support, as indicated by STWDSR research, it is diagramed below and described further:

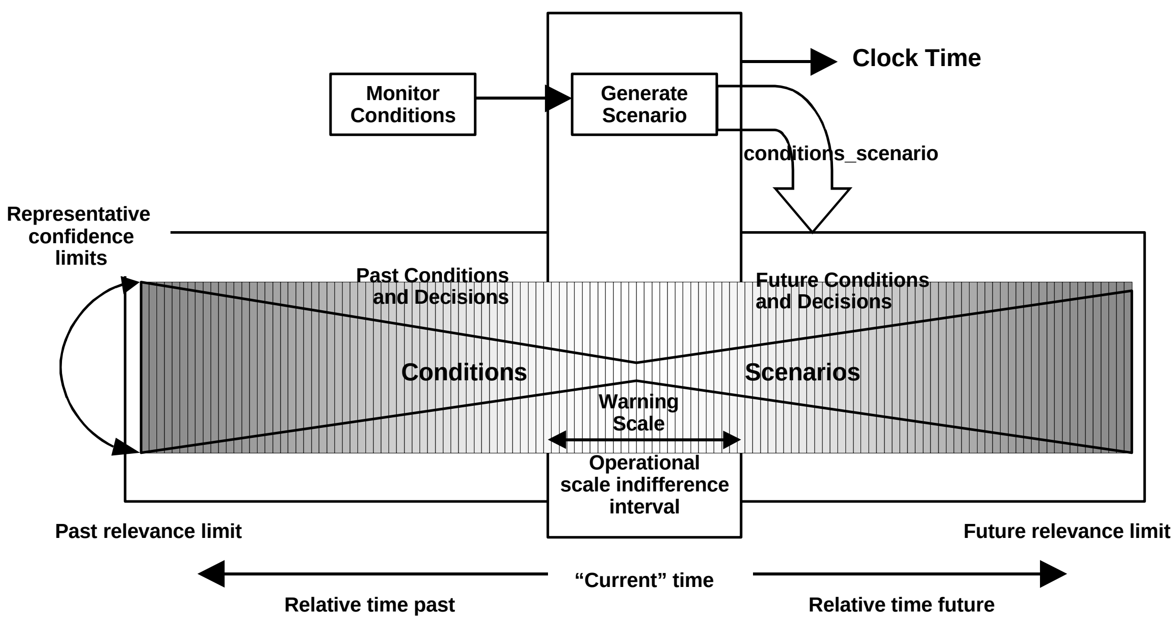

Figure 5.3.5: Schematic of the conditions_scenario Data Object for the WIST-DSS

The time-scenario formatting of conditions_scenario allows Monitor Conditions to emulate human monitoring and awareness processes by considering the chaining of decisions relative to the time sequencing of environmental context. The STWDSR research shows that what has happened in the past can affect decisions, as well as predicted context. Put another way, all decisions are prospective, in terms of dealing with possible future actions. However, decisions are also anticipatory, meaning that past as well as future events are logically prior (causal) to the decision. This symmetry of past and future information relative to decisions is reflected in the symmetry of the conditions_scenario information. The "bow tie" representation of the information reflects the uncertainty range of the information, that generally increases away from current time. This also works symmetrically in time. Past information has less certain causality on the present and future because of intervening information. The same physical effect results in greater uncertainty of predictions over longer time horizons. The STWDSR research also showed that some knowledge of information reliability in this regard is important to decision making. In principle, the inherent uncertainty of real information requires risk decision procedures that must use statistics on the contextual information (also called the "state of nature" in the risk-decision approach versus the outputs controlled by the decision). However, the risks also include uncertainty about the outputs (i.e., failures in carrying out decided actions).

The process of creating conditions_scenario by Generate Scenario is indicated as driven both by clock time and the data flows from Monitor Conditions. The clock triggers are represented by putting Generate Scenario inside the moving box of "current time". As indicated, the reference point for this interval can be defined in different ways, relative to clock time. It is shown as an interval because there is a separation between operational and warning scales. At the scale of making an operational decision, there is always some interval of indifference: The decision maker considers contextual information as quasi-static over some interval that may be on the order of an hour. This is the interval in which it is not necessary to consider context updates for purposes of the decision. This interval stipulates the time discretization for defining the scenario. Even high-resolution (meso scale) weather information is rarely updated more than once per hour. The disretization interval may be larger at farther horizons.

Note that human examination of context is also spatially distributed, especially to look at "upstream" weather conditions that may track into the spatial jurisdiction of the decision. The purpose of this is, of course, prediction of the focal location. The user has the option to query for any spatial jurisdiction via the GIS GUI. The GUI should include animation, that is inherently a display of the time-sequenced information in the scenario. In this way, tracks are represented as moving across a specified spatial area. Logically, the scenario is still arrayed over time, for a specified location. If animation or tracking is desired, the logical process is for Monitor Conditions to request the appropriate set of scenarios, and their animation or graphical construction is part of the mechanics of the GUI. The process would also supply the statistical information to show the spatial range of tracks, contours reflecting attribute probabilities, etc.

Monitor Conditions

Monitor Conditions is interactive with the decision making. Monitor Conditions has four basic functions: stipulating Generate Scenario, triggering Present Decision, presenting information to Make Decision and stipulating Update Context. The latter refers to altering the context_operational structure as opposed to the more frequent formatting of information from that database.

Monitor Conditions may be viewed as being at the logical center of the interactive processes that include itself, Generate Scenario, Present Decision and Make Decision. It is, with Make Decision, a bi-partition of the most interactive parts of the human decision-making process. That is, the consideration of what decisions to make cannot be separated from the construction of a contextual perception by focusing on parts of the world selected relative to an intended decision. In the WIST-DSS, Make Decision is viewed as closer to the human interface and will be the least automated part, while Monitor Conditions, is shown at a distance from the human, is more automated, but is also largely driven by human inputs. The role of being both automated and user-responsive centers the software engineering challenge on Monitor Conditions.

Monitor Conditions “looks” for contextual conditions requiring a decision, and specifies which decision(s) should be made by triggering Present Decision. In considering the human decision process, a sequential representation separates this trigger (identifying a decision) from making the decision that requires additional information that corresponds to the criteria of decision performance. In this sequential view (that partly corresponds to the awareness and monitoring decisions identified in the STWDSR research) there is a two-step process of scanning the context, and then more actively going back to get more information. This roughly corresponds to the data flows from Generate Scenario, and the data flows from Monitor Conditions back to Generate Scenario (optionally to Update Context). In learning mode, at planning scale these interactions are extended to external evaluation processes and include Select Context.

Looking at context and considering a decision is always a manual option. User inputs regarding this are also processed via Monitor Conditions. But since the CHI is directly attached to Make Decision, the response also involves Present Decision. In drawing the process diagram, it was strongly considered showing a separate user-presentation process. However, because the degree of decision making automation is left open, the extra step of creating a CHI is buried in Make Decision, even if that becomes a misnomer when decision making is completely manual.

Note that because of the interaction of monitoring and decision making, information usually is tailored both to the decision at hand and the context the decision is responding to. This is another reason why Monitor Conditions is central to interaction both with Generate Scenario and Make Decision. The data flows associated with Monitor Conditions are:

> context_selector triggers Update Context to alter the contents or format of context_operational when the monitoring or decision making functions cannot be satisfied by information already in context_operational, but when it is feasible within operational scale (i.e., from available information sources). Note that although this logically corresponds to client-server interactions, it should not be interpreted in this way, and the mechanics of that protocol should be limited to Update Context and its interface. In other words, Monitor Conditions as a logical function within the WIST-DSS should not be

confused with the specific protocol requirements that are accommodated by a standardized Application Program Interface (API) layer.

scenario_selector stipulates the contents of conditions_scenario to Generate Scenario. This data flow is generated in response to a user input or after Monitor Conditions is better able to specify the information needed to support a specific decision.

situation_selector stipulates the contents of decision_situation to Generate Scenario. This data flow is generated in response to a user input or after Monitor Conditions is better able to specify the information needed to support a specific decision.

decision_selector triggers Present Decision to format a decision for presentation to Make Decision. It triggers selection from a quasi-static data store of decision types.

decision_criteria sends to Present Decision the information to describe completely a decision in terms that correspond to the decision making criteria. That is, the information adds attributes to decision types based on evaluating them against the context information. For example, decision_selector may trigger the decision type “select chemical for loading”, and decision_criteria includes the scenario of predicted road temperature, the situation of environmental sensitivities of the beat etc.

Present Decision

Present Decision selects a decision type, adds contextual information corresponding to the decision making criteria, and formats the decision information suitably for Make Decision. This process is based on a contextual (planning scale) data store of decision types, whose range correspond to the span of control of the decision maker. Within the span of control, decisions are selected from the types based on environmental context triggers identified by Monitor Conditions and communicated through decision_selector. A key parameter in these triggers is the time lead between current time and the triggering event (e.g., onset of snow, formation of ice, end of work shift, etc.). This corresponds to the chaining of the preparatory, dispatching, treatment and cleanup decisions in winter road maintenance. The type selection and the addition of the decision criteria information is prompted by the interactive loop between Present Decision, Make Decision and Monitor Conditions. This can be prompted by user inputs via Make Decision, by Monitor Conditions automatically forwarding the appropriate information, or by requests from Present Decision via Make Decision. Learning processes for individual decision makers can substitute the automated processes for direct user input over time. The data flows associated with Present Decision are:

decision_file is the data store of decision types. Stored types may be stipulated by context_parameters from Select Context to reflect the decision making span appropriate to the organizational type and procedures of the decision maker. The decision types will have attributes that match information in decision_selector (as the type-selection criteria) and will have other attributes that specify or limit the types of decision making criteria that apply, to match information in decision_criteria.

query_decision requests a decision type from the decision_file based on contextual information passed to Present Decision in decision_selector. Depending on the amount of processing allocated to Present decision, the information in query_decision may be the same or different from that in decision_selector.

response_decision passes the decision type and attributes for further formatting to Present decision.

decision_operational is a formatted decision type with decision making criteria passed to Make Decision. The full format may be filled only after iteration through Make Decision, Monitor Conditions and Present Decision. For instance, the types may be refined (from clusters to individual decisions) based on user review, and the user may request various decision making criteria. The formatted information is logically equivalent to a user display of the decision, the alternative choices, and the criteria information to evaluate each choice (ranging from several types of criteria for user weighting, to a single measure of merit for each alternative).

Make Decision

Make Decision creates the system output of a decided action by deciding between alternative actions for a given decision using decision criteria, the contextual information to evaluate the criteria, and a decision process to transform the decision criteria to a choice. Make Decision may select the presented decision with criteria information. Alternatively, Make Decision reviews contextual information for situational awareness in order to prompt additional information through Monitor Conditions that then prompts Present Decision. Make Decision may conduct these processes automatically, may only forward human user inputs and presentations, or may do both in combination. As the immediate CHI, Make Decision contains the user GUI and other input/output interfaces, that generally are separate applications or utilities in the platform. There will be several user-adaptive parameters set for these from Select Context or by adaptive learning at operational scale. The data flows associated with Make Decision are:

input_user are commands originating in Make Decision or from the CHI that stipulate Monitor Conditions. For the CHI, these are simply GUI, keyboard or other user inputs, but transformed into specifications on data objects within the system (e.g., spatial and attribute parameters for GIS layers).

presentation_user is contextual information presented to Make Decision. This primarily serves review of the contextual situation by the decision maker for situation awareness and to override the automated decision selection process. Otherwise, the primary function of making a decision is served by the decision_operational data flow. Both flows are formatted into the GUI or other CHI for interface to the human user.

5.3.3 Interfaces to External Systems

These are described in the interfaces document.

5.3.4 Performance Parameters

The WIST-DSS will be hosted on typical PC platforms. External interfaces will be buffered by the Select Context and Update Context processes that filter data into internal data stores. It is expected that this will eliminate the speed of external information transfers from being bottlenecks to DSS performance. Other RMA attributes of the external sources are not allocated to the DSS.

The primary performance attribute of the WIST-DSS is that it shall be able to complete a cycle of user query and decision making, or a cycle of context update and decision making, substantially within the indifference interval of the operational scale, for all specified operational decisions. This interval is relative to the type of decision, the spatial jurisdiction of the decision maker, and the environmental threat. An upper value for the operational cycle interval shall be set at 10 minutes for winter road maintenance.

The WIST-DSS is an operational system that shall be designed for continuous operation and high RMA values. It is expected that overall system RMA will be determined by the external interfaces and the PC platform. The WIST-DSS shall incorporate provisions for maintaining data that are otherwise externally provided by internal prediction when updates are cut off. The WIST-DSS shall provide user warnings when information quality is deteriorated in this way, and shall be expected to provide reasonable backup only up to some backup interval after loss of external information. This backup interval will vary according to the time horizon of the supported decision and shall be equal to half the decision time horizon, defined as the interval between the decision and a triggering environmental context event. The WIST-DSS shall be able to restart within the operational cycle interval when external data sources are restored. Availability of the WIST-DSS with the data backup process shall be that as determined by the PC platform availability with local power backup (i.e., generator or battery). However, by integrating stovepiped information systems, the WIST-DSS does create a single-point failure node. Mitigation provisions to increase availability over single PC platforms include multiple hot backup platforms with independent communications connections. Achieving higher availability in this way is an economic decision that should be left to the user. The system shall include options in the software to support the hot backup and communications switching.

The software reliability of the WIST-DSS shall be no worse than that measured by system failures of the PC platform operating typical COTS office software. Maintainability shall be ensured by full time availability of software support for the system.

The WIST-DSS shall be flexible and adaptable by conformance of its software design to applicable standards of modularity and control. Similarly for its hardware and communications interfaces, that shall obey applicable protocol and architecture standards. The WIST-DSS shall use COTS platforms.

The WIST-DSS shall be as portable as its PC platform, and shall be available for mobile platforms using wireless communications as these become available. The software shall be portable via CD or smaller bulk storage medium to typical COTS PC platforms.

System safety and security shall be ensured based on the importance of the system to operational safety of the road system and maintenance crews. Overall system safety and security shall be the responsibility of the operating agencies and according to procedure for their operating facilities and equipment. The software shall support change control by establishing multiple levels of change access including: 1) Changes prohibited except as controlled changes to all installations by the system supplier; 2) Changes allowed as local adaptations by a controlled process within the user organizations, and; 3) Changes at user discretion.

5.4 WIST-DSS Users

The WIST-DSS users are the same as described for the RWIS. The WIST-DSS shall use the Select Context process, user inputs and adaptive learning to tailor the system to particular user environments. The WIST-DSS shall accommodate users making operational-scale decisions in any of the four organizational levels identified for the RWIS. The WIST-DSS need not support warning-scale decisions for treatment crews. The WIST-DSS shall support a user with the profile cited as typical for the RWIS, and in particular shall assume no special meteorological expertise. The WIST-DSS shall assume familiarity of users with PC platforms.

The WIST-DSS shall support explicit risk decisions by including decision payoff statistics and alternative selections based on risk, with either assumed user risk neutrality or user-specified risk preferences.

The WIST-DSS shall be adapted for the specific operational environment by availability of appropriate GIS information for the operating jurisdiction, and other planning-scale context via the Select Context process. The WIST-DSS shall facilitate external interfaces for the learning (evaluation) modes in order to adapt the system.

The WIST-DSS shall facilitate the collaborative mode and shall be flexible for decision support to consolidated decision responsibilities, particularly of traffic and road maintenance management.

5.5 Support Concept

WIST-DSS deployment will be evolutionary and decentralized. It is expected that the WIST-DSS will consist of modular improvements to the RWIS. These will be supplied by vendors who provide the RWIS. Development of the improvements will include FHWA participation in research and operational tests, along with other public and private stakeholders. However, the concept of integrated decision support and open systems necessarily implies convergence on certain standards and relatively uniform functionality and CHI. The degree to which the WIST-DSS software and PC platform hardware will be fully standardized cannot be foreseen. It is possible that the WIST-DSS will be supplied by a single entity with the competitive vending occurring more for the information resources. How this evolves strongly affects the support concept.

The PC platform shall be supported by the process typical for PC platform support within the user organization. The communications interfaces to the WIST-DSS shall be supported by the process typical for the existing information resources.

The WIST-DSS software shall be supported by dedicated, full-time support trained by the developing organization and funded by a continuing organization designated for WIST-DSS control and support. This may occur with multiple vendors or a single source.

Training will be a vital part of WIST-DSS deployment. Because deployment will be evolutionary and decentralized, training also will have to be incremental and decentralized. Basic training on information system platforms and applications will continue to be necessary, and not specifically for the WIST-DSS. With GUIs and the Internet, a great deal of application training has become informal and intuitive. The mechanics of using the WIST-DSS may also follow this process, with vendor manuals and training available but not necessarily relied on.

Since the WIST-DSS concept responds to operational best practices, such as risk-decision making, there is a component of training that logically falls under the agencies responsible for maintenance operations. For state DOTs this has occurred by FHWA-AASHTO partnership, and through the American Public Works Association (APWA) for local agencies. These agencies will have to respond to a closer association of the operational practices and the decision support systems through their training programs. This probably will be quite different from the dissociation of general operational practices from specific RWIS offerings. To the extent that RWIS vendors become WIST-DSS vendors, it is implied that the vendors become much more oriented toward the specific operational decision support, changing from experts in environmental information to experts in winter road maintenance. While possible, this is not the most likely prospect. Therefore part of WIST-DSS evolution is likely to be an evolution in how training in operations and the information systems in decision support are integrated. A model for this is the involvement of some NWS forecast offices in outreach and training to their customers, including DOT staff. An alliance between weather experts and operational experts to plan and conduct training is desirable. As with office applications training today, training programs under public agencies will have to respond to the multiplicity of WIST-DSS vendors either by keeping reference to specific deployments general, picking a few for detailed training (probably in concert with the vendors) or choosing one system as a standardized version of the WIST-DSS. This need not affect the competitive multiplicity of information source vendors, not the competitive multiplicity of vendors supplying the WIST-DSS according to the standard. There is analogy here to the dominance of a few word processing applications (within what has become a nearly universal platform), or to the Internet with its standard protocols but a growing profusion of content sources.

6. Operational Scenarios

6.1 Threats, Decisions and Decision Clusters

Operational scenarios for the WIST-DSS are based on support for discrete decisions that are sequenced in time to treat snow and ice threats at the operational scale. The set of decisions varies by operational jurisdiction and the span of control of the decision maker, but one set of decision clusters is applicable across jurisdictions.

The discreteness and time sequencing of the decisions is fundamental to the WIST-DSS operational concept. This allows the decision maker to focus on one decision at a time and for the WIST-DSS to tailor information for one decision at a time. This in turn is due to important physical characteristics of both the weather threats and the treatment resources, namely that both have time lags between information and occurrence, with equivalent predictability time horizons within the operational scale.

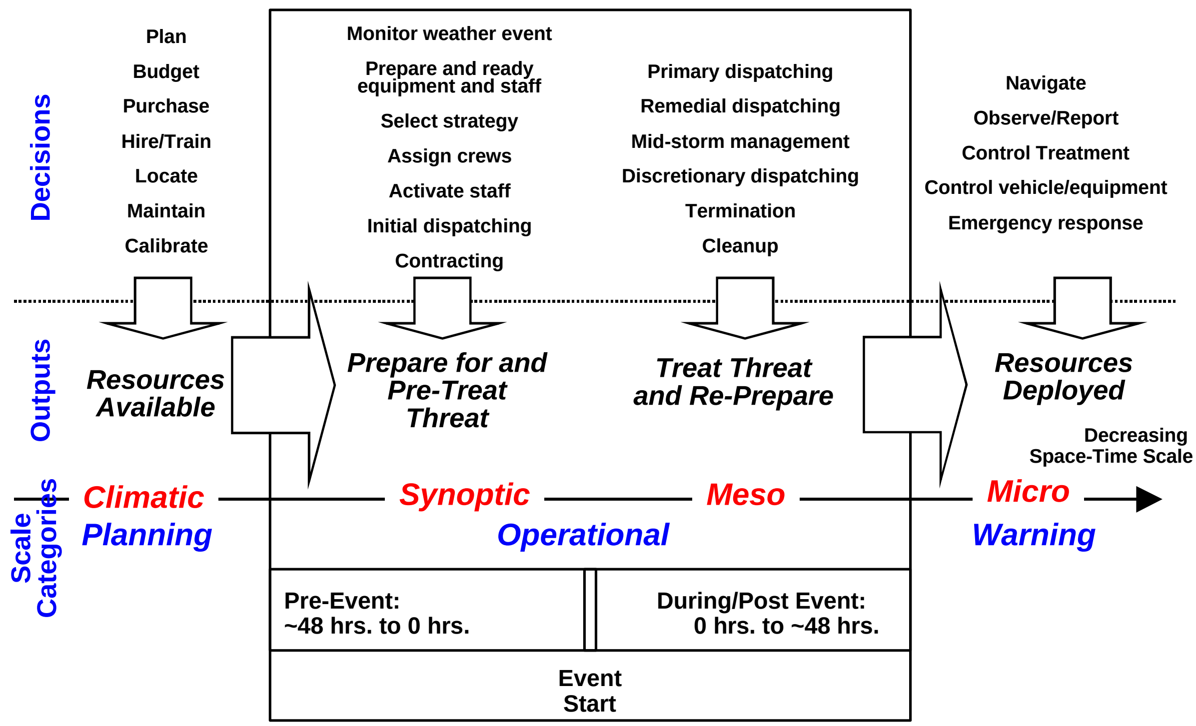

Figure 6.1.1: Scales of Decisions and Outputs Relative to Threat Event

The figure above is a schematic of the decision clusters in each scale and the operational scale span before, during and after the threat event. The operational scale and decisions is the only one that can clearly be related to a threat "event", since the planning scale is independent of discrete events, and the warning scale concerns deployed actions that can occur at any time relative to an event (e.g., pretreatment, treatment, cleanup).

A weather threat is not generally a discrete event. A single storm or freezing event is discrete only in its starting time in a specific location. The basis of the conditions_scenario data object that spans many hours of prospective and retrospective time horizon is that all contextual conditions–of the environment, treatment resources and decisions–can be relevant to a decision. However, the human approach to decision making includes the simplification of defining a reference event, such as the weather-threat onset generalized to somewhere in the jurisdiction. This creates a set of well-defined lead times for preparatory activities, based on the lags required for each kind of activity (e.g., alerting crews, splitting shifts, loading and dressing equipment and deploying to treatment beats). This in turn creates an orderly sequence of decisions to consider (the function of the Present Decision process) although details (the selection of a decision from within a cluster and the decision criteria) may be tailored according to details of resources and the expected threat. This is an explanation for one result from the STWDSR research:

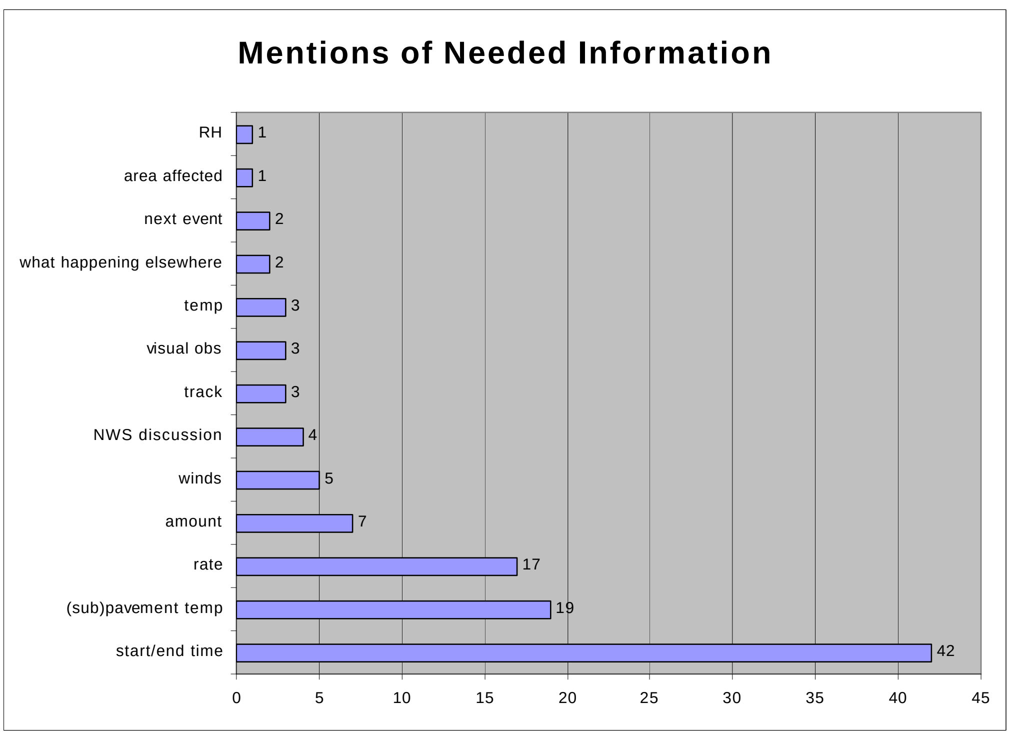

Figure 6.1.2: Responses on Types of Decision Support Information Needed

In the user response forms for the STWDSR stakeholder group, the dominant response on information needed (but not available) for decision support concerned threat-event timing. It appears that decision makers need the pre-event specificity to make the discrete preparatory decisions.

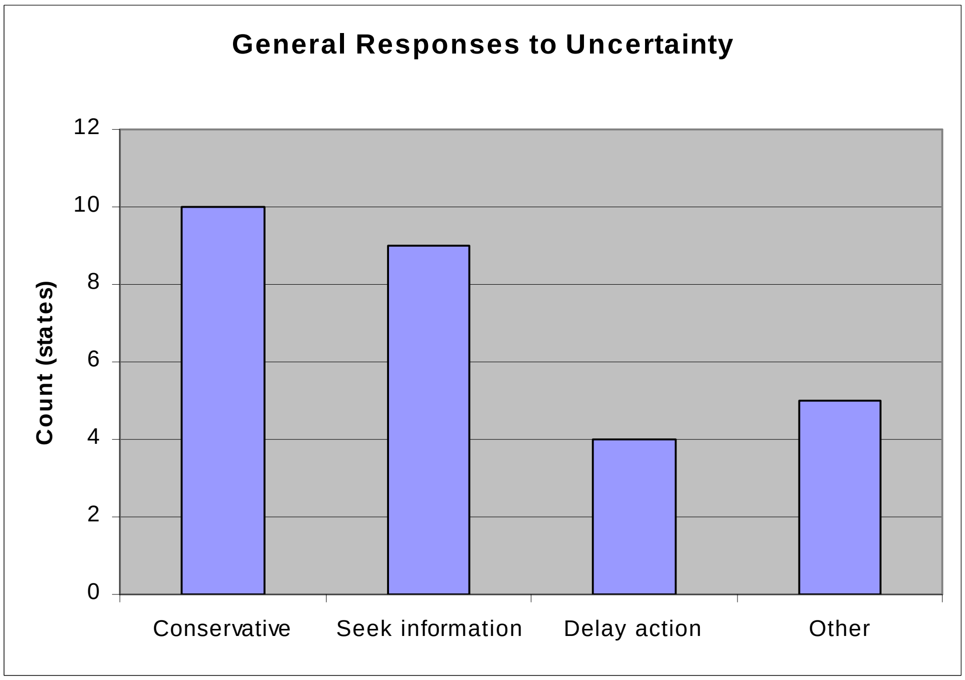

Figure 6.1.3: Responses to Predictive Uncertainty about a Weather Threat

The figure above indicates that most decision makers decide the preparatory actions on a risk-averse (conservative) basis of being prepared for a serious threat even with predictive uncertainty. This also leads to the desire for statistical bounds in conditions_scenario since many will respond to extreme rather than central statistics of the threats. "Seek information" as a response to uncertainty can be read either as determining the bounds by comparing predictions or tightening the uncertainty bounds by better (possibly later) information (compare with "delay action").

Decision makers make a distinction between the preparatory events, in which they are constrained by their resource response lead times (primarily due to the crew shift structure and geography of the jurisdictions), and decisions after the event start. Within the duration of the threat (a winter storm or pavement-freezing as it varies over the network) there tends to be a much more event-adaptive approach. The resources are deployed, and treatments are adjusted to observed conditions, often at lower organizational levels and down to the treatment crews at warning scale. In this interval, the time-lead definition is lost and it can no longer be stated that there is a well-ordered and discrete set of decisions. In this interval, decision making within a jurisdiction is likely to be more complex, more decentralized and more collaborative between organizational levels, and between jurisdictions for mutual aid.

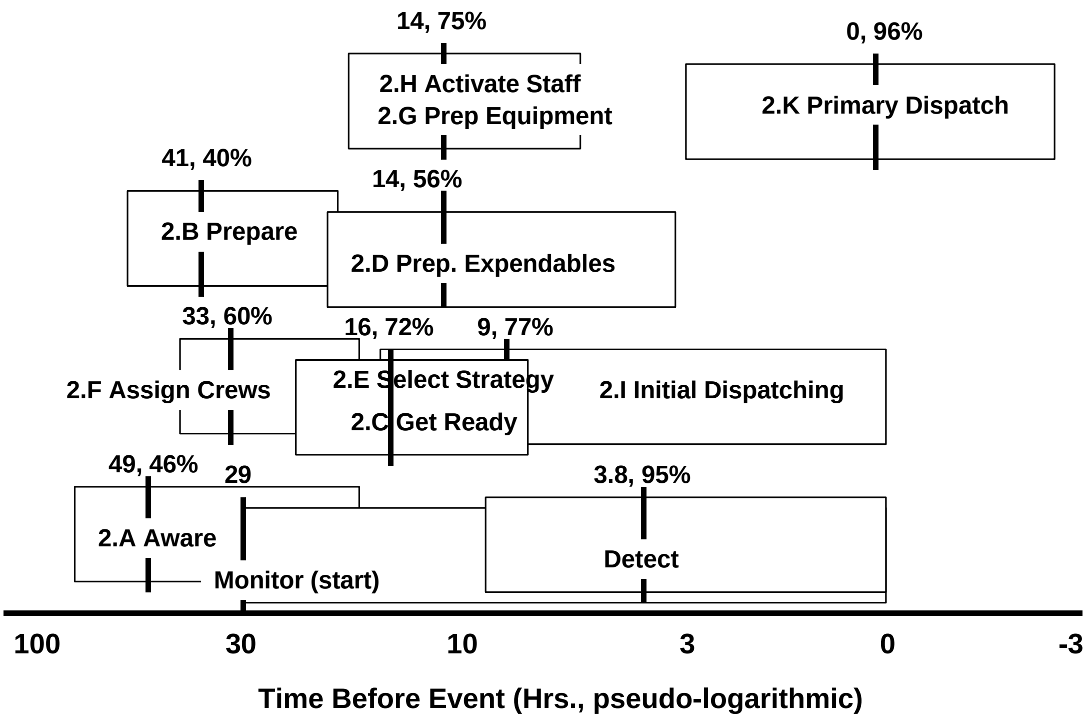

Figure 6.1.4: Decision Clusters, Time Lead and Confidence

The figure above shows the STWDSR stakeholder research results for the average time lead and confidence (the average certainty that the event would occur) at which the preparatory decisions were made. The bars show the range of responses for lead time. The earliest decision was awareness of the event (deciding that a threat was imminent) at 49 hours, although in the few weather event scenarios used, the earliest value approached 100 hours. The duration of the reactive decisions depends of course on the nature of the event. However, other data collected from decision diaries in IA and MO in 1999 gives an average treatment duration of 15.7 and a maximum of 42 hours. These data are the basis for saying roughly that treatment can be divided into the 48 hour preparatory period and the 48 hour treatment/cleanup period, although ranges will exist on both ends.

Specific decisions were defined, by scale, in the STWDSR V1.0 and refined by stakeholder responses into a V2.0 table. This is shown below:

Table 6.1.1: Winter Road Maintenance Needs, V2.0

			Micro-Scale	Meso/Synoptic	Synoptic/Climatic
DM#	**#**	**ID**	**Warning**	**Operational**	**Planning**
1.0 Infrastructure Operators					
1.1 Highway maintainer (winter)					
	1	1.1	control spreader/sprayer application		
	2	1.2	program treatment control		
	3	1.3	control plow		
	4	1.4	control static (bridge) anti-icer		
	5	1.5	observe/report		
	6	1.6	navigate spreader/plow truck		
	7	1.7	select chemicals		
	8	1.8	actuate traffic control messages (e.g., sign on truck)		
	9	2.1		become aware of weather threat	
	10	2.2		monitor weather threat	
	11	2.3		identify weather threat occurrence	
	12	2.4		assess sufficiency of staff, equipment and consumables	
	13	2.5		replenish consumable stocks	
	14	2.6		check readiness of staff, equipment and consumables	
	15	2.7		mix expendables	
	16	2.8		repair/PM equipment to augment fleet	
	17	2.9		check staffing availability	
	18	2.10		assign minimum staff to monitor and manage	
	19	2.11		select event-treatment strategy	
	20	2.12		assign crews to shifts, schedules	
	21	2.13		disseminate important weather information to field staff	
	22	2.14		forward-place equipment and stocks	
	23	2.15		put supervisory staff on event schedule	
	24	2.16		alert supervisory staff to monitor/prepare	
	25	2.17		confirm strategy-plan in place	
	26	2.18		alert crews (flexible plan)	
	27	2.19		split crew shifts	
	28	2.20		call in crews	
	29	2.21		select treatment expendables	
	30	2.22		dress and load equipment	
	31	2.23		dispatch patrols	
	32	2.24		dispatch crews to wait at routes	
	33	2.25		dispatch crews to treat (anti-ice)	
	34	2.26		program treatment control	

DM#	#	ID	Warning	Operational	Planning
	35	2.27		dispatch crews to treat (plow/spread)	
	36	2.28		dispatch crews to treat (plow cake, deice)	
	37	2.29		dispatch crews to treat (bulk removal)	
	38	2.30		dispatch crews to treat (ice-spot treatment)	
	39	2.31		dispatch crews to treat (drifting)	
	40	2.32		alert contractors	
	41	2.33		call in contractors	
	42	2.34		request out-of-jurisdiction resources	
	43	2.35		coordinate: traffic mgt.	
	44	2.36		coordinate: emergency mgt.	
	45	2.37		coordinate: public (traveler) information	
	46	2.38		manage incidents	
	47	2.39		close roads	
	48	2.40		monitor crew working time and conditions	
	49	2.41		rest crews	
	50	2.42		reevaluate storm intensity and duration	
	51	2.43		identify threat end	
	52	2.44		determine that level-of-service goal is reached	
	53	2.45		plan for cleanup	
	54	2.46		dispatch snow cleanup (push back banks)	
	55	2.47		dispatch snow cleanup (phase 2, turnouts and bridges)	
	56	2.48		open roads	
	57	2.49		dispatch damage repair (facilities, trees, power lines etc.)	
	58	2.50		assign cleanup (equipment & yard)	
	59	2.51		dispatch abrasives cleanup	
	60	2.52		release crews	
	61	2.53		return to normal procedure	
	62	3.1			locate facilities
	63	3.2			establish organization
	64	3.3			specify equipment/services
	65	3.4			devise/revise response plan
	66	3.5			define level-of-service goals
	67	3.6			hire staff
	68	3.7			train staff
	69	3.8			buy equipment/services
	70	3.9			stock stores and consumables
	71	3.10			budget

DM#		#	ID	Warning	Operational	Planning
		72	3.11			schedule seasonal tasks (incl. end-season abrasives cleanup)
		73	3.12			calibrate treatment controls
		74	3.13			check seasonal readiness (equipment, consumables, staff)
		75	3.14			repair/adjust/PM of equipment
		76	3.15			forward-place equipment and stocks
		77	3.16			confirm plans in place
		78	3.17			evaluate performance

This table gives the decisions (equivalent to management actions) that define the user needs to be served by decision support. The planning and warning scales are included but only the operational scale decisions, with the 2.x indexing, are considered here. There are 78 decisions represented in total, 53 of operational scale. The decisions capture all the variations stated by the STWDSR stakeholders that could be put in uniform phrases. It was recognized that the list of 53 operational decisions was too varied for a general operational concept. Also, a simpler scheme was desired to define the lead time and confidence parameters of decision groups. By looking at how the decisions groups in lead time, the decision clusters were defined. These are tabulated below with their constituent decisions.

Table 6.1.2: Decision Cluster Definitions

ID	Decisions	Ct.	Avg.	Cluster ID, Name
2.2 2.1 2.3	monitor weather threat become aware of weather threat identify weather threat occurrence	4.00	1.00	2.A Monitor Conditions* *Note: this will include monitoring of all relevant conditions–traffic, incidents, weather etc.
2.6 2.9 2.4	check readiness of (staff,)* equipment and consumables check staffing availability assess sufficiency of (staff,)* equipment and consumables * staff may defer to cluster 2.F	4.00	1.00	2.B Prepare
2.18 2.13 2.10 2.14 2.16	alert crews (flexible plan) disseminate important weather information to field staff assign minimum staff to monitor and manage forward-place equipment and stocks alert supervisory staff to monitor/prepare	9.00	1.67	2.C Get Ready
2.7 2.21 2.5	mix expendables select treatment expendables replenish consumable stocks	6.00	2.17	2.D Prepare Expendables
2.11 2.17	select event-treatment strategy confirm strategy-plan in place	4.00	2.50	2.E Select Strategy

ID	Decisions	Ct.	Avg.	Cluster ID, Name
2.12	assign crews to shifts, schedules (cancel leaves)	10.0	2.80	2.F Assign Crews
2.22	dress and load equipment	18.0	3.00	2.G Prepare Equipment
2.20 2.19 2.15	call in crews split crew shifts put supervisory staff on event schedule	4.00 10.0	3.00 3.30	2.H Activate Staff
2.25 2.23 2.35	dispatch crews to treat (anti-ice) dispatch patrols coordinate: traffic mgt.	16.0	4.19	2.I Initial Dispatching
2.33 2.32 2.24	call in contractors alert contractors dispatch crews to wait at routes* (* variable sequencing)	3.00	4.67	2.J Contracting
2.27 2.26 2.8	dispatch crews to treat (plow/spread) program treatment control repair/PM equipment to augment fleet	22.0	4.91	2.K Primary Dispatching
2.28	dispatch crews to treat (plow cake, deice)	3.00	5.67	2.L Remedial Dispatching
2.34 2.30 2.42 2.44 2.41 2.36 2.37 2.38 2.39 2.40	request out-of-jurisdiction resources dispatch crews to treat (ice-spot treat) reevaluate storm intensity and duration determine that level-of-service goal is reached rest crews coordinate: emergency mgt. coordinate: public (traveler) information manage incidents close roads monitor crew working time and condition	4.00	6.25	2.M Mid-Storm Management
2.29 2.31 2.47 2.49	dispatch crews to treat (bulk removal) dispatch crews to treat (drifting) dispatch snow cleanup (phase 2, turnouts and bridges) dispatch damage repair (facilities, trees, power lines etc.)	4.00	7.00	2.N Discretionary Dispatching
2.52 2.43 2.53 2.45 2.48	release crews identify threat end return to normal procedure plan for cleanup open roads	7.00	7.00	2.O Termination
2.46 2.50 2.51	dispatch snow cleanup (push back banks) assign cleanup (equipment and yard) dispatch abrasives cleanup	10.0	7.10	2.P Cleanup

The “Ct.” measure is the count of mentions of decisions in the cluster from the STWDSR response forms. The “Avg.” measure is the average ordinal position of the decision when it was mentioned among a general set of decisions and the order in which they are typically made. The numerical values for confidence and time lead for the clusters given in a previous figure are from data on responses to specific weather scenarios. The decisions were assigned to clusters based on their homogeneity of order and time lead.

With the exception of cluster 2.A, that includes monitoring and may extend throughout the decision making and detection that always occurs near the threat start, the clusters generally order by their time horizon before event start or sequence within the event duration. The cutoff of preparatory decisions is generally between cluster 2.I Initial Dispatching and 2.K Primary Dispatching. The cluster 2.J Contracting may be prior to or after event start. The cutoff corresponds to the Detection decision, that averages 3.8 lead, but with a range between12 and 0 hours. This range represents an interval in which confidence of the event start is about 100% and treatment can be committed. The cluster 2.K represents this in contrast to cluster 2.I that covers pre treatment or patrol dispatching to confirm road conditions. After detection, time leads are no longer defined since the weather "event" has become the complex and continuous space-time occurrence of the threat.

The decision clusters are the basis for operational scenarios. While the WIST-DSS is decomposable into its processes, a functional WIST-DSS is at minimum the processes and information necessary to support a decision cluster. This forms a minimal thread of processing from external information resources through decided action. The minimum sufficient WIST-DSS to support a winter road maintenance manager is the set of threads that serves the decision clusters within the manager's span of decision making. For most decision makers, except possibly the top and bottom of the four generic levels defined, all the clusters must be served.

Part of the scenario specification is the external information needed to characterize the environmental context, as well as other context information. These information elements are discussed in more detail in the interfaces document. However, the table below is indicative. It contains STWDSR stakeholder responses on information desired for the decisions within the clusters, based on the weather scenarios presented. The categories are common labels selected for the various types of information shown with the count of the number of mentions (and used in figure 6.1.2). The "information desired" items are the corresponding user statements that elaborate the categories. An appendix to the interfaces document completely lists the information required for each decision type.

Table 6.1.3: Information Desired for Cluster Decisions

Actions and Triggers for Scenarios		
Clusters	**Categories**	**Info Desired**
2.A Monitor		
Monitor	(sub)pavement temp (5)	RWIS data
	start/end time (1)	Pavement temp/thermal map
		RWIS data
		subsurface probes
		check shaded areas/RWIS
		start/end time
2.B Prepare		
Alert crew/flexible plan	(sub)pavement temp (3)	Surf temp, snow start/end, rate
	start/end time (8)	start/end time, snow amount
	rate (3)	start time
	amount (2)	Start time, rate, duration
	NWS discussion (1)	Rate of snow fall
	track (1)	more definite timelines
		NWS discussions
		RWIS, VAMS
		surf. Temp models/RWIS
Activate district ops center		event timing
Loaders at remote stockpile		start time, rate of movement
		Timing, amount, duration
2.C Get Ready		
Check readiness	winds (1)	Start time, intensity
	start/end time (2)	Start time, rate, duration
	rate (3)	wind speeds, jetstream
	amount (1)	forecast
	NWS discussion (1)	duration, intensity
		NWS discussions
2.D Prepare Expendables		
Mix chemicals/abrasives	start/end time (2)	Timing, amount, duration
Stir liquids	rate (1)	Start/end time, accumulation rate
	amount (1)	
2.G Prepare Equipment		
Dress/load equipment	start/end time (5)	start time, rate of movement
	rate (1)	start time
	track(1)	precip window (time)
	temp (1)	Start/end time, accumulation rate
		event timing
		forecast
		temp FR and SAT

2.H Activate Staff		
Split Crews	start/end time (10)	start time, rate of movement
	rate (2)	Time to precip start
	track(1)	wind speed
	(sub)pavement temp (2)	forecast
	winds(2)	duration, intensity
	NWS Discussion (1)	NWS discussion
	what happening elsewhere (1)	what happening elsewhere
	amount (2)	pavement temp,
		actual start and end of storm
		amount and duration
Mobilize/Dispatch crews		start time
		start time
		end time
		duration, intensity
		rate of snow fall
		Timing, amount, duration
		Duration
		wet pavement, low temp
Partial crew report		storm start
2.I Initial Dispatching		
Do anticing/pretreat	start/end time (8)	Surf temp, snow start/end, rate
	rate (5)	snowfall rate
	(sub)pavement temp (3)	Pavement temp/thermal map
	winds (1)	precip start
	what happening elsewhere (1)	Start/end time, snow amount
	amount (1)	start time
	area affected (1)	Start time and intensity
		How other districts hit
		intensity, duration
		detail on pavement temps, area affected, precip rates, timing
		snow end time, winds
2.J Contracting		
Call contractors	start/end time (2)	start time
		precip window (time)
2.K Primary Dispatching		
Plow/spread	start/end time (4)	storm end time, temp
	rate (1)	visual obs
	(sub)pavement temp (3)	storm end time, temp
	winds (1)	snow rate forecast
	temp (1)	Duration
	visual obs (2)	
		snow end time, winds
Salt/deice		RWIS, patrol obs.
Other		
Traffic management	next event (2)	snow rate forecast
Spot treatment	rate (1)	
Clean up snow/ice	(sub)pavement temp (3)	future warming, rising temps
Clean up sand	RH (1)	
Plan for Cleanup	temp (1)	temps, RH, next event expected
Terminate response	visual obs (1)	road pavement temp
	NWS discussion (1)	RWIS, crew obs
Road closure		NWS discussion

For the operational scenarios, examples may be chosen on a cluster basis. The biggest distinction between the clusters are between cluster 2.A Monitor Conditions, the other clusters in the preparatory phase and the clusters in the duration of the event. Cluster 2.A Monitor Conditions corresponds closely to the Monitor Conditions process when used for situation awareness. The preparatory clusters are most discrete based on the predictive time lead, and also most face predictive uncertainty that is a function of the time lead. Clusters in the duration are less sequenced, more decentralized and most likely to be more collaborative.

Three scenarios are detailed below. These are chosen from each of the three types of clusters: monitoring, preparatory to, and during the event. Each step in the scenario is described by an initiating event, the process performed by one or more of the level 1 functions and the result or output.

The three scenarios, and the particular assumptions used for each, cannot exercise the whole functionality or all the possible branches of the system, yet they are the closest the OCD comes to a functional description for the next level of system specification. It is asserted that in terms of general functional operation, there is significant overlap between clusters and decisions. The selected scenarios therefore are sufficient for purposes of the OCD. Further, it is likely that the scenarios can be easily extended to other types, if not scales, of decisions.

6.2 Scenario 1: Monitor Conditions

This scenario describes the operation of the WIST-DSS, internally and from the user's point of view, for the specific decision cluster of 2.A Monitor Conditions. The thread that supports this cluster supports all of the following decisions, with parameters shown from the STWDSR stakeholder data:

Cluster 2.A Decisions	**Lead avg., [range]**	**Confidence avg., [range]**
2.1 become aware of weather threat	49 hrs., [18, 96]	46%, [18, 80]
2.2 monitor weather threat	29 hrs., [0,72]	N.A.
2.3 identify weather threat occurrence	3.8 hrs., [0, 12]	N.A.

The mode of operation is the prospective decision mode. The scenario may be initiated by the Monitor Conditions process upon receipt of external information, or by user query based on a normal monitoring cycle (e.g., start of work shift) or prompted by an external information source (e.g., radio broadcast). A cyclical user query is assumed. The sequence of events forming the scenario are tabulated below:

#	Initiation	Process	Result
0.	(system initial state)	Select Context has provided system with context_planning and context_parameters. Update Context has filtered (per context_parameters) latest operational information to data store context_operational.	System provided with external planning and operational scale information (types 2.x and 3.x per information taxonomy in interfaces document).
1.	(Parameter) minutes of user inactivity and no threat detection by Monitor Conditions.	Monitor Conditions sends presentation_user to Make Decision.	GUI displays default input window of user choices. Includes basic activities of "make decision" and "monitor conditions".

#	Initiation	Process	Result
2.	Road maintenance manager (viz. state DOT district manager, northern plains state) queries system at start of shift (7AM local) by mouse click on “monitor conditions”.	Make Decision sends input_user to Monitor Conditions requesting GUI display for “monitor conditions”. Display is specified per context_parameters for user and time/date and contains threats of significant (parameter amount and probability) frozen precipitation or road pavement temperature drop below (parameter, e.g., 1^{o}C) over parameter (e.g., 48 hrs.) horizon. Also displays active NWS watches and warnings for jurisdictional area.	User sees N. American synoptic threat situation on GIS GUI and area watches/warnings in flashing text box. Threats displayed as color-coded contours for (parameter) amounts and flashing route lines (appropriate to scale) for road freezing.
3.	User draws square with mouse on GIS GUI including states around jurisdictions.	Make Decision sends input_user and Monitor Conditions responds with threat situation blow-up of designated area to GIS GUI.	User sees blow up of threat situation.
4.	User chooses “animate threats” from pull-down command.	Make Decision sends input_user and Monitor Conditions responds with command window to GUI giving start/end and interval time choices, based on information available in context_operational. [Request of archive situation would result in additional Update Context process.] Animation speed is (default parameter) but can be selected in another pull-down menu.	User sees window with animation choices.

#	Initiation	Process	Result
5.	User selects animation parameters.	Make Decision sends input_user and Monitor Conditions sends scenario_selector to Generate Scenario. Generate Scenario selects appropriate information from context_operational to create conditions_scenario that contains requested animation scenes. Monitor Conditions slices conditions_scenario into scenes and forwards to GUI to create looped animation sequence.	User determines what threats exist for jurisdiction or are tracking toward jurisdiction within selected time horizon. (Pull-down options exist to view conventional front/air mass pictures, to re-window GIS, etc.)
6.	User becomes aware of weather threat (frozen precip) to jurisdiction. User stops animation and windows GIS GUI to jurisdiction area.	Make Decision sends input_user. Monitor Conditions, by default, interprets selection of jurisdiction area as request for specific threat and situation assessment. Monitor Conditions sends scenario_selector and situation_selector to Generate Scenario to specify conditions_scenario and decision_situation for (parameter percentile) of predicted time of (first) threat start. Monitor Conditions forwards presentation_user to GIS GUI via Make Decision.	User sees GIS GUI with color-coded contours of (parameter percentile) of predicted precipitation. Superimposed windows give: Distribution of start time anywhere in jurisdiction; distribution of end time anywhere in jurisdiction; dominant phase and liquid content of precip; resources situation at the (parameter percentile) of threat start time.

#	Initiation	Process	Result
7.	User windows on subarea of jurisdiction on GIS GUI to better specify information.	Make Decision sends input_user. Monitor Conditions is able to determine whether selected resolution is meaningful within (parameter) reliability to re-window GIS GUI. Assuming it is (e.g., to garage area within district) Monitor Conditions will re-specify scenario_selector and situation_selector and get new information from Generate Scenario to create new presentation_user.	User sees GIS GUI down to garage area with color-coded contours of (parameter percentile) of predicted precipitation. Superimposed windows give: Distribution of start time anywhere in garage area; distribution of end time anywhere in garage area; dominant phase and liquid content of precip; resources situation for the garage at the (parameter percentile) of threat start time.
8.	User chooses pull-down menu to re-specify parameter percentile for precip amount. Suppose 50^{th} %tile is default and user specifies 30^{th} %tile as basis for early decision.	Make Decision sends input_user. Monitor Conditions shifts precipitation amounts according to distribution contained in conditions_scenario creates new presentation_user for GIS GUI display via Make Decision.	User sees GIS GUI at garage area with new color-coded contours of 30^{th} %tile of predicted precipitation plus superimposed windows. User either decides to: Monitor weather threat; make early preparatory decision or; to identify occurrence of weather threat.
9.1	Option: User continues to monitor weather threat	Repeats from event #2 after user selected interval, or Monitor Conditions confirms threat from (parameter) thresholds and alerts user via GUI or other alarm (including pager).	Repeat threat monitoring.

#	Initiation	Process	Result
9.2	Option: User makes early preparatory decision. User selects from pull-down menu “present decision”.	see second operational scenario.	
9.3	User decides to identify occurrence of weather threat. User repeats event #8 but with identification confidence threshold, e.g., 95%.	repeat event #8 process.	If user identifies threat, will also go to decision. See operational scenario 2. If threat not identified, go to event 9.1 to continue monitoring
	end of scenario		

6.3 Scenario 2: Activate Staff

This scenario describes the operation of the WIST-DSS, internally and from the user’s point of view, for the decision cluster of 2.H Activate Staff. The thread that supports this cluster supports all of the following decisions, with parameters shown from the STWDSR stakeholder data:

Cluster 2.H Decisions	**Lead avg., [range]**	**Confidence avg., [range]**
2.15 put supervisory staff on event schedule	15 hrs., [8, 36] for cluster	69%, [40, 90] for cluster
2.19 split crew shifts		
2.20 call in crews		

The mode of operation is the prospective decision mode. The scenario may be initiated by the Monitor Conditions process upon receipt of external information, or by user query based on a monitoring of a threat event (see operational scenario 1). In this case initiation by Monitor Conditions will be assumed but the events are similar by user initiation after manual monitoring. The sequence of events forming the scenario are tabulated below:

#	Initiation	Process	Result
0.	(system initial state)	Select Context has provided system with context_planning and context_parameters. Update Context has filtered (per context_parameters) latest operational information to data store context_operational. Previous monitoring has created current conditions_scenario and decision_situation sequence to Monitor Conditions. Relevant threat has been identified and confirmed via user approval of previous preparatory decisions made via Present Decision.	System provided with external planning and operational scale information (types 2.x and 3.x per information taxonomy in interfaces document). Monitor Conditions has situational awareness equivalent to user's.
1.	Monitor Conditions receives clock-cycle update of conditions_scenario.	Monitor Conditions continues to confirm threat (significant snowfall in jurisdiction) after sequence of user interactions on previous preparatory decisions and monitoring. Monitor Conditions uses conditions_scenario to evaluate distributions (e.g., fuzzy sets) of time lead and confidence of threat.	Monitor Conditions combines time lead and confidence distributions with decision history and sends them in decision_selector to Present decision.
2.	Present Decision receives decision_selector information from Monitor Conditions.	Present decision evaluates decision_selector and composes query_decision to match attributes of decision_file.	The decision_file produces response_decision to the query.

#	Initiation	Process	Result
3.	Present Decision receives response_decision.	Present Decision finds the 2.H Activate Staff cluster matches attributes. Based primarily on time (of day and day of week), Present Decision selects decision 2.19 split crew shifts as immediate candidate (i.e., time to start of event is such that current shift can be split for later crew call-in, but event is not near enough to activate event schedule for supervisory staff).	Present Decision sends decision_operational to Make Decision containing cluster 2.H decisions and recommendation to make decision 2.19.
4.	Make Decision receives decision_operational.	Make Decision presents cluster 2.H choices and recommendation to make decision 2.19 to user in GUI text window (or to paging device, etc.)	User either affirms decision 2.19 as next appropriate decision or indicates other choice (e.g., decision 2.15).
5.1	(option) User affirms decision 2.19.	Make Decision composes input_user containing decision 2.19 choice and information from decision_operational that contains the decision-making criteria for decision 2.19.	Make Decision sends input_user to Monitor Conditions.
5.2	(option) User selects decision 2.15.	Make Decision composes input_user containing decision 2.15 choice and information from decision_operational that contains the decision-making criteria for decision 2.15.	Make Decision sends input_user to Monitor Conditions.
6.	Monitor Conditions receives input_user.	Monitor Conditions composes situation_selector to obtain the information that fills the decision criteria for the selected decision and with respect to threat information (e.g., which jurisdictional sub units are affected).	Monitor Conditions sends situation_selector to Generate Scenario.

#	Initiation	Process	Result
7.	Generate Scenario receives situation_selector.	Generate Scenario creates query_scenario to obtain updated decision criterion information from context_operational. This will include staff on current shifts, available staff for forthcoming shifts, total times worked and contact information for the staff–all for the relevant jurisdictions. Information is receive in response_scenario.	Generate Scenario sends updated and specific decision_situation to Monitor Conditions.
8.	Monitor Conditions receives decision_situation.	Monitor Conditions composes decision_criteria.	Monitor Conditions sends decision_criteria to Present Decision.
9.	Present Decision receives decision_criteria.	Present Decision composes decision_operational that contains complete information for making the current decision.	Present Decision sends decision_operational to Make Decision.
10.	Make Decision receives decision_operational.	Make Decision evaluates all criteria information for the current decision and makes an action recommendation (e.g., who to contact, when and where for special shift assignment). Make Decision also composes a table of available alternatives with appropriate criteria information.	Make Decision presents GUI with: threat situation (e.g., type, onset), current decision and action recommendation. Option exists for user to review action alternatives and criteria.
11.	User views GUI.	User reviews recommended action.	User optionally acts on recommendation or selects alternatives review.
12.1	(option) User acts on recommendation.	User initiates contact of affected staff.	User responds that recommendation is selected (context is updated). Staff contacted for shift change. Go to end of scenario.

#	Initiation	Process	Result
12.2	(option) User reviews alternatives.	User determines whether or not to modify recommended action, or can delay decision.	User either modifies action or indicates deferral of decision through GUI.
13.1	(option) User modifies choice.	Make Decision sends input_user to Monitor Situation reflecting choice. May require additional decision_criteria information and repeat of above events.	User choice confirmed on GUI. Go to end of scenario.
13.2	(option) User defers choice.	Make Decision sends input_user to Monitor Situation reflecting choice. Monitor Situation will re-activate decision loop after indicator or default delay.	User choice confirmed on GUI. Go to end of scenario.
	end of scenario		

6.4 Scenario 3: Mid-Storm management

This scenario describes the operation of the WIST-DSS, internally and from the user's point of view, for the decision cluster of 2.M Mid-Storm Management. The thread that supports this cluster supports all of the following decisions, with parameters shown from the STWDSR stakeholder data:

Cluster 2.M Decisions	**Time Lead**	**Confidence**
2.30 dispatch crews to treat (ice-spot) 2.34 request out-of-jurisdiction resources 2.36 coordinate: emergency mgt. 2.37 coordinate: public (traveler) information 2.38 manage incidents 2.39 close roads 2.40 monitor crew working time and condition 2.41 rest crews 2.42 reevaluate storm intensity and duration 2.44 determine that level-of-service goal is reached	within storm event: nominal range 1-3 hrs. for cluster	high (observation-based) for cluster

The mode of operation is the prospective decision mode with the collaborative mode being used for some decisions and events. The scenario may be initiated by the Monitor Conditions process upon receipt of external information, or by user query based on a monitoring of a threat event. The basic processes are a mixture of monitoring (see operational scenario 1) and decision making (see operational scenario 2). The various decisions within the cluster generally will involve close DSS and user interaction with prompts from both sides. Also, multiple decision maker levels are likely to be involved, with some of the decisions that are more strategic, and involving resources, being at higher levels while decisions involving environmental variations are more likely to be at lower (garage) levels. The scenario will illustrate only a few of the possible options. The sequence of events forming the scenario are tabulated below:

#	Initiation	Process	Result
0.	(system initial state)	Select Context has provided system with context_planning and context_parameters. Update Context has filtered (per context_parameters) latest operational information to data store context_operational. Previous monitoring and decision making have created current conditions_scenario and decision_situation as a result of treatments and resource expenditure. The context is rapidly changing and is updated according to external observations and near-horizon weather predictions. The near-horizon road condition predictions, since they are highly dependent on treatment decisions, are partly synthesized in Update Context.	System provided with external planning and operational scale information (types 2.x and 3.x per information taxonomy in interfaces document). Monitor Conditions has situational awareness equivalent to user's. It is determined that the cluster 2.M is current. Environmental and resource context are equally important to further decisions within the cluster.
1.	Monitor Conditions receives clock-cycle update of conditions_scenario.	Monitor Conditions maintains an automatic background-decision loop for decision 2.44 determine that LOS is reached. This is part of user prompts on resource allocation decisions.	Monitor Conditions sends decision_selector and decision_criteria to Present Decision for decision 2.44.
1.1.	(LOS loop) Present Decision receives decision_selector and decision_criteria from Monitor Conditions.	Present Decision evaluates decision_selector and queries decision_file to compose decision_operational with decision_criteria.	Present Decision sends decision_operational to Make Decision.

#	Initiation	Process	Result
1.2	(LOS loop) Make Decision receives decision_operational	Make Decision displays GUI window that presents decision 2.44 as user options of: a) showing time distributions of LOS satisfactions at current resource allocation (equivalent to automatic decision); b) showing distributions of LOS satisfaction at user-specified time horizon, or; showing resource requirements of LOS satisfaction at user specified time.	User selects option via GUI and Make Decision sends input_user.
1.3	(LOS loop) Monitor Conditions receives input_user	Monitor Conditions requests update of predicted road-conditions at appropriate time horizon via process in Update Context.	context_selector sent to Update Context.
1.4	(LOS loop) Update Context receives context_selector.	Update Context uses external information on road conditions, resource deployment (current or user-specified) and weather to predict road conditions relative to LOS criteria.	Update Context sends context_update to the context_operational data store. Note that the user option to explore the effects of a change of resource allocation on LOS creates a contingent prediction of road condition that must be so identified in context_operational.
1.5	(LOS loop) context_operational updated with (contingent) road-condition prediction.	Generate Scenario responds to update trigger to revise decision_situation (including contingent resources) and conditions_scenario (including contingent LOS).	New decision_situation and conditions_scenario to Monitor Conditions.

#	Initiation	Process	Result
1.6	(LOS loop) updates received by Monitor Conditions	Monitor Conditions slices conditions_scenario per user request. Also uses decision_situation to revise decision_criteria.	presentation_user revises GIS GUI to Make Decision and revised decision_criteria updates decision_operational via Present Decision.
1.7	(LOS loop) Make Decision receives revised GIS GUI presentation of road LOS (at user selected times or route-segment time distributions of LOS satisfaction) and window shows decision criteria (resources used, user-specified time, time to full LOS satisfaction).	User considers decision (i.e., predicted LOS situation) and goes to next options that include: proceed with current treatment situation; revise LOS satisfaction time option; go to different decision.	end LOS loop
2.	User decides to make decision 2.34 request out-of-jurisdiction resources (collaborative mode)	User activates pull-down command on GUI to choose decision.	Make Decision sends input_user to Monitor Conditions.
3.	Monitor Conditions receives input_user.	Monitor Conditions sends context_selector to Update Context if extra-jurisdictional information not already in context. context_operational and the products of Generate Scenario updated accordingly.	Monitor Conditions receives information on decision_situation (resource use and availability) for the jurisdictions concerned. Monitor conditions creates decision_selector and decision_criteria.

#	Initiation	Process	Result
4.	Present Decision gets decision_selector and decision_criteria.	Present Decision queries decision_file based on attributes. Formulates decision that gives options for requesting other resources, including collaborative interaction with chosen jurisdiction.	Present Decision sends decision_operational to Make Decision.
5.	User receives decision_operational via GUI.	User reviews information window on availability of resources and threats in adjacent jurisdictions. User selects a jurisdiction to open collaborative decision with (assumes that the other jurisdiction is at equal level or an external jurisdiction). User also has option for external communication (e.g., telephone) but does not select that.	User sends input_user to Monitor Conditions.
6.	(collaboration loop) Monitor Conditions receives input_user.	Monitor Conditions(A) opens external interface with Monitor Conditions(B) in the system of the selected jurisdiction for collaboration. Monitor Conditions(A) forwards decision_selector(A) and decision_criteria(A) to Monitor Conditions(B) to emulate user(A) decision. Monitor Conditions(B) considers local conditions_scenario(B) and decision_situation(B) to compose decision for user(B), i.e., 2.27 dispatch crews to treat jurisdiction(A) under situation of resource constraints in(B).	User(B) responds to decision_operational(B) for dispatching resources to (A) and result is sent back to user(A) via Monitor Conditions(A). context_operational is appropriately updated for both jurisdictions. Go to next decision.

#	Initiation	Process	Result
7.	(close roads decision 2.39) Update Context receives external information 2.1.1.4.3 snowfall accumulation rate, from radar algorithm prediction.	Update Context sends context_update to context_operational data store that indicates increased predicted rate of snowfall. Generate Scenario updates conditions_scenario accordingly. Monitor Conditions recognizes a threshold threat to road LOS based on current decision_situation of deployed crews.	Monitor Conditions sends decision_selector and decision_criteria to Present Decision.
7.1	(close roads decision 2.39) Present Decision receives decision_selector and decision_criteria.	Present decision queries decision_file for decision 2.39 close roads.	Present decision composes decision_operational for Make Decision.
7.2	(close roads decision 2.39) Make Decision receives decision_operational	Make Decision creates GUI window for decision 2.39 and alert to user. Monitor Decision has also passed critical slices of conditions_scenario through presentation_user to GIS GUI via Make Decision. Note: this implies decision 2.42 reevaluate storm intensity and duration is automated, but manual intervention in decision 2.42 would have same effect.	User alert to changed situation, GUI display of deterioration of LOS at critical time horizon and display of decision window for decision 2.39.
7.3	(close roads decision 2.39) User reviews GUI.	User reviews GIS GUI for predicted road condition (may optionally monitor condition for other times, window other information such as radar, etc.). User reviews decision window with recommended road closures and options to continue or withdraw treatment.	User makes selection of road closure on selected routes but with continuation of treatment.

#	Initiation	Process	Result
7.4	(close roads decision 2.39) Monitor Conditions receives input_user	Monitor Conditions recognizes conditions for initiating decision 3.37 coordinate public (traveler) information.	Monitor Conditions sends decision_selector and decision_criteria to Present Decision.
7.5	(close roads decision 2.39) Present Decision receives decision_selector and decision_criteria	Present decision queries decision_file and composes decision_operational for Make Decision.	Make Decision composes GUI window for user.
7.6	(close roads decision 2.39) User alerted to new decision window on GUI.	User reviews recommendation to coordinate public information. Sees contact information for state patrol, traffic management, ISPs, etc. Selects which he will contact manually. Option: Automatic messages to be composed for external interface. Option: Collaborative decision with other agency.	Close roads decision executed by information to responsible agencies. Context to be updated regarding traffic. Go to next decision.
8.	Additional decisions initiated by input_user or change recognized by Monitor Conditions.	etc.	etc.
	end of scenario		

7. Summary of Impacts

7.1 Operational Impacts

7.1.1 Impacts on the User

The user will be impacted significantly by integrated and tailored decision support from the WIST-DSS. Information no longer will be stovepiped and manual integration will be minimized. A larger number and type of external information will be accessed and automatically processed by the WIST-DSS. This can cut both ways as the user is removed from the external information sources (e.g., weather information displays) that are usually accessed directly. This may create the feeling of some loss of situational awareness. However, the user is also removed from information that the user cannot competently assess manually, and options always exist to display more external information in an integrated GUI. The WIST-DSS primarily will display immediate decision criteria and the GIS GUI information that spatially and temporally represents the situations for the decisions (e.g., road conditions as affected by weather or by resource deployment as opposed to weather and treatment-independent road condition predictions). Situation awareness will be enhanced by the situation-detection and decision-formulation capabilities of the WIST-DSS. For many users, the WIST-DSS will require more CHI than previously. However, this will also have advantages in keeping record of context changes from decisions that the user previously would have to record or remember manually. The integration within the WIST-DSS also facilitates the learning mode, and the capability to track improvements in output and outcome performance will have a major impact on user performance through feedback and DSS adaptation.

The WIST-DSS exchanges the simplification and tailoring of decision support information for focus on other parameters: the risks of the decisions and the dynamic space-time situations of the decisions. The way in which users make decisions and review context will change with the information capabilities of the WIST-DSS. This will require training and experience to get used to.

7.1.2 Impacts on Interfaces

The impacts on interfaces are covered in the interfaces document. Some additional performance requirements will be levied on external information resources. All external information resources will be integrated within a common open system architecture and protocol standards.

7.1.3 Impacts on Procedures

The impacts on procedures have to be addressed in the larger spiral evolution cycle. No impacts are foreseen, but different perceptions of situations and learning through the WIST-DSS may prompt adaptive operational changes in each user organization. The WIST-DSS planning-scale context initially assumes the existing treatment operations for snow and ice threats. The WIST-DSS will complement pretreatment procedures, but those are proliferating independently. The WIST-DSS should improve the efficiency of all treatment decisions.

7.1.4 Impacts on Support

The WIST-DSS will create a separate support function for itself, in addition to the support of the external information resources it uses. The WIST-DSS support includes software maintenance and user training. Since the information will no longer be stovepiped, neither will the support be bundled with the information resources and this will require a new support entity, although it may grow out of an existing information resource. This is a key issue of coordination between the public and private sectors since it will create new relations between the multiplicity of VAMS, the WIST-DSS users and the WIST-DSS supplier.

The open system integration of the information resources will by itself create new support responsibilities, in terms of adherence to evolving standards. This is occurring independently of the WIST-DSS, that is just an application exploiting the emerging open system integration.

7.2 Organizational Impact

The WIST-DSS has no foreseeable impacts on the user organizational structure. The WIST-DSS will serve the existing decision making structure. The organization, like the maintenance procedures, may evolve over time due to new decision support but this will be individual and over the longer horizon of the spiral evolution process. It is expected that any level of decision maker that will benefit from the WIST-DSS will be staffed by people capable of being trained for WIST-DSS use. No significant displacement of staff or changes in staff qualifications is foreseen, independently of the general trend in management automation.

User agencies are generally the acquiring agencies, and no impact is expected. Technical support and acquisition responsibilities may decrease as a result of the elimination of stovepiping. However, this will depend on the bundling and pricing of the external information resources and physical communications utilities in the open system.

The developer agencies for the WIST-DSS necessarily will have to shift their domain focus from the information resource to the supported operations. In this case that is a shift primarily from meteorology and road-condition prediction to winter road maintenance operations. The STWDSR project is attempting to mitigate this impact by a system engineering approach that allocates the operations research functions separately from the system development functions. This is just the classic approach to complex systems integration. However, the support functions require a dedicated agency and probably a new organization for that.

7.3 Impacts During Development

WIST-DSS development requires a partnership effort as initiated by the STWDSR project. This includes the users, system developers and information resource providers. The FHWA and a system integrator play a facilitating role. The partnership is intended to be continued and enhanced during prototype development, operational test, and deployment phases. Development will require participation of operational staff, but on a non-interference schedule with operational duties. Development prior to operational testing will be non-interfering with operational systems.

Since the deployment of the WIST-DSS is evolutionary, operational testing will occur by successive integration of modular capabilities to the baseline system. Depending on the capability added, the threat of failure or interference by the added capability will vary from degradation back to baseline capability, to system failure. The latter shall be mitigated by thorough testing prior to operational test and maintaining parallel systems for transition.

Since the primary intent of the WIST-DSS is integration of currently stovepiped information, it is unavoidable that some stage of development will require deployment of a new capability between the user and all contributing information sources. This will create operational reliance on some components whose failure will degrade operations. However, in operational test it will be relatively easy to maintain the baseline capability as a backup and failure of the tested components will result only in degradation back to baseline capability. In the operational scale, the applicable time leads (order of an hour) should make backup transitions relatively transparent. Further, although operational testing will require additional effort and attention by operational staff, the episodic and predictable arrival of critical weather events mitigates the interference of participating in test readiness with operational decision making. However, test preparation and scheduling will have to be closely managed to minimize interference.

8. Analysis of the Proposed System

8.1 Summary of Advantages

The WIST-DSS will increase the effectiveness and efficiency of existing treatment procedures for snow and ice in winter road maintenance. It will do this by addressing the two major deficiencies in the existing RWIS: lack of integration of the external information resources and deficient tailoring to specific winter road maintenance decisions.

The prior lack of detailed operations research in decision support to winter road maintenance prevents good quantification of prospective WIST-DSS benefits. The best-documented benefits of RWIS are for support of anti-icing pretreatment and traveler information (especially for isolated visibility threats). In the former case, improved DSS clearly reduces costs (of chemical application and plowing of bonded ice) and environmental impact by more specific space-time threat identification. Benefits to road-user safety and mobility are improved by more reliable threat detection for treatment by winter road maintenance. While traveler decisions have not been considered explicitly in this OCD, it is expected that deployments of the envisaged WIST-DSS will also improve traveler information and threat-avoidance or coping, either through traffic management allied with maintenance, or application to traveler information systems directly.

Some questions remain about the impacts of improved threat information on transportation outcomes via treatments. These can be resolved only by further evaluation of the improved decision support. Cost savings and environmental benefits where pretreatment is already practiced must come from limiting unnecessary applications, but it is not well known if this also results in some “missed alarms” or inadequate applications that have negative impacts on safety and mobility outcomes. In general, little quantification exists on differences in LOS or outcomes over entire maintenance jurisdictions due to more efficient allocation of resources during various threat levels, for pretreatment or treatment during storms. Further, the baseline information that has been effective is clearly stovepiped and only modestly tailored to the decisions (e.g., mostly point ESS observations, static thermal maps and several weather prediction sources) so that the incremental benefits of the WIST-DSS cannot easily be extrapolated. Existing LOS standards that control treatment during storms reflect traditional and intuitive balances of costs and road-user benefit. On the highest level routes, treatment is limited mostly by the dedicated resources and based on direct and local observation. It is still likely that integrated decision support can improve LOS in these cases, and for lower-level routes, by better preparation and allocation of resources within and between jurisdictions.

It is expected that the WIST-DSS will improve the reliability of threat identification, the efficiency of pre- and post-event treatment, and traveler information regarding threats through coordination between maintenance and other agencies. Much of this can be accomplished by the decision mode, but the collaborative mode may also be necessary to a significant part of the benefit. Part of the total benefit will be allocated to the improvements in the external information resources, which is not credited to the information integration and tailored decision support of the WIST-DSS. It may be that decision support in the planning scale, which is not considered here but can borrow from the operational-scale OCD, and from the learning mode is necessary to better provide resources. Operational scale decision support cannot take credit or blame for inappropriate provision of resources, and the benefits of better allocation of given resources have to be assessed while controlling for varying resource levels. Such carefully controlled evaluations of operational tests of the evolutionary WIST-DSS improvements remain to be done. The three-year Foretell evaluation is the only known effort that approaches the desired experimental design. Further operations research for WIST-DSS development can at least better define the cost components to be affected and the relations between treatment efficiency and LOS.

8.2 Summary of Disadvantages and Limitations

No operational disadvantages or greater use of resources is expected for the WIST-DSS. The WIST-DSS will require access, at established prices and communications costs, to the external information resources, and greater reliance on the DSS computer platform and the software support organization. However, this is equally true for the baseline trend. The effects allocatable to the WIST-DSS are of integrating and tailoring what otherwise will be a growing profusion of stovepiped sources and non-integrated user applications.

The most significant possible limitation and disadvantage is that the profusion of information resources, in any case, requires greater filtering, fusion and processing to make it comprehensible to the user. Some users will believe that this removes the decision maker from the only "reliable" source of situation awareness, in direct observation. The WIST-DSS explicitly will transform weather information and direct road-condition observations into the predicted, spatially distributed decision criteria with reliability parameters. It is the hypothesis that this will improve the decision outcomes and outputs. It is reasonable to expect that this will be an improvement over reliance on limited direct observations, naive predictions and intuitive assessments of risk. However, this can be proved only by careful evaluation of operational tests.

The WIST-DSS imposes the constraint of reasonable PC platform facility and training by the user. This is not expected to be a greater constraint than for baseline systems. It may be, as for baseline systems, that some decision makers will not be adept. As for the baseline system this will tend to reallocate the management responsibilities to those who are adept.

8.3 Alternatives and Trade-Offs Considered

As an evolutionary system, the WIST-DSS is not entirely controlled by the STWDSR project or this document. At the highest level, the alternatives are a baseline improvement in stovepiped information resources to winter road maintenance, or continued specification and promotion of the WIST-DSS concept. The latter alternative has been chosen. Within the WIST-DSS significant alternatives are:

1. The allocation of the interface between the WIST-DSS and external information resources;

2. The structuring of the level-1 processes and data flows and;

3. The degree of human intervention in the Make Decision process.

For (1), extensive consideration was given in the interfaces document to the boundary between the external resources and internal functions. The alternative is to bring more of the weather and road-condition prediction process into the WIST-DSS. This corresponds to user perceptions of the RWIS. The main reason for defining the interface as shown is to focus on decision support components that are least attended to in the baseline RWIS. Also, keeping information resources functionally distinct (as opposed to physically stovepiped) promotes an appropriate allocation of environmental-information domain expertise. That is, decision support needs integrated systems expertise, while weather and other ITS information sources are technically distinct. The assumption of open system integration will make all the information resources, as they improve, available to decision support. The STWDSR project is also attending to requirements for the external resources through the interfaces document as well as programmatic activities other than for WIST-DSS development.

Regarding (2), in this OCD the level 1 structuring serves the operational scenario description and to check completeness of the logical functions and data objects included. This structuring will only generally constrain further specification levels. Alternative structures and allocations of functions are possible and may be used at lower levels (i.e., for software items). It is possible that the OCD will be subjected to controlled change as further development proceeds.

Regarding (3), there are relatively strong assumptions in the OCD about the user capability to perceive and process all the information needed to support decisions. The degree of automated processing allocated to the WIST-DSS reflects a judgment and trade-off on this matter. An alternative is to push more processes down to the logical Make Decision process that presently is ambiguous as to the human versus automated role, other than for the mechanics of CHI input and output processing. Alternatives can be explored at lower levels of development. However, pushing the logical functions all the way to the CHI simply represents the current stovepiping and manual decision making.

9. Glossary

AASHTO	American Association of State Highway and Transportation Officials
API	Application Program Interface
ASOS	Automated Surface Observing System
ATIS	Advanced Traveler Information System
ATMS	Advanced Traffic Management System
ATWIS	Advanced Traveler Weather Information System
AWIPS	Advanced Weather Interactive Processing System
BMP	Best Management Practice
CFR	Code of Federal Regulations
CHI	Computer-Human Interface
COTS	Commercial Off-the-Shelf
CPU	Central Processing Unit
DID	Data Item Decsription
DOD	Department of Defense
DOT	(state) department of transportation
ESS	Environmental Sensor Station
FHWA	Federal Highway Administration
GIS	Geographic Information System
GPRA	Government Performance Review Act
GUI	Graphical User Interface
HCRS	Highway Condition Reporting System
HOTO	Office of Transportation Operations (office code)
HTML	Hypertext Markup Language
IRRIS	Integrated Road and Rail Information System

IRS	Interface Requirements Specification
ISP	Information Service Provider or Internet Service Provider
ITS	Intelligent Transportation System
ITS-JPO	ITS Joint Program Office
IVHS	Intelligent Vehicle/Highway System
LAPS	Local Analysis and Prediction System
LDAD	Local Data Acquisition and Dissemination
LOS	Level of Service
MOS	Model Output Statistics
NCEP	National Centers for Environmental Prediction
NEXRAD	Next Generation Radar, aka Weather Service Radar (WSR) 88D
NIDS	NEXRAD Information Dissemination System
NHS	National Highway System
NOAA	National Oceanographic and Atmospheric Administration
NWP	numerical weather prediction
NWS	National Weather Service
OCD	Operational Concept Description
OFCM	Office of the Federal Coordinator for Meteorology
PC	Personal Computer
PDA	Personal Digital Assistant
RMA	Reliability, Maintainability, Availability
RPU	Remote Processing Unit
RWIS	Road Weather Information System
SHRP	Strategic Highway Research Program
SOP	Standard Operating Procedure

STWDSR	Surface Transportation Weather Decision Support Requirements
TCP/IP	Transmission Control Protocol/Internet Protocol
TMC	Traffic Management Center
USDOT	United States Department of Transportation
VAMS	Value Added Meteorological Services
VMT	Vehicle Miles Traveled
WFO	Warning and Forecast Office
WIST-DSS	Weather Information for Surface Transportation Decision Support System
WIST-JAG	Weather Information for Surface Transportation Joint Action Group
WMO	World Meteorological Organization
XML	Extended Markup Language

Appendix A: Technology Components

The several national labs involved in the STWDSR project created OCD summaries for WIST-DSS system components they presented to the STWDSR stakeholder group. These are considered to be technology components that have been demonstrated in other applications or that are specified at a lower level than this OCD with the intent of performing one or more of the level 1 functions. These OCD summaries are presented here as guidance for further specifications development. The OCD summaries follow the format only of section 5.3 of the OCD.

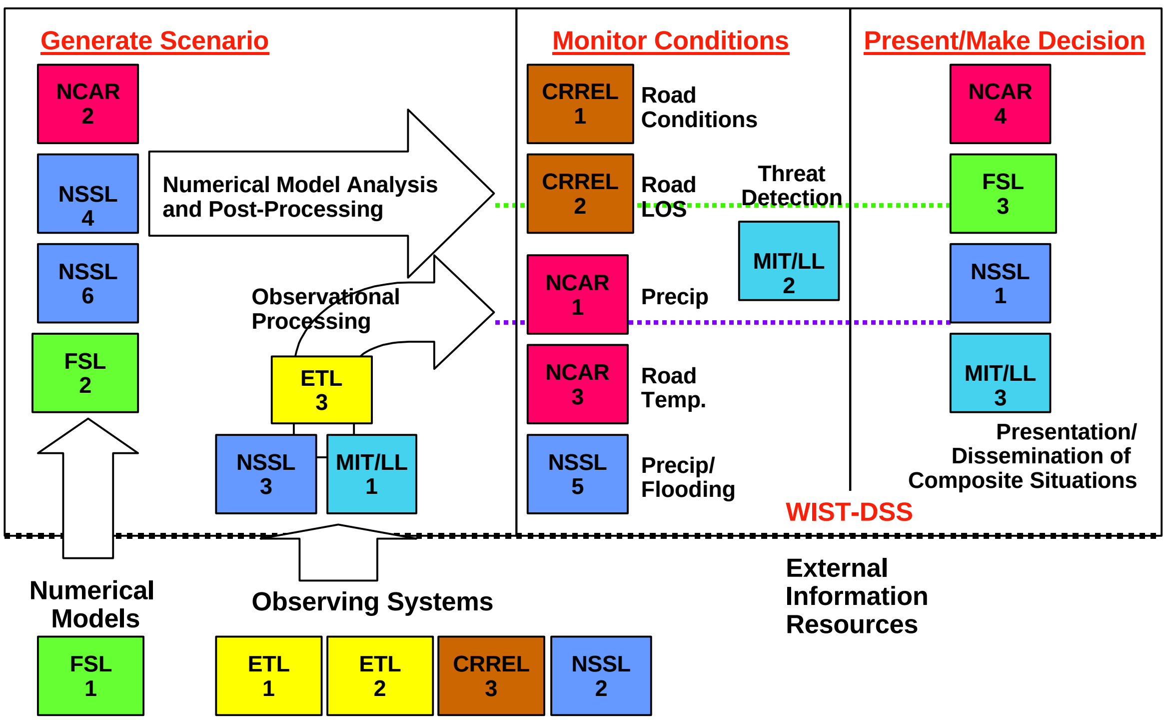

Figure A.1 Technology Components Within the WIST-DSS

The figure above summarizes how the proposed technology components fit into the general WIST-DSS structure. Several of the components are properly in the external information resources. The Environmental Technology Lab components being primarily there are described in the interfaces document.

A1. U.S. Army Corps of Engineers Cold Regions Research and Engineering Laboratory (CRREL)

A1.1 Description of : Terrain Surface Condition Prediction Algorithm

1. The operational environment and its characteristics; This algorithm is expected to run "in the background" to provide the mathematics and physics associated with making predictions based on input data. The algorithm is expected to be suitable for PC-based systems. Output will be in the form of a GUI and produce maps, charts and other modes tailored to make as simple as possible the visualization of predicted current and future state of the terrain surface. Road maintenance decision makers will use the results of this tool, but will never need to know more than that the algorithm is taking input and producing maps and charts for him/her to use. Refinement, calibration and modification of the algorithm is a "research" task and will be achieved by contractors/subcontractors selected to support the ongoing WIST-DSS effort.

2. Major system components and the interconnections among these components; This algorithm will be made up of a number of models to facilitate the prediction of surface phenomena ranging from power line icing to frost heave in a pavement system. The algorithm's GUI will provide the interconnection with the user and is the means by which specific models are engaged or ignored (depending on the type of prediction the user desires). All of the models in the algorithm will have some degree of interconnectedness, so that complex modeling predictions can be achieved (such as the determination of road subgrade moisture content, when soil thawing, local snow melt runoff, river ice jambs, and rainfall are influencing factors).

3. Interfaces to external systems or procedures; We expect this algorithm to be a stand-alone module in the WIST-DSS. The input required will be common to other needs of WIST-DSS and the output will be compatible with the workstation on which it is installed.

4. Capabilities of the new or modified system; This algorithm will provide a means to predict, in both temporal and spatial dimensions, the state of the terrain surface on and near a road corridor. The algorithm will most likely develop over time to include more and more sophisticated models, but initial deployment will focus on road surface state issues like temperature, contaminate (snow, ice, slush, water) type, state and thickness; frost/thaw development; snow drifting; and level of service (LOS).

A1.2 Description of : Maneuver Control System

1. The operational environment and its characteristics; This algorithm is expected to run "in the background" to establish the relationships associated with making predictions based on input data. The algorithm is expected to be suitable for PC-based systems. Output will be in the form of a GUI and produce maps, charts and other modes tailored to make as simple as possible the

visualization of the predicted current and future state throughput on a road network. Road maintenance decision makers will use the results of this tool, but will never need to know more than that the algorithm is taking input and producing maps and charts for him/her to use. Refinement, calibration and modification of the algorithm is a "research" task and will be achieved by contractors/subcontractors selected to support the ongoing WIST-DSS effort.

2. Major system components and the interconnections among these components; This algorithm will be made up of a number of models to facilitate the prediction of traffic flow, having used the output from the Terrain Surface Condition Prediction Algorithm as the predicted state of the road corridor. The algorithm's GUI will provide the interconnection with the user and is the means by which specific models are engaged or ignored (depending on the type of prediction the user desires). All of the models in the algorithm will have some degree of interconnectedness, so that complex modeling predictions can be achieved.

3. Interfaces to external systems or procedures; We expect this algorithm to be a stand-alone module in the WIST-DSS. The input required will principally come from the Terrain Surface Condition Prediction Algorithm and from other sources common to other portions of the WIST-DSS. The output will be compatible with the workstation on which it is installed.

4. Capabilities of the new or modified system; This algorithm will provide a means to temporally predict for a road corridor, the sustainable speed and quantity of traffic. This algorithm takes into account the level of service and traction characteristics of the road, and its geometry. Output will be in the form of speed and volume maps and can be used by planners to determine the most effective timing for maintenance activities and their likely impact on throughput.

5. Performance characteristics, such as speed, throughput, volume frequency; The algorithm will be tailored to run as efficiently as possible. Our goal will be for the output to take well less than an hour to produce, so as to be responsive to road maintenance personnel's decision timetable. It will be possible to have user-selected degrees of resolution and range, with their associated time-to-run indications, so that decision makers may choose the type of analysis based on their anticipated time-to-respond horizon.

6. Quality attributes such as reliability, maintainability, availability, flexibility, portability, usability, efficiency; We will strive to maximize all of these features in the algorithm. The algorithm will be made up of a number of existing (many validated) models, thus adequately addressing several of these features from the start. A version of this model is currently in use by the US Army, however, some adaptation will be required for the WIST-DSS application. There is strong motivation in the Army to continually upgrade this algorithm making it likely that the ITS configuration of the model will in part be facilitated by ongoing Army research. We can visualize other "commercial" applications for this algorithm, and will thus make every effort to ensure its flexibility and portability.

7. Provisions for safety, security, privacy, and continuity of operations in emergencies; This algorithm will be a software component of WIST-DSS, and thus will be protected and available as part of the system as a whole.

A1.3 Description of : Road Surface Sensors

1. The operational environment and its characteristics; These tools will constitute a portion of the Environmental Sensor Stations (ESS) network. They will, for the most part, record raw data and will require varying amounts of automated or human processing before being used by other components of the WIST-DSS. While the data provided by these sensors can be available to the whole ITS community, it is most likely that decision makers and road maintainers will only access these data indirectly when using “downstream” algorithms.

2. Major system components and the interconnections among these components; The sensors we foresee being developed for this application involve active and passive technologies and will monitor various aspects of the state of the terrain/road system. We envision several types of non-contacting sensors as well as traditional embedded sensors for measurement of properties such as: surface temperature; the phase state of water at 0<C; the radiative transmittance at the surface; subsurface temperatures, water content, and water phase state; road roughness; presence of contaminates on the surface (ice, snow, slush, etc.); atmospheric icing; and road surface friction coefficient.

3. Interfaces to external systems or procedures; Some of the sensors will be fixed and others will be part of mobile measurement platforms. The output from the sensors will supply information about the road surface and will join the WIST-DSS input data stream in the most efficient fashion. In some cases this will require hard wired or periodic data storage dumps, in others the data may be remotely collected, and still others may be part of mobile packages that telemetry data real-time to collection and processing centers.

4. Capabilities of the new or modified system; Accurate predictions of road surface condition, as a function of existing and anticipated weather patterns will require good “ground truth” information in distributed and key locations. The values of temperature, etc collected by this family of sensors will be vital to development of accurate locally-tuned algorithms of surface state and will provide the periodic “correction” needed when longer-range models are being updated in the middle of critical weather events.

5. Performance characteristics, such as speed, throughput, volume frequency; The majority of devices used in this effort will sense environmental characteristics in real time. The frequency of data sampling, and how often those data are stored and transmitted will be situation dependent. Likewise, the installation plan will also be application dependent. However, the goal in all cases

will be that the sensors provide adequate information to support the needs of all WIST-DSS developers and users.

6. Quality attributes such as reliability, maintainability, availability, flexibility, portability, usability, efficiency; We will strive to maximize all of these features in each sensor. However, each sensor type will be optimized for its principal purpose.

7. Provisions for safety, security, privacy, and continuity of operations in emergencies; These sensors will be components of the ESS that supports WIST-DSS, and thus will be protected and available as part of the system as a whole. Care will be taken to develop the sensors and their installation procedures to ensure that they provide robust service under all conditions and that they have the longest possible service life.

A2. NOAA's Forecast Systems Laboratory (FSL)

The NOAA Forecast Systems Laboratory proposes to develop, test, and implement the provision of very high resolution gridded weather forecasts to winter road maintenance operators and/or their VAMS. The clientele has indicated that timely delivery of highly-detailed weather information is critical to doing their jobs more safely and efficiently. FSL can help by adapting the existing and near-future capabilities of the local forecast offices of the National Weather Service to optimize the delivery of the data. FSL can also help by research and development leading to improved forecasts of the relevant weather elements.

A2.1 Provision of High Resolution Digital Weather Forecast Data

1. Scope

1.1 Identification: This item describes development of and improvements to automated and interactive scripts for providing high-resolution gridded weather services to surface transportation clients via National Weather Service (NWS) Warning and Forecast Offices (WFOs).

1.2 System Overview: The NWS is on track to begin routinely creating forecasts in gridded format via a new AWIPS (Automated Weather Information Processing System, the computing and communications platform for field operations of the NWS) component called the Graphical Forecast Editor, which allows forecasters to use nationally-provided forecast grids or locally-generated forecast grids to create a "first guess" set of local, high-resolution weather forecast grids, and then make modifications to those estimates based on knowledge of systematic model errors, new observations, etc. before posting the official gridded forecast information. Automated text and graphic formatters use these grids to draft traditional text products and new kinds of graphics, which are copied to the forecast office's LDAD (Local Data Acquisition and Dissemination) module, another AWIPS component. LDAD is the external security, data processing, and data serving subsystem that actually provides the gridded, graphical, and textual forecast information to the public, including the surface transportation community.

LDAD can provide weather data via automated ftp-based scripts that transmit over dial-in or dedicated phone line, or the Internet. LDAD also provides a web site with highly interactive Java application/applets that present the data as graphics or text, plus "probe" tools that allow users to determine the impact of weather on their area of concern. These software components will be extended for the purposes of the surface transportation community; the specific nature of these extensions will depend on client requirements (i.e., road maintenance operators and/or their VAMS). Many components of AWIPS, including the weather data display workstation, the Graphical Forecast Editor, and LDAD, were developed at FSL.

A2.2 Improved Numerical Forecasts of Key Weather Elements

1. Scope

1.1 Identification: This item describes the development of modeling techniques to improve forecasts of those weather elements that affect winter road maintenance operations, specifically, the type, amount, timing, and distribution of precipitation; near-surface air temperature, wind, and humidity; and surface-perspective cloudiness. The approach takes advantage of the new High Performance Computing Facility at FSL, which features a parallel processing platform with hundreds of nodes, the modeling expertise of the FSL staff, and the co-location in Boulder of the NOAA Environmental Technology Laboratory (ETL).

1.2 System Overview: The surface transportation community could use forecasts of 1-meter spatial resolution if they were timely and skillful. This will happen someday, but today, substantial improvements to forecasts of all these weather elements are possible, and the solution rests in three areas:

- Running forecast models at much higher spatial resolution than current operational models. The NWS runs its primary forecast model, the Eta model, on a 40-km grid, and is thus unable to resolve county- or city-sized cloud systems and precipitation. FSL can run this model (or any of several alternative models, such as MM5) over a limited domain on 5-km grids, or even finer, down to 1 km over embedded "nests" that cover metropolitan areas or regions of complex terrain.

- Improved parameterization of cloud and precipitation processes. Current models handle clouds as if they cover 100% or none of a model grid box. Partial cloudiness can be diagnosed indirectly from other model fields such as relative humidity and static stability, which will not only provide a much more useful field of cloudiness (which exhibits a very strong control on surface freezing and melting), but also renders a far more accurate representation of the evolution of the thermal structure in the lowest kilometer of the atmosphere. This is crucial to properly forecasting practically all types of precipitation systems.

- Better specification of initial conditions. FSL is a leader in the area of using "all" available observations to determine the most accurate possible gridded description of the atmosphere, which is the input to the numerical forecast models. Analysis methods based on variational calculus approaches are emerging at FSL, and many new candidate environmental sensor systems are being prototyped by our colleagues in FSL's sister organization ETL.

A3. Massachusetts Institute of Technology Lincoln Laboratory (MIT/LL)

A3.1 Component I – Short-term (0-2hour) Precipitation Tracking and Forecasting

Acronyms:

NEXRAD: Next Generation Weather Radar (WSR-88D). The National Weather Service Doppler weather radar.

TDWR: Terminal Doppler Weather Radar. The FAA's Doppler weather radar located at 45 major airports across the country.

ASR-9: Airport Surveillance Radar. The FAA's aircraft tracking radar, which has been equipped with a second receiving channel to receive weather data. Located at most moderately sized airports not serviced by TDWRs.

System Overview:

Advanced radar processing techniques can be used for short-term prediction of the location and intensity of precipitation. MIT/LL has been successfully utilizing this patented tracking technique for convective weather at each of its' four ITWS field sites over the last 1-2 years. The field sites are located in New York (covering all three NY airports (LGA,EWR, JFK), Dallas Fort Worth, TX Memphis, TN and Orlando, FL. The initial work was sponsored by the FAA's Aviation Weather Research branch under the Convective Weather Product Development Team. Several private weather providers have also licensed the algorithm and/or software for inclusion in their own forecast systems. The storm tracking and forecast algorithm is a candidate for a pre-planned product improvement to ITWS. The ITWS deployment is scheduled to begin next year. More details on the algorithm and its' success can be found in the following references:

Forman, B.E., et al., 1999: Aviation User Needs for Convective Weather Forecasts. Preprints, 8th Conf. On Aviation, Range, and Aerospace Meteorology, Dallas, TX, pp 526-530.

Hallowell, et al., 1999: The Terminal Convective Weather Forecast Demonstration at the DFW International Airport, Preprints, 8th Conf. On Aviation, Range, and Aerospace Meteorology, Dallas, TX, pp 200-204.

Wolfson, M.M., et al., 1999: "The Growth and Decay Storm Tracker". Preprints, 8th Conference on Aviation, Range, and Aerospace Meteorology, Dallas, TX, pp 58-62.

Radar data taken from NEXRAD, TDWR or ASR-9 radars (or a combination of those radars in a mosaic) are filtered using an elliptically shaped match filter. The filtered data is then run through a cross-correlation tracker to extract the "envelope" (tracks a collection of storm cells as opposed to a single cell) motion of the precipitation system. The motion vectors are then used to advect the precipitation appropriately for up to 2 hours. In an organized storm system (cold fronts, stratiform (uniform) rain/snow) the forecast has been shown to be accurate to within 10km for predictions out to 1 hour. On average, for the 20 organized convective weather days examined (DFW), the 30 minute forecast accuracy was 80%, 60 minute accuracy was 60%.

While most of Lincoln's current testing has focused on convective weather events, the algorithm is designed to work in all types of precipitation. Most of our sites are outside the snow-belt (at least as defined by the last 2 years), but we believe that the generally organized nature of snow storms and snow squalls will be similar to thunderstorm squall tracking.

A3.2 Component II - Weather Condition Identification from Images/Video (WxCIIV)

System Overview

MIT Lincoln Laboratory has been a leader in the development of automated recognition algorithms for the DOD (aircraft, tanks, missiles, etc) and FAA (aircraft, weather hazards, data quality assessment, etc). Powerful image processing tools have been developed within the Laboratory which allow us to rapidly develop image processing algorithms for identifying specific types of targets or conditions.

There has been an explosion in the number and quality of live video images available to users of all types. Many of these cameras are situated at key intersections which allow State DOTs and others to assess traffic and road conditions during winter events. Most of this analysis is done via visual inspection of each of the many camera views available. Like radar data, video images can quickly become too voluminous to examine in real time.

MIT/LL would propose to create a system for examining video feeds in realtime and present users with a summary of important information extracted from each camera. For example, during snow storm events video images could be used to assess the following weather/traffic variables:

- Visibility
- Precipitation Type
- Precipitation Rate
- Traffic Speed
- Traffic Volume
- Accident Identification
- Road Surface Coverage

These variables could then be viewed on a 2-dimensional map with all the other standard weather sensors to give users an enhanced view of overall conditions.

MIT/LL is currently undertaking similar DARPA work in support of a battlefield weather surveillance program called WeatherWeb. While this program is only just beginning, many of the same state variables are desired for military operations.

A3.3 Component III - ITWS Situation Display as a model for displaying information to state DOT (Winter Weather Display Engine)

System Overview

MIT/LL has developed a weather display which was tailored for use by Air Traffic controllers. Controllers, like State DOTs, are not weather experts and therefore require the data to presented in a simple manner requiring little interpretation.

A3.4 Component III - Incorporation of FAA Sensors into Observing System

System Overview

MIT/LL would assist in the analysis of FAA sensors for State DOT needs. There are three primary sensors which would be of use to winter weather decision making are:

- TDWR - Terminal Doppler Weather Radar covering 45 major airports and over 40% of the US population. Although the range is limited, this radar provides better quality coverage than NEXRAD at most sites.

- ASR-9 (WSP) - Airport Surveillance Radar - Wind Shear Processor covers all moderately sized airports not covered by the TDWR. The beam pattern of this radar only allows for volumetric views of the weather, but it has an update rate of 30 seconds and can be used in conjunction with other radars to improve overall quality of the system.

- LLWAS - Low-level Wind Shear Alert System. A series of anemometers (usually 9-13 locations) which report the current winds every 10 seconds. This sensor may be useful in estimating blowing and drifting snow conditions.

A4. National Center for Atmospheric Research (NCAR)

The NCAR modules are shown in the following schematic:

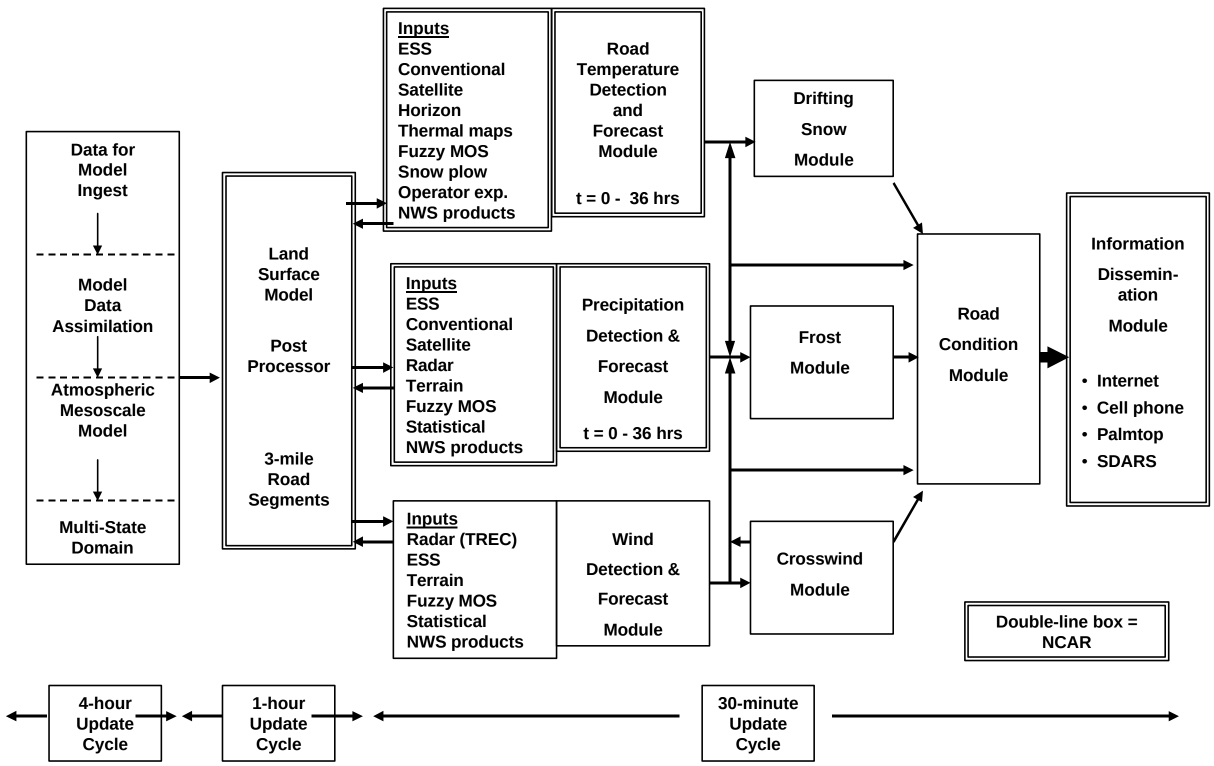

Figure A2: Road Condition DSS to Support Winter Maintenance (Functional Diagram)

A4.1 Land Surface Model Post Processor (LSM-PP)

System Overview: This sub-system is a component of a Weather Information for Surface Transportation Decision Support System (WIST-DSS) designed to provide road condition decision information for winter maintenance personnel. This component of the overall system functions between the mesoscale numerical model and the various detection and forecast subsystems (See attached functional diagram). The primary function of the LSM-PP is to focus more course numerical model output over a multi-state domain to individual 3-mile road segments along all interstates and secondary roads. This sub-system also serves as a translator from the atmospheric variables provided by the model to the temperature and moisture variables associated with the road surface.

The LSM-PP would allow a much higher update cycle thus the output for other modules downstream within the system would be refreshed frequently. The atmospheric model would run every four or six hours (depends on hardware resources and size of domain); however, the LSM-PP would run at hourly or half-hourly intervals (to be determined via experimentation to optimize system performance) and would take advantage of information received since the last run. Some of this information would include the 4-km NEXRAD precipitation accumulations, satellite depiction of solar insolation reaching the surface, and ESS reports.

The LSM-PP would explicitly solve physical equations at each of the individual points (3-mile spacing) along all of the primary and secondary roadways to derive road temperature, substrate temperatures, soil moisture, and water runoff. This is in contrast to traditional procedures using one-dimensional "road condition models" that are based on equations derived through regression and tuning techniques derived from empirical data.

Land Surface Models are being used as research and development or operational tools in very few facilities compared to the mesoscale numerical models that are proliferating. The basic LSM that is suggested for this DSS development is a product of Oregon State University. It has been modified and enhanced by F. Chen at the National Center for Atmospheric Research. The intellectual property from both sources is freely available without licensing requirements.

Functionally, the LSM-PP would be most efficient if co-located with the atmospheric mesoscale model. Both of these modules would be located at a single central site that would serve all of the decision makers within the multi-state area served.

A4.2 Road Temperature Detection & Forecasting Module (RT-DFM)

System Overview: This sub-system is a component of a Weather Information for Surface Transportation Decision Support System (WIST-DSS) designed to provide road condition decision information for winter maintenance personnel. This component of the overall system functions between the LSM-PP and the Road Condition Module (See attached functional diagram). The RT-DFM consists of several fuzzy logic-based algorithms designed to a) provide frequent updates of road temperature detection and forecasts (out to 36 hours from current time), b) incorporate all high-resolution, localized data that are either not available to the atmospheric mesoscale model or are available at a 30-min frequency or higher and therefore need more frequent servicing, and c) allow incorporation of human-derived information, analyses and forecasts (NWS products for example).

Information that would be assimilated in this module using fuzzy-logic mathematical functions would include but not be limited to LSM output, ESS data, conventional surface weather observations, satellite estimates of solar insolation reaching the roadway, satellite skin temperature observations, horizon data, thermal mapped data, fuzzy Model Output Statistics

(Fuzzy MOS), IR temperature data from snow plows, maintenance operator's observations, knowledge of local effects such as mountain drainage winds, and NWS analyses and forecasts. Weighting of these intelligence sources would be heavily toward the near-real-time observations for the first three hours of the forecast period but more toward the model-derived and NWS sources for the remaining hours of the forecast period.

Although this type of algorithm construction has been employed with good success in DSSs to support the aviation sector, there are no precedents for this development in the road weather community. The algorithm would be developed from scratch using general techniques that have worked well for other purposes.

The RT-DFM would be most efficient if co-located or incorporated with the system running the LSM-PP and the mesoscale model.

A4.3 Precipitation Detection & Forecasting Module (P-DFM)

System Overview: This sub-system is a component of a Weather Information for Surface Transportation Decision Support System (WIST-DSS) designed to provide road condition decision information for winter maintenance personnel. This component of the overall system functions between the LSM-PP and the Road Condition Module (See attached functional diagram). The P-DFM consists of several fuzzy logic-based algorithms designed to a) provide frequent updates of precipitation detection and forecasts (out to 36 hours from current time), b) incorporate all high-resolution, localized data that are either not available to the atmospheric mesoscale model or are available at a 30-min frequency or higher and therefore need more frequent servicing, and c) allow incorporation of human-derived information, analyses and forecasts (NWS products for example).

Information that would be assimilated in this module using fuzzy-logic mathematical functions would include but not be limited to LSM output, radar, ESS data, conventional surface weather observations, satellite data, fuzzy Model Output Statistics (Fuzzy MOS), maintenance operator's observations, knowledge of local effects such as orographic enhancement of precipitation, and NWS analyses and forecasts. Weighting of these intelligence sources would be heavily toward the near-real-time observations for the first three hours of the forecast period but more toward the model-derived and NWS sources for the remaining hours of the forecast period.

There is a host of previous work that would provide the foundation for this sub-system development. These include algorithms developed for the Weather Support for De-icing Decision Making system built by NCAR for the FAA, radar/rainfall studies, satellite/rainfall studies, and model/radar/rainfall studies conducted at many R&D facilities. The fuzzy-logic architecture could be derived in general from many other DSSs built for the aviation sector, but the specific architecture for this subsystem would be new.

The P-DFM would be most efficient if co-located or incorporated with the system running the LSM-PP and the mesoscale model.

A4.4 Information Dissemination Module (IDM)

This sub-system is a component of a Weather Information for Surface Transportation Decision Support System (WIST-DSS) designed to provide road condition decision information for winter maintenance personnel. The IDM functions as a dissemination interface to the remainder of the DSS. The IDM consists of a graphical database that contains road condition information for all primary and secondary roadways within the DSS geographical domain. The graphics include scales from the entire DSS domain down to individual road segments of 12-mile lengths. The IDM also includes a textual database for providing site-specific information for any 3-mile road segment within the DSS domain.

Four dissemination modes to decision makers are serviced by the IDM - direct internet access from a user's computer (fixed or mobile), mobile cell phone access, mobile palm computer access, and in-vehicle access via SDARS technology. All four of these modes have been demonstrated in either R&D or operational environments.

Direct internet access is the primary means of disseminating information from DSSs. The IDM server complex provides direct transmission of graphic or text data to each maintenance decision maker. The user's profile is maintained within the IDM, which allows prioritization of products and dynamic alerting functionality. The user can convert this fixed-facility functionality to a mobile function by utilizing a cell phone, cell modem and laptop computer in the field vehicle.

Direct access by cell phone is also a function of the IDM. This type of access is well established within the ITS community. The ATWIS program at the University of North Dakota (Meridian) is a good example.

Direct access by palm computer connected to a wireless service is supported by the IDM. The palm computer is loaded with software that is an extension of the IDM that allows direct connection to the servers via the internet to download critical decision-making information in either graphical or text format. Graphical information is limited to the performance characteristics of the palm device used.

The IDM services data streams to both of the U.S. satellite digital audio radio system (SDARS) providers - XM Radio and Sirius Radio - and to ORBCOMM Global, LP and INMARSAT. These four providers service most of the in-vehicle satellite systems available to car, truck and marine manufacturers. Transmission of weather graphics at bandwidths up to 64 kbs using the SDARS technology is well established within the aviation community.

A5. NOAA's National Severe Storms Laboratory (NSSL)

A5.1 Warning Decision Support System Integrated Information (WDSS-II)

Acronyms: Storm Research and Applications Division (SRAD). National Severe Storms Laboratory (NSSL). Geographical Information System (GIS). National Weather Service (NWS).

WDSS-II is a testing and development platform for NSSL's severe weather detection and prediction applications and also serves to test and field innovative algorithm and display concepts.

WDSS-II, currently under development by SRAD at NSSL, is a completely redesigned system primarily focussed on integrating many data sources (including multiple WSR-88Ds). WDSS-II has been developed primarily to support NWS meteorologists, but can, with appropriate training, be easily interpreted by non-meteorologists. WDSS-II helps organize and display critical weather information that can be used for generating warnings and short-term forecasts. These WDSS-II goals are accomplished by using a newly designed display that is linked to a GIS through a relational database foundation. This GIS base allows a tight integration of weather and relevant geographic information, such as streets, terrain, major landmarks, streams, and drainage basins. Other geographical information can be included, tailored to particular user needs. This GIS linkage allows the user to visually integrate meteorological and critical non-meteorological information to aid in making weather-sensitive decisions. The relational database will not only organize the input and output data and improve performance speed, but will also allow the storage of algorithm- and user-created information that can be recalled easily at a later time.

A5.2 Polarimetric Radar Precipitation Estimation and Hydrometeor Types

Algorithms are currently being developed to use polarimetric radar measurements to 1) improve precipitation accumulation estimates, and 2) identify dominant hydrometeor types.

Since conventional radars measure only a single variable (power return), determination of precipitation type can be quite ambiguous. Polarimetric radars, on the other hand, measure a large number of variables, each of which is dependent on precipitation size, shape, and ice density in its own way. In addition to improved precipitation accumulation estimates, the variables can be combined to better discriminate between precipitation types in winter storms. For example, conventional radars will frequently see only a gradual change in power return across a rain/snow transition line, making it difficult to determine exactly where the transition from rain to snow occurs. However, by combining the power return with polarimetric radar measurements of differential reflectivity (ZDR) and correlation coefficient (rhv), the location of this transition becomes more clear. For example, along with the gradual change in power return through the transition region, we would also see a peak in the ZDR (due to the presence of large, spheroidal drops) just prior to the transition, and a large dip in rhv (due to a large spread in the distribution of hydrometeor sizes and types) before the onset of snow. Techniques are also being developed to use weighting functions to automatically combine the polarimetric variables into an estimate of the most likely precipitation type. Though most algorithm tests so far have been on warm season convective storms, the algorithm has demonstrated great skill at discriminating between regions or large drops, light rain, moderate rain, heavy rain, snow, graupel, hail, and rain/hail mixtures. In the future, this algorithm will be upgraded and tested on winter storms.

A5.3 Quantitative Precipitation Estimation and Segregation Using Multiple Sensors (QPE SUMS).

Project partners: Salt River Project, National Oceanic and Atmospheric Administration.

QPE SUMS is a multi-sensor proof of concept technique that utilizes satellite data as well as radar data for quantitative precipitation estimation. QPE SUMS removes echo suspected to be from ground clutter and anomalous propagation. It also mosaics reflectivity from several radars. The algorithm classifies precipitation type (convective, stratiform, liquid, frozen) and utilizes data from remote sensors and in-situ sources to estimate precipitation rates. QPE SUMS is also maximizes amount of low-level radar coverage. QPE SUMS has been primarily tested in the intermountain West, and testing and calibration is needed in other regions. However, correlation between rainfall (snowfall) rates and cloud top temperatures are not always strong. With these limitations in mind, QPE SUMS provides more accurate estimates where radar is sampling in/above bright band and mitigates range biases, which facilitates further calibration by gauges.

A5.4 Precipitation-Type Algorithms

Precipitation-type algorithms are computer programs that evaluate numerical model data, or upper-air observations, to determine the most likely type of precipitation (e.g. snow, rain, freezing precipitation, or frozen precipitation) at a particular location. Although these algorithms are time independent, they have predictive value if used with numerical model data. When used with radar reflectivity data, these algorithms provide an estimate of the precipitation types within areas of precipitation.

NSSL will provide a set of five algorithms to be used with numerical model output and/or upper-air data. These algorithms are currently being evaluated by meteorologists at the National Severe Storms Laboratory and National Weather Service forecasters at the Storm Prediction Center and the Hydrometeorological Prediction Center. Currently, researchers at NSSL are examining the use of these algorithms to create probabilistic forecasts based upon the output from each individual algorithm. These probabilistic forecasts indicate the level of uncertainty within a particular forecast by computing the probability of a particular type of precipitation. The algorithm ensemble output can also be used to identify the most probable type of precipitation at locations within the domain defined by the input data.

A5.5 The Areal Mean Basin Estimated Rainfall (AMBER) Program

A Tool to Assist in Flash Flood Forecasting. Participants: Cooperative Institute for Mesoscale Meteorological Studies CIMMS) National Severe Storms Laboratory (NSSL), Western Intermountain Storms and Hydrometeorology (WISH) Team.

The AMBER Program is, by appearances, a large “book keeping” program to keep track of the precipitation falling in multiple basins. Input consists of precipitation estimates from the Weather Surveillance Radar - 1988 Doppler (WSR-88D). AMBER provides valuable, up-to-date information to users for many drainage basins over various time intervals. AMBER monitors precipitation accumulation and rate on the basin level and alerts the user to potential flash flooding. Output is the average basin rainfall (ABR) rates and accumulations. AMBER was originally developed by Bob Davis (Pittsburgh NWSFO) and Paul Jendrowski (Honolulu NWSFO) over the past 15 years. AMBER was first operational in May 1985 at Pittsburgh. Originally, AMBER used 10-mi^2 basins delineated manually from a fishing stream map of Pennsylvania and no ABR computation was made – AMBER simply overlaid comparisons between WSR-57 rainfall estimates and rain gauges. Eventually ABR computations were added, but all output was text-based. It was discovered that smaller basins were needed to be able to accurately forecast flash floods. Hence, 3-mi^2 basins were manually delineated from 7.5 minute topographic maps. WSR-88D rainfall estimates were then mapped to the new basins. AMBER became operational with 3-mi^2 basins in May 1996 at Pittsburgh. AMBER became operational with 1-mi^2 basins in urban areas in May 1999. In the future, The NWS plans to include an AMBER-like functionality as part of the Flash Flood Monitoring and Prediction (FFMP) program to be implemented in the Advanced Weather Interactive Processing System (AWIPS). An initial version will be operational by Summer 2001. Updates and modifications will continue after that date. NSSL has been tasked with delineating basins (2-mi^2 minimum basin threshold) and preparing FFMP data sets for every NWSFO in the country. Thus, the data needed for transportation management will also be available. This will be an initial effort to make the FFMP operational for everyone as quickly as possible.