Surface Transportation Weather
Decision Support
Requirements

Draft Version 2.0

Preliminary Interface Requirements

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

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for

Paul Pisano, Coordinator
Road Weather Management Program
Office of Transportation Operations
Federal Highway Administration

by
Mitretek Systems, Inc.

Contacts

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

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

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

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1. STWDSR Preliminary Interface Requirements

1.1 Purpose

This Preliminary Interface Requirements (PIR) is a draft document for the Surface Transportation Weather Decision Support Requirements (STWDSR) project. The STWDSR project is being conducted by Mitretek Systems, Inc., for the Federal Highway Administration (FHWA) Office of Transportation Operations (HOTO) Road Weather Management Program. The PIR complements the STWDSR Operational Concept Description (OCD) document, and both documents together constitute the STWDSR version 2.0 (V2.0) deliverable. The PIR defines requirements on the external information sources for the winter road maintenance decision support functions described in the OCD.

1.2 Background

The full background to this document can be found in the FHWA Weather Team White Paper[1], the STWDSR V1.0 document[2], and the V2.0 OCD[3]. An abbreviated background and relation between the OCD and PIR is given here.

The FHWA Weather Team was formed in 1997 to coordinate several FHWA weather-related activities. The Weather Team was closely associated with the rural Intelligent Transportation System (ITS) program and focused on the information and management-decision aspects of surface transportation with respect to weather threats. The Weather Team White Paper of 1998 was based on a stakeholder meeting that identified actions aimed at improving surface transportation with respect to weather threats and through the ITS. The Road Weather Management Program, formerly the Weather and Winter Mobility Program, was created as the organizational center of FHWA weather interests when the FHWA reorganized in 1999. The

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

[2] Surface Transportation Weather Decision Support Requirements, Draft Version 1.0, Mitretek Systems, Inc., January 24, 2000. Available as document 12144 (executive summary is document 11823) at www.its.dot.gov/welcome.htm

[3] Surface Transportation Weather Decision Support Requirements, Operational Concept Description, Draft Version 2.0, Mitretek Systems, Inc., January 24, 2000. Available as document 13134 at www.its.dot.gov/welcome.htm

Program is now carrying out several of the White Paper recommendations, and coordinating with other agencies on requirements for surface transportation weather information.

The Road Weather Management Program launched the STWDSR project in 1999 to define requirements for weather information to meet highway system performance goals. The STWDSR focuses on decisions that are made regarding highway resources to accomplish the goals. The decisions rarely depend only on weather information. However, the production and use of information on environmental conditions, defined as weather and the road conditions related to weather, requires additional attention in the framework of the ITS. The two primary objectives of the STWDSR project are:

- To provide requirements at a high level, that can be allocated to lower levels within a spiral evolutionary process, on a Weather Information for Surface Transportation Decision Support System (WIST-DSS).

- 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.

The OCD emphasizes the operational decisions to be supported, and it strictly addresses the first STWDSR objective. The STWDSR V1.0 document contains a list of all types of decisions that relate to weather threats and surface transportation. The OCD and the PIR select winter road maintenance as the first set of decisions for analysis.

Environmental information, including weather, is just part of the unorganized information resource for decision support. The PIR emphasizes the environmental information required for the OCD functions. The PIR objectives cut across both STWDSR objectives, and can be stated as:

- To define the interfaces of the WIST-DSS functions (in the OCD) to types of external information, at a high level appropriate to the OCD, in a way that can be allocated to lower level functions when they are further defined or actually built.

- To identify requirements for improvements in the quality of the external information resources for the WIST-DSS.

The first PIR objective is accomplished by a hierarchical taxonomy of information types. The second objective requires a programmatic broadening beyond the FHWA's interest in support to transportation decisions that directly affect transportation performance. The WIST-DSS internal requirements in the OCD and the interface requirements in the PIR serve the operational practice of winter road maintenance managers, and improve highway system performance through an evolution of the existing Road Weather Information System (RWIS). The FHWA is not a highway operator nor RWIS customer, but the FHWA has a stake in the system described in the

OCD because it promotes best practices, and forges links to the public and non-profit research community to complement WIST-DSS development by private sector vendors. The FHWA works with public and private partners who are transportation operators and who will be WIST-DSS users.

The objective of better environmental information goes beyond the WIST-DSS interface to a mix of public sector (e.g., National Weather Service (NWS)), and private sector (e.g., RWIS) providers of weather and weather-related information. Environmental information is common to many user communities, so beyond the interface are issues removed from transportation, even though weather information has application to road-condition information.

Inter-federal coordination issues that include weather are being addressed via the Office of the Federal Coordinator for Meteorology (OFCM). The OFCM has organized the Joint Action Group for Weather Information for Surface Transportation (JAG-WIST) that is addressing weather information requirements across all surface modes. The FHWA has an important role in the JAG-WIST, and also in the Committee on Integrated Observing Systems (CIOS). The CIOS is expected to be the forum in which the fusion of all environmental observational data is addressed. The FHWA serves on OFCM committees as the federal representative of state and local highway operating constituencies.

The public sector coordination is not intended to displace or minimize the role of the private sector in environmental information, or in deployment of decision support. The private sector is included in OFCM activities, and in the stakeholder group for the STWDSR project. As a public agency, the FHWA is interested in the national weather services (to include those of other countries, and weather services operated under the military or other federal agencies) as an essential infrastructure to any value added by the private sector. The PIR attempts to make it clear that there are more synergies than contention between the public and private sectors.

The PIR looks at *all* types of information needed by the WIST-DSS. These generally fall into the categories of environmental (weather and road condition), transportation, and treatment resource. The latter two types are (or will be) included in the ITS. Weather information is external to the ITS, although Environmental Sensor Station (ESS[4]) information on road conditions is mostly processed within the ITS. The PIR covers all relevant information flows in the ITS and from the ESS. The unique aspects of environmental information, that include combining weather and road-condition information, are also a focus of the PIR.

The PIR has a difficult task once it moves beyond specifying the *types* of information needed by

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[4] Consistent with the ITS terminology, ESS will be identified with fixed and mobile road condition sensing equipment. The ESS typically measure near-surface atmospheric conditions as well, overlapping with weather observational equipment. The ESS have been referred to as RWIS sensors. Here, RWIS is reserved for the entire road/weather information system.

the WIST-DSS to the *quality and sources* of that information. The quality and sources require looking at environmental information processing as a separate system, but one tied to transportation performance through specific decision support functions. The OCD argues that decision support is a missing link between better highway performance and the wealth of existing weather and road-condition information. Better information about the environment *can* improve decision effectiveness and efficiency *if* it is properly related to decisions and the human capacity to comprehend information. There are few, if any, adequate evaluations of the effects of an increment of environmental information (as opposed to better decision support using a baseline of information) on transportation performance. With respect to the WIST-DSS, the value of an increment in environmental information would have to be proved through a decision support system that does not yet exist, but that is part of the evolutionary cycle of the WIST-DSS. Therefore, the PIR *does not quantify* requirements on environmental information resources. However, there are some important qualitative and structural issues to be identified, mostly stemming from the open systems concept discussed in both the OCD and PIR.

1.3 Basic Structural Concept

The OCD treats the WIST-DSS as an evolutionary improvement on the current RWIS. The RWIS includes the ESS and value added meteorological services (VAMS) that tailor weather information into road-surface and driving-condition prediction. By being much closer to road decisions than general weather information, the RWIS has been viewed as a decision support system. However, the OCD identifies two primary deficiencies of the RWIS: It is not an open system, and the information mostly characterizes the road environment rather than evaluating options for treatment decisions. The open system concept is shown in figure 1.3. 1.

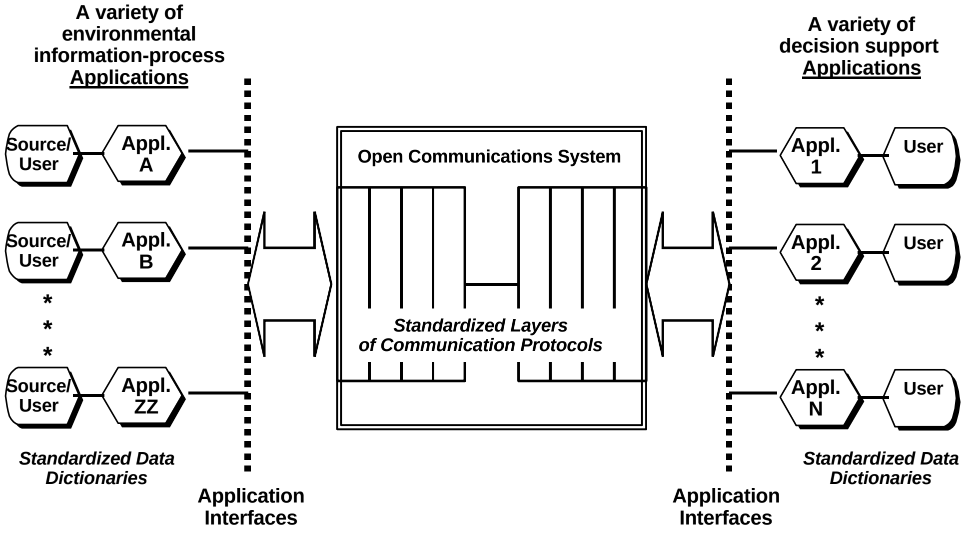

Figure 1.3.1: Basic Structure for the Information System

From the OCD perspective, an open system is needed to allow access to all relevant information by the DSS. The PIR comes to the conclusion that failing to be an open system is the most obvious structural deficiency in the environmental information system itself, and needs correcting to enable improvements in information quality.

The basic assumption is made that the DSS involves computer-to-computer data communications. An open system is one whose computer-to-computer communications are modularly structured in layers, and between each layer there is a published (also called non-proprietary) protocol for transacting information.

The “open communications system” as shown in figure 1.3.1 is just part of the end-to-end communication between users, and generally is provided as a utility for many communications purposes. The TCP/IP protocol of the Internet, and including various physical means of communications (telephone, terrestrial wireless, satellite wireless, etc.) is an example. The concern of the DSS is extended to users via their interfaces to computer applications. For instance, a user might be using a radio receiver, cell phone, pager, fax or computer terminal to access information coming from an application on a (possibly remote) host computer. An Internet browser is an application. The WIST-DSS and all the functions described by the OCD is an application. The open communications system, as a utility, stops at interfaces to applications. The open communications system transacts information only as directed groups of signals. Only at the application does information take on functional meaning for manipulation in the application processes. DSS applications process meaningful instances of data objects (such as numbers used in an arithmetic process or words in text) to be conveyed to a human user. The computer-human interface (CHI) is included in WIST-DSS interfaces and in the extended end-to-end open system concept. Direct human-to-human communications (e.g., directly via telephone or voice radio) are not included in the WIST-DSS interface nor the open system concept.

The purpose of an open communications system is to facilitate the exchange of information between any applications. The extended concept includes the uniformity of the data objects processed by the applications, and in the CHI.   From the viewpoint of any single application, an open system creates an “information infrastructure”, much like the transportation infrastructure, that can be used at will as long as the rules of use are known, and a fare is paid when that applies. It is not necessary that a single open standard be used, but an application has to know each standard to access and fuse information. There certainly is no necessity for applications to be the same, nor for their human or device interfaces to be the same, because that is where the purpose-specific tailoring occurs. There are, however, good reasons to standardize some CHI elements so that similar information is similarly presented. That includes how the application is manipulated (e.g., standardized keyboards, mouses and GUIs) as well as standardized symbology for environmental conditions.

An open system does not impinge on proprietary rights over information. The layering concept of open systems insures that better processes can be licensed and fit into an existing system, subject only to the inter-process protocols. Open-source processes are not requisite for open systems. Proprietary rights concerning the use of the information at the application ends can be protected by encryption and passwords, to restrict who has access or to charge for access. These issues are being addressed for the Internet and other open systems. The Internet is a good example of how open systems facilitate permitted access and thereby increase the potential market for priced access (e.g., e-commerce). Open systems are not a threat to private sector activities, but like the transportation infrastructure promote the market for private sector activities.

The OCD contrasts *stovepiped* to open systems. Stovepiping represents the inability to decompose the parts of the communications channel, so that there is an inseparable application-to-application bundle of processes, that acts like a pipe from an automated source, like an ESS to CHI, or from CHI-to-CHI. At the CHI the information cannot be further processed by any automated application. Stovepiping means multiple CHIs if multiple information sources are needed. Multiple CHIs require that a decision maker look or listen to multiple sources. This is the “swivel chain integration” that the OCD identifies as a barrier to better decision support. No RWIS source currently provides all information needed for winter road maintenance, let alone the whole set of transportation decisions.

A DSS uses an open system to have multiple information sources feed a single application. Figure 1.3.1 shows multiple decision support applications (one for each type of decision maker) on the right, and multiple environmental information processes on the left. But the PIR takes a broader view than the OCD and decision support systems. In that case, there really is no distinction between information-source applications (that produce data object types) and decision-support applications. <u>An open system should cross-connect environmental information applications as well as to DSS applications</u>. This is how better environmental information processes can be freely inserted for use by any DSS application.

The PIR can now address the full implications of the open system structure for systems outside the WIST-DSS by starting with four axioms:

1. There is only one physical environment, that supplies (some of the) interface information for the WIST-DSS.

2. There are many decision makers and many kinds of applications using the environmental

information.

3. Converting the physical environment to information serving many decision makers requires many applications that interact with the environment, and with each other.

4. Environmental information processes and decision support processes are both applications with a need to cross-connect to each other.

The first two axioms and the fourth are obvious. The third is made clearer below in Section 3. The implications of the axioms are:

- Open systems benefit both users of DSS applications, in accessing environmental information, and environmental information processors, who are really both users and suppliers of information.

- If tailoring is defined as the customizing of information for specific applications, it occurs at *every* application.

- A stovepiped system defines tailoring over a thread of application processes and communications because they are all bundled together. An open system allows selection among many possible threads, and if tailoring is at every application it is not inherent in the information system beyond the application.

- Although there is one physical environment, application tailoring means that there is no unique representation of it in the open information system. An open system represents a market, or evolutionary system that is continually adapting to provide better representations of the environment (or other sources of information) according to changes in user needs, environmental constraints and technological capabilities.

Adaptive evolution is assured by free interaction of all applications in an open system. This is the real meaning of an environmental information infrastructure.

Since the WIST-DSS interfaces through the ITS, the architecture and standards of the ITS are relied on to promote an open system. The ITS depends mostly on other open communications systems. But the ITS is concerned with the extended, application-to-application, system and so it extends protocol standards to data dictionaries and message sets[5]. This reflects the user-specific tailoring in the applications versus the greater generality of computer-to-computer

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[5] To be precise, the message set standards usually also contain parts of the communications protocols, by including message addressing in headers, as well as syntax that contributes to extracting the meaning from the information. The data dictionaries concern data objects that generally are relevant to applications but not the communications protocols.

communications. The ITS generally does not cover CHI issues of concern to the WIST-DSS, including display symbology. However, display symbology is closely allied to FHWA concerns that result in the Manual of Uniform Traffic Control Devices (MUTCD), and other human factors research.

1.4 Public and Private Responsibilities

The STWDSR project is often asked to address the allocation of responsibilities between public and private sectors in providing either the DSS or environmental information applications. Neither the project nor the FHWA has any policy or prejudice on this matter. However, it is assumed that DSS applications will be supplied by private vendors, generically called the VAMS. Public agencies do not build such systems, but they may be users, and like the FHWA may be involved in their specification and development. For environmental information applications, the situation is more mixed. The RWIS is mostly private, the NWS is public. Both types of sources are still largely stovepiped. The National ITS Architecture generally specifies environmental information as coming from the Roadway Environment terminator (and via the ESS data objects) and from the Weather Service(s) terminator. The ESS is currently privately supplied, and Weather Services does not specify between VAMS, the NWS or other possible providers of the information.

The public-private contention has centered around limiting the role of the NWS authorized in its legislative charter for "...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."[6] By historical definition, "commerce" includes surface transportation. Service to "navigation", historically limited to maritime transport, has certainly resulted in maritime *and* aviation services of the NWS. The limits of the NWS role are *not* modal. Meteorology involves a land-air interaction as much as a ocean-air interaction, so the principle that the NWS can serve aviation because it is in the air but not commerce on the ground is weak.

In the STWDSR project, the interest is not in defining the role of the NWS *vis a vis* the VAMS, but only to ensure that there are no *artificial* restrictions on providing better environmental information. The existence of the NWS is, much like the existence of public highway agencies, based on the idea of an environmental information infrastructure. However, the open systems concept supercedes the idea of publicly-owned and produced information. Open systems facilitate openly available information even if it is not publicly owned. It is really scale economies and public benefit (that cannot be captured in prices) that justify a national public agency like the NWS. This weighs in favor of some public functions, as enumerated in more detail in the STWDSR V1.0 document. An open system facilitates private endeavors in some

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[6] 15 USC Sec. 313 as of 1/26/98.

niches, especially in DSS applications.

It has been argued that the limits of the NWS role are defined by "tailoring", meaning that characterizing the environment is permissible, but not for specific users of the information. This argument is refuted by the open system perspective, where tailoring has no meaning outside of individual applications, and all uses of environmental information are applications. The argument of tailoring does not bear on the kinds of environmental information under NWS jurisdiction. The private sector *does* provide most applications, whether to the public or the NWS. The private sector *should* provide the decision support applications that serve the multiplicity of decisions that use environmental information, and rarely environmental information exclusively. That is the firmer demarcation of responsibility.

By using stovepiped systems, a provider can claim that a whole service (e.g., RWIS) is "tailored". By promoting open systems, the OCD and the PIR reject this approach and argument. Perhaps its most specific manifestation is in the ESS and its extension into RWIS. ESS are purchased by public agencies. Sharing of the ESS information is inhibited both by contractual agreement and the stovepiping of the ESS information system. VAMS protect access to the information, because the observations are also the basis of their value-added road condition prediction services. The open system approach is clear: Although a single vendor may gain competitive advantage by guarding a subset of environmental observations, it is not possible to have a good RWIS when restricted to that set. All RWIS vendors, and the NWS will gain from *open-system* (not necessaily "free") access to ESS and other information. All VAMS will gain from open-system access to NWS information. The market for environmental information will grow when RWIS improves and all users have open-system access to products.

The tailoring argument is sometimes strengthened to reserve for the private sector what it *can* do. If we are unwilling to deny the NWS all weather processing applications, then the NWS still has a role in further improvements, some of which are on behalf of surface transportation and the VAMS processes for the RWIS.

The demarcation of responsibility now is mostly traditional, and altered occasionally by legislative mandate, such as service to aviation. Technology and demand is stressing the functional demarcations, which is exactly what should happen in an evolutionary, open system. As the capability to model atmospheric, oceanic and terrestrial interactions for weather improves, it is harder to separate the atmosphere as belonging only to weather, and vice versa. It is one physical environment. As the scale of meteorological information gets finer, there needs to be coordination of sub-national prediction domains, and management of the observation pool to support the finer scale. The issues become national in scale even though the information is local. The NWS is also moving toward better decision support in weather analysis, so there is the issue of scale economies in sharing graphical and other products used within the NWS to external applications.

It is only when the environmental information is applied to the dozens of decision maker types, and hundreds of decisions, in surface transportation (as identified in the STWDSR V1.0 document) that we return to specialized niches. The clearest role for the private sector is in the decision support applications, beyond pure environmental information.

The DSS that the NWS uses (e.g., the Advanced Weather Interactive Processing System, AWIPS) should have collaborative interfaces with other DSS. The NWS and private vendors should be fully open to each other in providing appropriate parts of the environmental information system. It is the appropriateness that always has to be decided, by the Congress and NWS policy in terms of the NWS responsibilities.

The FHWA has no policy on what parts of road condition or meteorological information should be produced by public versus private agencies. The Road Weather Management Program is and will be funding research to develop processing and decision support applications where the common benefits and excessive risk to private vendors justify that. The Program will work cooperatively with the public and private sectors in the development and organization of environmental information and decision support services. The Program will advocate those approaches that best serve the public in transportation system performance.

1.5 Approach

The OCD followed a formal system engineering data item description (DID) format, according to IEEE/EIA std. 12207 for software life cycle processes, or the earlier MIL-STD-498. As a system is specified into software and hardware implementation modules, the interfaces to the modules are described by a DID called the Interface Requirements Specification (IRS). An IRS is premature for a system specified only at the high level of the OCD, so the PIR is not an IRS, but is more a needs analysis for the external information sources. The OCD and the PIR are coequal offshoots of the STWDSR V1.0 needs analysis, and both were originally drafted in parallel. The objectives of both the OCD and the PIR are approached by the following steps:

1. Definition of user needs. The OCD defines needs as the sets of operational decisions. These were documented from users in STWDSR stakeholder meetings, and earlier surveys.

2. Allocation, at a high level, of functions to the WIST-DSS. This is done in the OCD.

3. Identification of general information types needed by each decision. This was done as part of the data collection, for both the OCD and PIR, from STWDSR stakeholders.

4. Consideration of available information sources, as generally defined by the ITS data flows, the ESS standard data objects, and NWS products. These were preliminarily identified in the STWDSR V1.0 document and are refined in the PIR.

5. Development of a hierarchical information resources taxonomy matched to the

functional requirements of the OCD. This is shown in the PIR.

6. Completing a traceability matrix from the needs to the information taxonomy. A partial matrix is included in the PIR as Appendix 2 and the full matrix is appended by reference.

7. Identification of issues about the structuring and quality of the information resources. This is done in the PIR, by general consideration of the relation of weather and road-condition information.

The hierarchical taxonomy of step 5 is the start of, but short of, a formal data dictionary for the WIST-DSS. A large part of the taxonomy was defined from ESS data objects. The National ITS Architecture and its standards, including data dictionaries and message sets, are essential to the open-systems infrastructure and the WIST-DSS application. All standards applicable to the WIST-DSS interfaces will be defined by the ITS. This PIR is not a standard. Because of the relatively late consideration of weather information in the ITS, the existing standards are not necessarily definitive for the WIST-DSS. The ESS draft standard is to be revised and published in 2003, and similarly for a Weather Report Message Set[7]. Issues relevant to the CHI, including graphical symbology, have yet to be addressed. A Maintenance & Construction Operations user service is currently being drafted, and will be the first formal inclusion of maintenance operations in the National ITS Architecture.

The information taxonomy is traceable to needs (step 6), defined as decisions. This PIR is concerned solely with the operational-scale decisions for winter road maintenance. The traceability matrix, that lists information needed against decisions, is large. The STWDSR V1.0 lists 426 individual decision types in surface transportation across 44 decision-maker categories and three scale categories. The scale categories are planning, operational and warning, corresponding roughly to climatic, synoptic/meso and micro scale in meteorology. The operational-scale winter road maintenance decisions started as a list of 10 decision types in the STWDSR V1.0. Through STWDSR research with users, as reflected in the OCD, that list grew to 53 types. The PIR contains 212 information types at the lowest level of the hierarchy for the 53 decisions. The types generally include environmental, transportation network and treatment resource categories. The traceability matrix consists of the 53 decisions against subsets of the 212 information types. An original and smaller set of types was expanded based on the matrix. Future STWDSR work will extend this analysis to other decision types.

The drafted ESS data objects[8] are used in the taxonomy and should aid eventual standardization of the taxonomy. Other weather data objects should conform to NWS standards. The taxonomy

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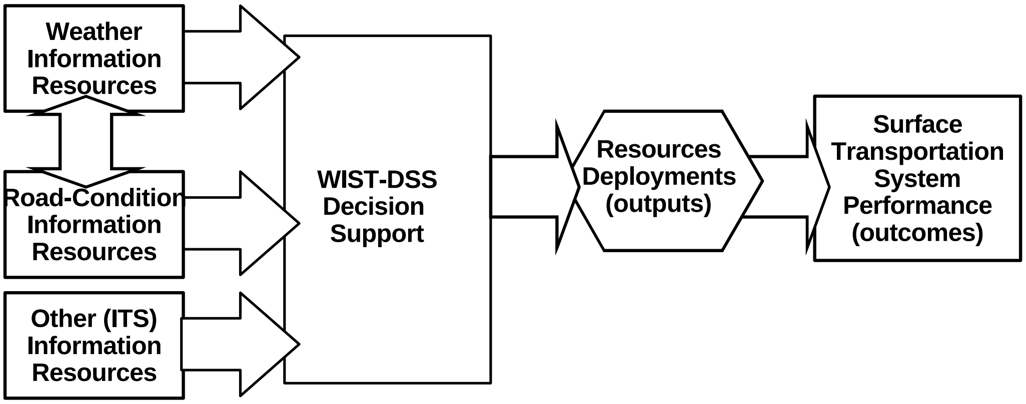
[7] Environmental Sensor Stations Working Group, Strategic Plan for 2001+. July 5, 2000.

[8] NTCIP Object Definitions for Environmental Sensor Stations (ESS). Joint AASHTO/ITE/NEMA Standards Publication TS 3.7-1998. Draft version 98.01.12, September 28, 1998.

generally stays at a level of weather information above items specifically formatted in NWS protocols. Reference to the NWS products implies use of their standardized formats. Because of the stovepiping of many RWIS products, there may be tailored weather products for which there are no standards as yet. These products may be incorporated into ITS data dictionary and message standards (especially for traffic management and traveler information).

It is expected that the STWDSR documents will contribute to the Maintenance & Construction Operations ITS user service and to other user services concerned with environmental information. Existing DSS, especially the FORETELL operational test, are already contributing to data dictionary and message set[9] standards concerned with weather and road-condition information.



Step 7, the identification of structural and quality requirements for the information sources, is a complex task. The second objective of the STWDSR project, and of the PIR, is to say something useful about how suppliers of information can better serve surface transportation users through decision support systems. There is a long analytical chain in doing this, summarized in the diagram below:

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[9] The term “information element” or just “information” will be used here to encompass data objects and messages specified in message sets. Data objects, data elements, data flows and other terms refer to discrete information objects as defined in a data dictionary. Message sets combine data elements with specified syntax and grammar, and “message sets” will be used specifically for that class of object.

Figure 1.5.1: The Chain from Information to Outcomes

Figure 1.5.1 emphasizes the difference between environmental information and decision support. Section 2 of the PIR will define the interface between the two more precisely. The argument of the OCD is that better environment information is neither necessary nor sufficient for better transportation performance, because decision support is a bottleneck, and the steady advances in weather information have not been well exploited. A test is needed of how a decision support application as described in the OCD will improve transportation performance. That is the baseline against which improvements in the environmental information can be judged. The three-year FORETELL evaluation is a start in that program.

The FHWA has established strategic goals corresponding to the transportation system performance measures. These are mobility, safety, productivity, human and natural environment, and national security. Weather threats and their treatment are just one factor that affects these. The Government Performance and Results Act (GPRA) that guides FHWA program performance emphasizes the difference between goals, as the ultimate outcome measures and outputs, like treatment resource deployment, that are the direct results of decision support. The analytical problem is to identify an outcome improvement in the transportation system and then allocate it back to a particular environmental information improvement. The challenges are that:

- There are many factors in transportation system performance beside the thread of environmental information-decision-treatment that is the focus here.

- Factors like annual climatic variations, that there is no control over, affect the outcomes apart from how the decision and treatment chain is altered.

- The allocation of an improvement to better operational practice, decision support, or environmental information may be difficult.

- Decision support is inherently a mixing (fusion) of information, and this makes it difficult to trace performance back to individual sources.

- Much environmental information is provided in common for many decisions, and there is no necessary economic or technical relation between the quality of information and transportation performance, or vice versa.

These challenges mean that most of the literature analyzes just a part of the chain, and short of ultimate outcomes. The most feasible approach is to measure surrogates for the outcomes against operational practices, and try to infer back from there to the decision support and environmental information. Road condition level of service (LOS) is directly affected by treatment and directly affects most of the outcome goals. Most LOS measures, used as the goals of winter road maintenance managers, are in terms of lane clearance and resource commitment (e.g., full time versus part time treatment). However, this can be quantified by road friction or traffic flow measures. A good surrogate for decision support performance is greater cost efficiency for a given LOS restoration. Reduction of chemical/grit deposition to achieve a given LOS can be added as a good surrogate for environmental impacts of treatment.

An application of the feasible approach has been documentation of LOS improvements and chemical use reduction by pretreatment of icing[10]. This in turn has been a large part of the motivation for RWIS and ESS deployment. It is tempting to conclude from this that at least more, and more accurate, ESS observations can improve the transportation performance. However, as Section 3 will make clear, the multiple threads of environmental information processing do not support this as a necessary conclusion. It is not yet clear what the most cost effective means of road-condition prediction is, nor what the performance impact would be of a given level of effectiveness. Absent this information, it is not possible yet to define an efficient or desirable quality of environmental information. There may be bottlenecks in the environmental information processing that have not been identified, because the best network of information processing has not been identified. The FHWA is awarding, in late 2000, a set of research grants for NWS, university and state DOT partnerships to investigate road condition prediction techniques, under the NWS/National Science Foundation (NSF) COMET program. This should help to address some of the unknowns.

Surface transportation is a sub-market for all environmental information, and technical progress in environmental information is not necessarily driven by that, or any market. So as a matter of policy impact, it is questionable how a close analysis of transportation impact will affect programs on environmental information quality. The impact will be much stronger on decision support, that is inherently tailored for the specific set of operational decisions. For RWIS information, that attempts to respond to the transportation market, the question is: “Why does the market need to be augmented at all?”. The answer of the OCD is not qualitative, but structural: RWIS is mainly stovepiped information sources lacking the decision support functions described by the OCD. That does not specifically impugn the individual information sources, whether

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[10] Ketcham, Stephen A. et. al., Test and Evaluation Project No. 28: Anti-Icing Technology, Field Evaluation Report, FHWA-RD-97-132, Office of Engineering R&D, FHWA, March, 1998.

public or private.

There may be other defects in how well the RWIS market responds to users needs, besides the lack of an open system. Because the market concerning winter road maintenance involves public agencies with public funds, the purchasers of RWIS services still need to be convinced of its transportation benefits in order to create the market for better RWIS. But this gets back to the problem of analysis in the long causal chain from information to, for instance, crash prevention. This is the bootstrapping effort alluded to in the spiral evolutionary process of the WIST-DSS. The sponsorship by the Road Weather Management Program and the ITS Program of a 3-year evaluation of the FORETELL operational test, the first such longitudinal study on maintenance and traveler decision support that includes outputs and outcomes, is an important part of demonstrating decision support benefits. This is how public involvement can stimulate the private market.

Given the problems with quantifying information requirements, there are still approaches to leverage the common investments in environmental information on behalf of surface transportation applications, and to address obvious structural problems in the information system. Some of these issues are:

- Establishing some state-of-the practice (SOP) and state-of-the-art (SOA) benchmarks for ESS deployment. This is being addressed by the COMET research, state DOT studies, and by literature review for the STWDSR that cites observation and prediction performance for road conditions.

- Integrating all environmental observations. This includes the goal of national assimilation of all observations for quality control and open-system access.

- Identifying technical and institutional issues in the combining of road condition and weather information within the information infrastructure (whether on the part of the NWS, the RWIS or other parts of the ITS).

- Defining opportunities for improved service from the NWS that are justifiable by its charter to serve commerce, the dissemination opportunities of the ITS, and better support to VAMS tailoring.

- Identification of ways to exploit other existing weather services (e.g., aviation and military) and surveillance technologies (e.g., remote sensing) for environmental information and the public benefit of surface transportation. The latter is a mission of a program established between NASA and the Research and Special Programs Administration (RSPA) of the USDOT.

- Identification and promotion of advanced observational and forecasting technologies and operations that are of interest to surface transportation as well as weather services.

- Combining with other user communities (e.g., airspace operation, agriculture, etc.) in research and deployment programs of mutual interest.

- Defining a concept for the organization of road/weather condition information production (e.g., regional centers to avoid duplication, ensure coordination and focus resources).

- Enhancing the representation of environmental information and its applications (especially maintenance) in the National ITS Architecture and standards as the framework for the open-systems information infrastructure.

Actions on behalf of these approaches are recommended in the last section of this PIR.

1.6 Document Organization

The approach of the PIR to defining the WIST-DSS interfaces and external information requirements is reflected in the following sections of this document:

Section 2: The Information Interface Taxonomy.

This section relates the functions of the WIST-DSS, as described in the OCD, to required types of information in a hierarchical interface taxonomy. The full taxonomy is given in the Appendix.

Section 3: Weather and Road Condition Information.

This section examines the relationships in the external processing of weather and road condition information, leading to requirements issues for technical and institutional integration.

Section 4: Weather Services.

This section describes the observational data and products that constitute weather information, primarily from the NWS, that will support the WIST-DSS.

Section 5: ITS and ESS Data Elements.

This section specifies the structure and data objects of the ESS within the ITS, and similarly for other information on the state of the highway system that is called for by the information taxonomy.

Section 6: Recommendations.

Summary of conclusions and programmatic recommendations for achieving the objectives of an open information infrastructure adequate for the WIST-DSS.

Appendices:

The appendices contain detail on the taxonomy, the decision-taxonomy traceability matrix, and a set of technology candidates for observational systems. The latter is part of the WIST-DSS technology components put forward by the national labs. Other components were listed in the OCD.

2. The Information Interface Taxonomy

This section summarizes the context definition and level 1 functional decomposition of the WIST-DSS. The context boundary also defines the interface to external information resources. The external information resource types needed by the WIST-DSS functions are summarized in a hierarchical taxonomy.

2.1 Context Definition

The representation of the WIST-DSS follows the IDEF[11] system engineering formalism. The WIST-DSS focuses on the filtering, fusion, and processing of external information and its presentation to support winter road-maintenance decision making. The context (IDEF level 0) of these functions consists of constraints, resources, inputs and outputs. The boundary between the system and its context is the system interface with the external world (other systems). The context diagram for the WIST-DSS is shown in figure 2.1.1.

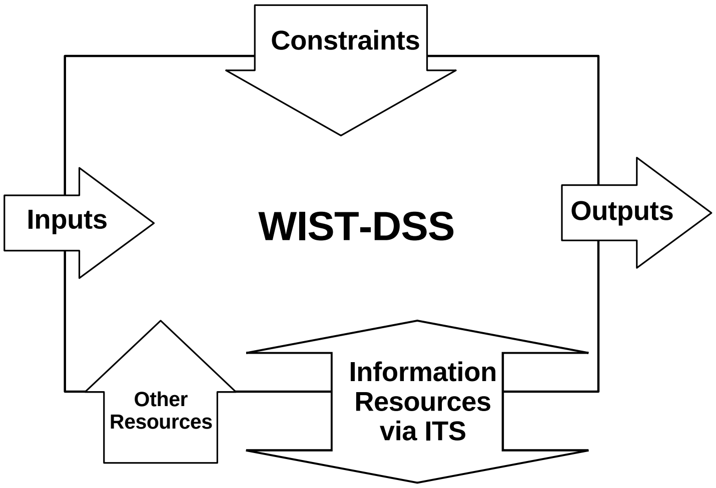

Figure 2.1.1: WIST-DSS Context Diagram

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[11] IDEF is an acronym for ICAM DEFinition, where ICAM is an acronym for Integrated Computer Aided Manufacturing. IDEF process representations have since been adopted for all kinds of processes, including logical processes for software design.

The context boundary establishes the allocation of responsibilities between systems. Inside the boundary, the OCD takes responsibility for defining the functions, and eventually the program for realizing the functions. The context boundary establishes that all information to be filtered and fused in the WIST-DSS comes from external sources under other programs. The PIR will be looking at the context of environmental information to recommend improvements, but those recommendations are outside of the program for WIST-DSS development. This is consistent with the principle that the WIST-DSS must operate with existing information, but can identify and anticipate improvements in that information. Four types of external flows are defined across the context boundary, and therefore constitute the WIST-DSS interface:

- Inputs are the institutional goals of the decision maker, in this case surface transportation system performance goals. These can be translated to more immediate goals of the decisions. In the case of winter road maintenance, meeting road surface level of service (LOS) criteria cost-effectively, and with minimal chemical and particulate loading of the environment, may be taken as the driving input to the decision support system. Inputs are *not* the information characterizing the environmental threats or other conditions, for which the inputs motivate outputs.

- Outputs are decisions. Within the WIST-DSS, there is no real distinction between decisions and the actions on the surface transportation system that the decisions direct. For winter road maintenance, at the operational scale of management decisions, outputs include commands that deploy ice treatment and snow removal resources.

- Resources support the decisions that respond to the inputs (goals). For the logical representation of the WIST-DSS in the PIR, the sole resource being considered is information. Other resources (physical structures, power, staffing, funding) are implicit. The information resource, passed from the external context through an interface to the WIST-DSS logical functions, can characterize any relevant feature of the highway system (roads, traffic, operational resources) and its environment (weather and the weather-related road conditions that are threats to highway use and operation).

- Constraints define the latitude of decisions, and are in the form of institutional, physical and other constraints.

A resource that enables a decision and a constraint that limits it are not that different logically. An insufficiency of any resource is a constraint. Conversely, the power of managerial authority also comes from the legal constraints associated with it. For the purpose here, the more important distinction is between the resources/constraints that exist in the transportation system (including the institutions that operate it), and their representations as information. Although information can flow both ways across the interface, most information types are into the WIST-DSS. This external information resource flow is characterized in figure 2.1.2.

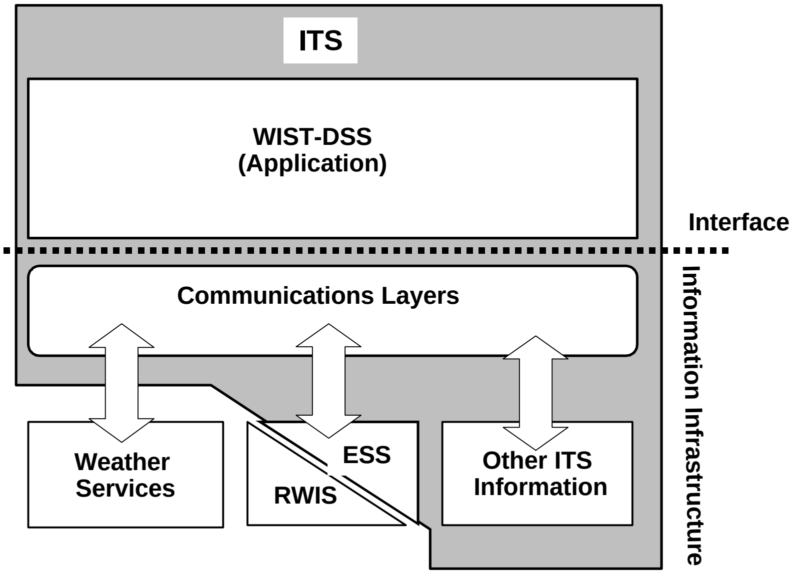

Figure 2.1.2: External Information Resources to the WIST-DSS

Figure 2.1.2 shows the important categorical distinctions used in this document. The WIST-DSS is an application and the external information resources are part of an information infrastructure that serves many applications. The interface separates the application from the infrastructure. Communications layers are assumed. They are not relevant to a logical description, but will be specified when presently part of a stovepiped channel. At the interface, the information sources become logical entities, called data objects or data flows[12].

Figure 2.1.2 shows ITS and non-ITS information resources, and four general types of information resources. The ITS is assumed to be the information infrastructure seen by the WIST-DSS, since the WIST-DSS is an application embedded in the ITS with other surface-transportation applications. The structure of the ITS relevant to the WIST-DSS interface is described in detail in Section 5. The National ITS Architecture defines terminator entities that it interfaces with. The NWS, and sources of weather information generally (hence the generic term “weather services”) are such terminators. The ESS, as a physical system, is really a terminator,

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[12] The PIR does not discriminate between data-flow or object-oriented logical representations. The OCD is stated mostly in data flow and process terms, as is the National ITS Architecture, and in general a named data flow maps to a data object, and a process to a method for changing data object attributes in the object-oriented paradigm. The hierarchy of information types complements the hierarchical structure of objects.

represented by the physical environmental conditions measured in the terminator Roadway Environment. The logical data objects of the ESS standard may be considered part of the ITS. The RWIS, as a mix of weather information and road conditions, some from the ESS observations, may encompass the ESS, but is otherwise outside of the ITS. This division of information sources shows the general scope of information taxonomy inclusion. The PIR is concerned mainly with the environmental information sources (Weather Services, RWIS and ESS). The ITS provides information on the state of the transportation system and treatment resources, and these sources are under various other ITS programs for development.

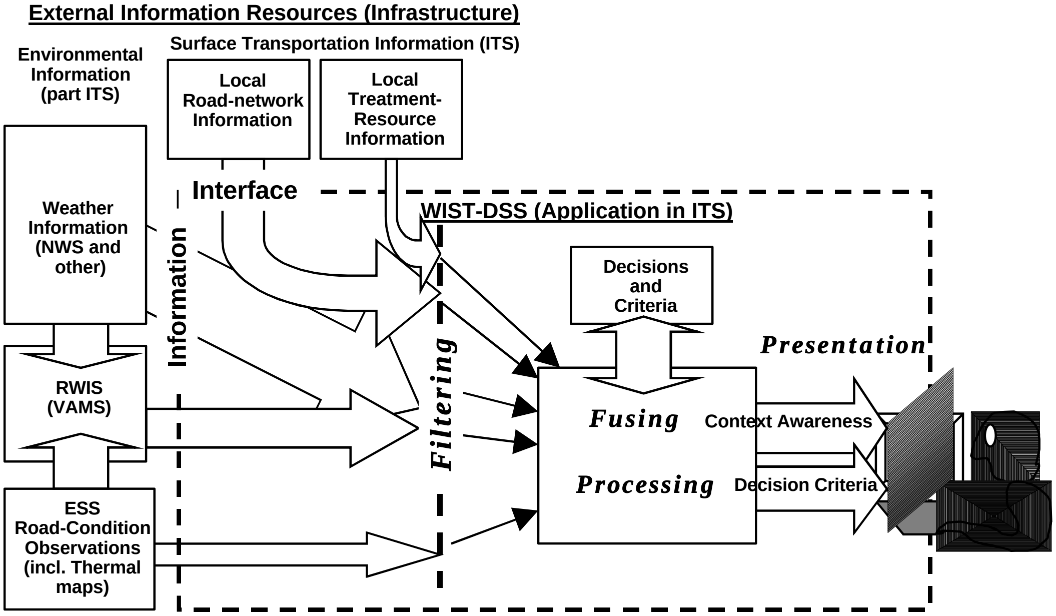

Figure 2.1.3: External Interfaces and WIST-DSS Functions

Figure 2.1.3 gives another level of detail on the context and introduces some of the internal processing. Filtering is the first function within the WIST-DSS. The figure emphasizes that there is an immense amount of external information. The greatest bulk probably is from weather services, characterizing the state of the atmosphere in various ways for large and small volumes and areas. An issue is how much of this is filtered and processed externally into the more relevant environmental conditions at roadways.

ITS information (other than environmental) is on the state of the road network that affects decisions and the state of resources that effect decisions. That information currently is narrow and local, and the role of the ITS is to broaden it and make it more available. That can increase the filtering needed within specific applications. Road condition information, especially from the ESS, is also mostly local now. One reason for combining weather and road condition information, in the external processes, is to apply the broadness of weather information to the entire road network. The OCD assumes that in lieu of appropriate fusion of information externally, there will be fusion within the WIST-DSS, and further processing to meet the need to evaluate the criteria for treatment decisions. It is expected that the DSS will fuse environmental with non-environmental information (the latter taken to be the transportation-state and treatment-resource information), while more fusion of environmental information to derive road conditions will be done externally over time.

The way decisions have been defined, they include monitoring of the external context (environment and transportation network state). This is always done with some purpose, and so the user is making a decision that affects the presentation. For all the decisions that the DSS supports, presentation concerns the evaluated criteria for the decision. In the case of winter road maintenance, the WIST-DSS should be thought of as presenting the choices, with their relative ranking, for the *who, what and when* of snow removal and ice treatment. The task of getting environmental information, and applying it to the decision presentation, is not trivial, and it is the focus of this document. But it is far upstream in the process to get better decisions and transportation performance improvement.

2.2 Scale and Context

The information taxonomy for the WIST-DSS interface must consider some principles in order to organize the information types in a hierarchy of categories. All the previous STWDSR documents have emphasized the scale concept as vital to logical structuring of the WIST-DSS and its external information resources, and scale is a major principle in the taxonomy. The main scale categories are repeated in the table below:

Table 2.2.1: Scale Definitions

Meteorological Scale	Decision Scale	Scale Range (time horizon)
Climatic	Planning	> weeks
Synoptic	Operational	12 hrs to days
Meso	Operational	1-12 hours
Micro	Warning	< 1 hour

Scale is a space-time parameter. The table shows only the time horizon dimension. In atmospheric physics (or translated to road thermal physics) the predictive time horizon relates to the spatial dimension of phenomena. The organization of highway maintenance tends to follow the principle that higher management levels with larger jurisdictions are concerned with the larger scaled decisions. Upper levels (e.g., state and regional offices) are most concerned with planning (resource availability), middle levels (districts, garages) with operational deployment of resources, and the most local scale (a crew and truck) with the immediate tasks of driving and treatment.

This document, and the OCD, are concerned strictly with operational scale decisions. For winter road maintenance, this practically falls into the ±1-48 hour time horizon range. There are several names for the jurisdictional extent covered, but it can be expected to be around county-sized (actual area varying greatly between urban and rural jurisdictions). Of course, for agencies like toll road authorities, the relevant dimension is strictly linear. The operational decision scale covers both synoptic and meso scales of weather information. This fact by itself raises some of the major issues in the environmental information sources. The NWS has, until recently, been concerned mainly with synoptic scale information, whose phenomena are large air masses and fronts, not extending down to convective storms, and well above resolution down to road segments. The VAMS and ESS have moved in to apply meso scales at and less than 5 km resolutions. The space-time scale relations for weather versus road conditions will be discussed further in Section 3.

Most of the activities within the WIST-DSS are of finer time scale than the information resources. This follows because the WIST-DSS should be able to respond to the environmental changes and not fall behind them. The categories of “contextual” and “interactive” information were used in the OCD. This reflects information on the external conditions versus the internal information processes. The terms also reflect a basic principle for defining the interface, that the DSS either does not, or only slowly, affects the external systems it is connected to. This principle is violated only for collaborative interactions, e.g., between two coordinating DSS in different jurisdictions. This is a special case for the collaborative mode of the WIST-DSS. Information types are therefore specified for this mode. Information is also specified for the learning mode. Learning mostly involves the aggregation of contextual information, so it is a “slow” process. However, the majority of information types concern the decision mode, which is simply the use of contextual information to support decisions.

Weather information is always contextual as a prior stipulation of treatment decisions, and is never altered by a treatment decision. Road condition can be managed, but weather cannot be (yet). Road condition is both the characterization of threats to road performance, and the result of decisions to improve performance. This could pose a problem of recursion, meaning the interaction between external information and the DSS output, except for scale. An operational manager starts with predicted road condition, compares it with goal LOS, and dispatches treatment accordingly. Later (but probably not less than an hour later), the manager may re-assess road condition for new treatment decisions (finish treatment, re-treat, cleanup, etc.). But logically, the situation is the same as the first decision. The learning mode is different only because it assumes that assessments of decision performance are reflected in changes to the DSS, rather than just in new decisions by the decision maker.

The collaborative mode is a challenge that was not extensively addressed in the OCD. It is important to realize that collaboration can affect any decisions that need to be coordinated. Clearly, the deployment of treatment resources by jurisdictions that can share the treatment resources is a matter for collaboration. But the PIR also points out that most processes that produce environmental information are really decisions with decision-support applications. This is most apparent with weather analysis supported by the AWIPS. The dominant perspective is that a weather analysis decision is contextual to transportation decisions. However, since a weather analyst is making a risk decision, the question of an appropriate decision depends on the ultimate applications of the information. The empirical research for the OCD indicated the need for the transportation decision makers to have more “background” on the weather analysis. This is one of the motivations for the VAMS services, that are often more collaborative. Such tailoring is institutionally prohibited for the NWS, or technically not possible for many weather products. It is recognized that changes in DSS technology can affect the whole organization of the joint DSS and external-information system. How collaboration between these systems occurs is one such change. One approach to affecting the change is to provide not point-decisions of what the environmental situation will be, but rather the risk statistics on the situation. This is an important kind of information. However, it was decided in the taxonomy that such information will be shown as implicit, or “meta data” for the enumerated types.

2.3 WIST-DSS Functions and Interfaces

Another important principle for the information taxonomy is that it should map to the functions of the WIST-DSS. The OCD specified the functions. The way the OCD did this is not unique, and there is a valid concern about the arbitrariness of the information taxonomy that results. This is a risk for any purpose-constructed organization of information. However, the functions are still so generic that the taxonomy is not overly specified by the functions. Construction of the taxonomy refers to the level 1 process diagram for the WIST-DSS shown below.

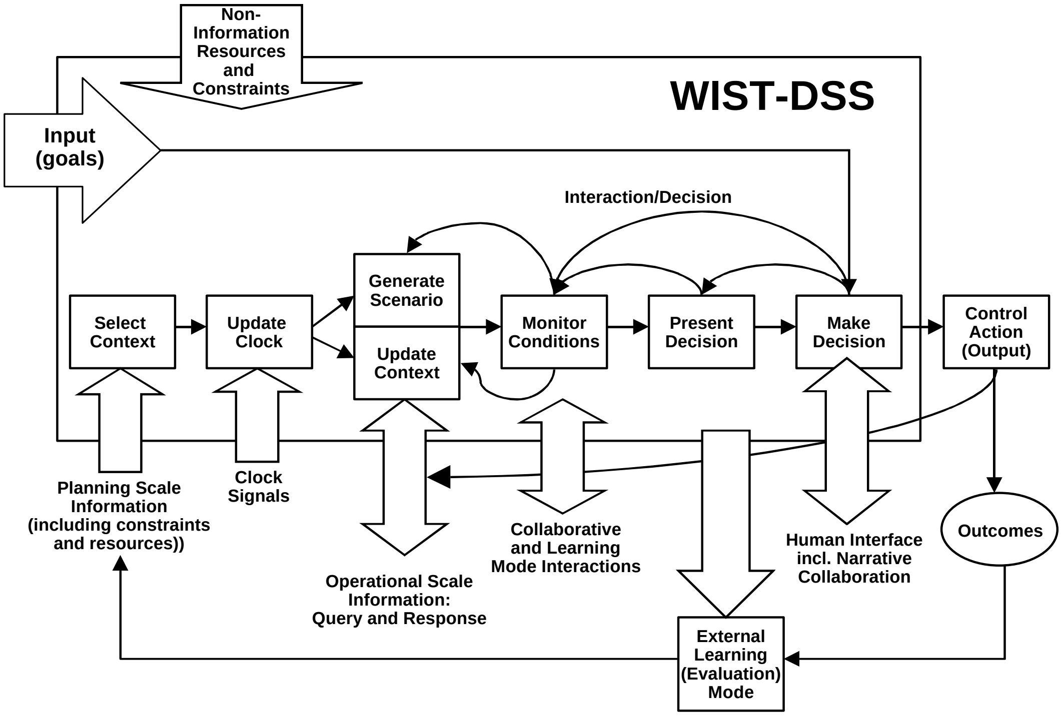

Figure 2.3.1: Level 1 WIST-DSS Diagram

The level 1 diagram refers to the IDEF hierarchy of system representations. The diagram shows the interfaces concerned with the three different modes of WIST-DSS operation. The learning-mode and collaborative-mode interfaces are distributed among design features of the system software and hardware, but the decision-mode interfaces are more localized to the two functions of Select Context (planning-scale information) and Update Context (operational scale information).

2.4 First and Second-Level Taxonomy Categories

Only the first three levels of the interfaces taxonomy will be defined here and in the next subsection, to orient readers. The full taxonomy is in Appendix A1. Discussion of some of the lower levels occurs in later sections. The first level of the taxonomy comes directly from the three decision scales and is organized as follows:

<u>WIST-DSS Information Resource Interfaces Taxonomy</u>

1 Warning scale information (elements not further specified in the PIR)
2 Operational scale information
3 Planning scale information

The warning (micro) scale of information is not included. For the operational scale of decision making, all micro-scale information becomes aggregated into operational-scale objects. For instance, the micro-scale information and decisions of truck drivers are not controlled in the same way that dispatching the truck on a beat is. The maintenance manager monitors where the truck is periodically and probably does not alter dispatching decisions on cycles less than an hour. The manager uses information that aggregates micro information into larger time cycles over the entire jurisdiction. The bulk of the taxonomy here will be under index 2.n, operational-scale information for the operational-scale decisions. However, the decisions also need, at least at the start of a decision sequence, planning-scale information. This represents, among other things, the resources made available to manage. The planning-scale information used for operational-scale decisions will be maintained under index 3.n. This will help maintain consistency when further decision support at the warning and planning scales is considered

The second level of the taxonomy maps directly to the functions and modes of the WIST-DSS shown in the level 1 diagram:

<u>WIST-DSS Information Resource Interfaces Taxonomy</u>

1 Warning scale information (elements not specified)
2 Operational scale information
    2.1 Operational scale information to Update Context
    2.2 Operational scale information to Update Clock
    2.3 Operational scale information unique to learning mode
    2.4 Operational scale information unique to collaboration mode
    2.5 Operational scale information unique to human interface
3 Planning scale information
    3.1 Planning scale information to Select Context used in operational decisions for winter road maintenance.

3.2 Information embedded in the WIST-DSS as parameter settings, etc., that adapt the system to its operational environment, and that are set in evaluation mode.

The functions Select Context (interface index 3.1) for planning-scale of information, and Update Context (index 2.1) for operational-scale information are the two major recipients of external information. The names of the functions are intended to indicate that the decision context is selected once, at planning scale, for an episode of decision making associated with a weather event, and then updated at operational scale within the episode. In general, Select Context receives the resources made available for treatment, information on the road network treated, and climatic-scale environmental data that provide a basis for inferring operational-scale conditions. Update Context then tracks the changes in these variables as they occur for the set of decisions around a weather event, with +/- 48 hour time horizons being the general limit. This includes resource disposition and output performance (e.g., road LOS) that are shown as feeding back through Update Context in figure 2.3.1.

The interface for type 2.1 information to Update Context is shown as two-way. This allows for information from the DSS to external sources. This could include user profiles, possibly event-specific, used to tailor the external information sources. Given some ambiguity about where road-condition information is generated (it may be inferred in the DSS until the external sources are mature enough to supply it) it is also possible that each DSS may act as a quasi VAMS and supplier of information to a common pool. The two-way interface, which is for logical information flows, is *not* intended to represent the two-way interactions embedded in client-server communications protocols. Except for pure broadcast information (e.g., from NOAAPort that supplies many NWS products), most computer-to-computer networked communication involves some two-way transactions as part of the mechanics of communications. It is generally correct to say that the external interfaces to Select Context and Update Context, that are the bulk of the information types, are one-way into the DSS.

The planning scale can also be considered as the one in which the resource of the WIST-DSS itself is provided. For logical purposes, this consists of setting the software parameters and structure that embody the requirements for decision support. The spiral evolution of the system implies that this logical resource keeps improving through learning. The learning mode of the WIST-DSS requires a correlation of internal states of the system with output or outcome performance, to reinforce the internal DSS states that match with the superior performance. This is shown in figure 2.3.1 as an evaluation function external to the operational-scale DSS (because evaluation is assumed to be at planning scale, although operational-scale learning is also a possibility). The evaluation mode receives outcome-performance information, but also needs an interface to the DSS to record internal DSS states. This interface is from distributed points in the DSS to the external context, and is indexed as type 3.2. The evaluation results in changes in DSS parameters, back through the type 3.1 information to Select Context.

The Update Clock function can operate autonomously, but in practice should receive external time-synchronization signals. Therefore, it probably will also have an external interface. Update

Clock provides local time as relevant to local resource schedules, and diurnal environmental or traffic effects. Update Clock also provides universal time, since this is the basis for NWS forecast delivery and other wide-area communications and coordination. The external clock synchronizations are the type 2.2 information, and are always from external context into the DSS.

The three remaining second-level interfaces at operational scale are types 2.3, 2.4 and 2.5. Type 2.3, “operational scale information unique to the learning mode”, accommodates possible operational-scale feedbacks in the learning mode. Learning from the usual evaluation cycle requires some ensemble of cases and was defined to occur at the planning scale. Bayesian approaches to learning can be implemented with adaptive updates during a decision making episode, and may be considered to occur at the operational scale.

Type 2.4, “operational scale information unique to the collaborative mode”, handles the exchanges between different DSS in that mode. This will be a two-way interaction, probably focused on the Make Decision function. It does not include the purely external human-human collaborative exchanges (e.g., telephone coordination).

Type 2.5 “operational scale information unique to human interface” covers the CHI and is a two-way interface centered on the Make Decision function. This will include user inputs for selecting displays, registering decided choices, and possibly setting some parameters (although the latter is usually done as programing at the planning scale), and the outputs that are the user displays.

The CHI is to the Make Decision process, but the interface along with the exact functions within the automated process are ambiguous because the extent of decision-making automation is left open. There is no clear delineation between decision making and decision support. It is defined that the WIST-DSS will always be under human supervision, if not always putting the human in the operational decision-making loop.   The human interface is defined as including a graphical user interface (GUI) because this is the only method able to accommodate the required integration and access to information. The GUI is typically associated with a mouse-activated cursor, but keyboard input is also typical. It can further be stated that the GUI includes GIS displays since so much, but not necessarily all, of the decision support must be related to geography of the road network. To be precise, a network display is in network space (e.g., route number and milepost) and not geographic space. However, the assumption is that relating to weather in geographic space requires that all road conditions be related to geographic space as well. This implies the required geocoding of all information that is embedded in physical space.

Narrative information will interface with the Make Decision process via the CHI. Outside of the WIST-DSS GUI, the human user can of course use the telephone, consult the TV or radio, read text, etc. These will continue to be stovepiped and subject to manual interpretation, but it is expected that the WIST-DSS will displace such narrative media as environmental information sources. There are textual information resources, such as the NWS watches and warnings that should be included in the interface to Update Context. These provide some difficulty for data fusion, and means to parse free-form text into standardized data objects and message sets must be used. Such parsing is used by various RWIS, including the FORETELL operational test. Narrative information between humans probably will remain essential in the collaborative mode.

The functions Generate Scenario, Monitor Conditions, Present Decision and Make Decision are interactive functions. Between them, most of the recursive and internal information transactions will occur, but stimulated by user inputs through the CHI to Make Decision and environmental-event triggers through Update Context. The Generate Scenario function produces the conditions_scenario data object. This represents the environmental and other contextual information at operational scale in the backward and forwards time array, organized as a database for consultation by Monitor Conditions relative to the space-time point of the current decision. Most of the information into Generate Scenario is directly from Update Context, but Generate Scenario is also where the information display is tailored by information from the other interactive functions.

The information flow, from contextual information resource to decision output, can be simplified into a “thread” as shown in figure 2.4.1. The figure illustrates the prospective decision mode only. The thread view is useful for describing functional scenarios for particular decisions and contextual events. The type 2.1, 2.2 and 3.1 interfaces for external information come in at the “upstream” end and the CHI (type 2.5 interface) is at the “downstream” or “front” end of a decision making thread. The filtering, fusion and processing of external information occurs by interactions between Generate Scenario, Monitor Conditions and Present Decision (that selects a decision cluster based on contextual triggers, such as time to event start for the pre-event clusters). The thread is controlled by the goal inputs, shown as coming in mainly through the front end CHI (the type 2.5 interface), although they may also be distributed in functions of the DSS. This control is implemented by user selections of what is presented, and this feeds back, mainly through the “interactive” functions, that include the filtering and fusion of the contextual information. The thread can also have contextual triggers (e.g., receipt of a weather warning or detection of certain “threshold” cases) that activate information from upstream to downstream. The concept is that this is still a processing of the information resource, not the true input. However, embedded system parameters that partially represent the goal inputs (type 3.2 interfaces) do determine what contextual information triggers DSS processes.

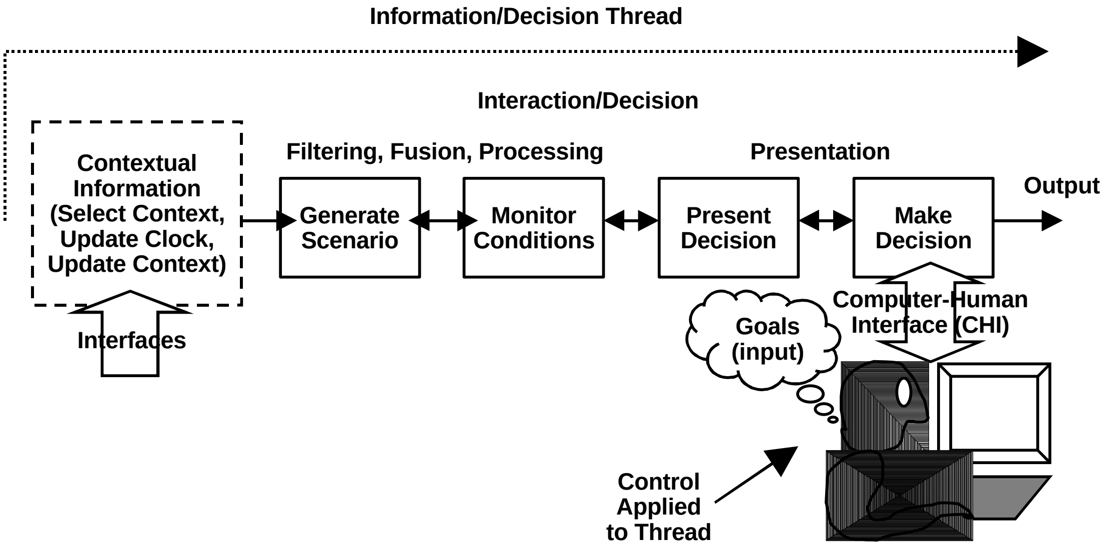

Figure 2.4.1: A Simplified "Thread" View of the WIST-DSS

The CHI passes to the user a presentation of the candidate decision(s) with their criteria (what resources, where deployed, when deployed) evaluated according to the contextual conditions. The activity of just monitoring contextual conditions is accommodated in this scheme by defining monitoring as a decision. In this case, the presentation can be just a view of the environmental situation, which is what most RWIS products consist of, but this is just a part of what the DSS provides. Every decision/environmental-context case can be defined as a processing thread of the DSS. A few of these are illustrated in the scenarios of the OCD, and these show in more detail how the process is to operate.

2.5 Third-Level Taxonomy Categories

The third level of the taxonomy is shown below. Some explanation of the third-level categories is given, but the detail is best seen in the full taxonomy in Appendix A1 and discussions of the weather and ITS/ESS information flows in later sections.

<u>WIST-DSS Information Resource Interfaces Taxonomy (to third level)</u>

1 Warning scale information (elements not specified here)
2 Operational scale information
    2.1 Operational scale information to Update Context
        2.1.1 Weather
        2.1.2 Terrestrial/hydrologic conditions
        2.1.3 Road condition
        2.1.4 Resources status
        2.1.5 Surface transportation network status
        2.1.6 Other transportation network status
        2.1.7 Communications contact addresses
        2.1.8 Communication, power and control system status
        2.1.9 Environmental impacts
    2.2 Operational scale information to Update Clock
        2.2.1 Time synchronization
    2.3 Operational scale information unique to learning mode
        2.3.1 System states
        2.3.2 System outputs
    2.4 Operational scale information unique to collaboration mode
        2.4.1 Other system states
        2.4.2 Other system outputs (decisions)
        2.4.3 Resource shadow prices
    2.5 Operational scale information unique to human interface
        2.5.1 Display
        2.5.2 User input
3 Planning scale information
    3.1 Planning scale information to Select Context used in operational decisions for winter road maintenance.
        3.1.1 Jurisdictional limits
        3.1.2 Resources
        3.1.3 Procedures
        3.1.4 Surface transportation network
        3.1.5 Other transportation network
        3.1.6 Road surface climate
        3.1.7 Atmospheric climate
        3.1.8 Surface characteristics and physiography
        3.1.9 Communication, power and control systems

    - 3.1.10 Social factors
    - 3.1.11 Other
- 3.2 Information embedded in the WIST-DSS as parameter settings, etc., that adapt the system to its operational environment, and that are set in evaluation mode.
    - 3.2.1 Graphical user interface (GUI) settings
    - 3.2.2 Meta data on information sources
    - 3.2.3 Program objects and parameters
    - 3.2.4 Hardware objects and parameters
    - 3.2.5 Communications network addresses
    - 3.2.6 Other

Most of the taxonomy is under type 2.1, the operational scale information to Update Context. This is where the environmental information categories are, and the most attention has been paid to expanding this category. The count of lowest-level types in the categories is as follows:

Type 2.1 (to Update Context)	133
Types 2.2 - 2.5	13
Type 3.n (planning scale information)	66
Total lowest level categories in taxonomy	212

Under type 2.1, the next level covers weather, road condition, treatment resources, state of the transportation network, current contact information, state of the information system, and environmental quality as might be affected by treatment. The definition and separation of weather and road condition information was not a trivial decision, as will be discussed further in the next section. While everything of interest to road operation or usage may be defined as a “road condition”, the critical issue to the DSS and the external information resources is where, and how well the various environmental information is transformed into relevant road conditions. It is safe to say that with few exceptions (radiation through the atmosphere and electrical activity in the atmosphere) the volume of interest extends a short distance above and below the local road level. This corresponds to what is observed as “surface weather”. Surface weather and road condition data objects are all defined by the ESS standard, and this became the primary basis for the type 2.1.n environmental categories. These are listed in detail in the section on ITS and ESS. That section will also enumerate the data objects that cover the transportation system state other than road condition.

Ideally, the RWIS uses weather information only to infer sensible surface conditions. It is possible that as the external information sources mature in the tailoring of environmental information for surface transportation decision support, there will no longer be any kind of weather information at the DSS interface, other than sensible surface conditions. Then, the transition from the user having to infer environmental conditions to having support directly to decisions will be complete. The other kinds of weather information will be used outside of the

DSS in the process of inferring surface conditions. This would include most of the current NWS product, including the numerical weather prediction (NWP) products whose improvement is now expected on the way to better road condition prediction. By focusing mostly on the ESS-based data objects, the taxonomy fairly represents the ultimate interface. However there are some categories under type 2.1.1 (radiation objects, lightning and severe storms) that may continue to be useful even if they are not strictly surface conditions. The categories of hydrometeors can affect visibility but otherwise are of interest in their surface effects of snow accumulation, surface wetting and flooding. Practically speaking, observations of hydrometeors by radar or numerical predictions will continue to be used, but there can be important variations between these data and the road-surface condition. Road condition generally requires fusion of hydrometeor information with road thermal characteristics, topography and surface winds.

The planning-scale information, necessary to the operational-scale decisions, is type 3.n.m. This includes the resources available, the “static” characteristics of the transportation network (e.g., a map of the active network), environmental climatology, surface physiography, the “static” data on the information network, and social and environmental sensitivities. The type 3.2 information includes the various embedded parameters that define the DSS itself as a resource.

2.6 Standards

Other than the human interface, type 2.5.n, all other interfaces are by computer-to-computer communications. These are covered by standards for open systems. The WIST-DSS relies on the National ITS Architecture, ITS standards, other standards pertaining to computer-to-computer communications, and other data formatting standards established among the information providers. An appropriate standard is considered implicit for all the computer-to-computer interfaces.

The CHI is to the application. Textual interfaces may be stipulated by the underlying data format standards. However, for textual information, but more especially for graphical icons and other display formats, there is little standardization and a great concern over ambiguity and effectiveness in the CHI. Weather symbology has become standardized over time. Even so, the desire to simplify it for lay users has eroded that standardization. The problem for other types of display in the CHI has hardly been addressed. This contrasts with the standardization being achieved in road signage and markings under the Manual of Uniform Traffic Control Devices (MUTCD) maintained by the FHWA. Additional efforts, and possibly an extension of the MUTCD to ITS application displays, are necessary. The CHI of the WIST-DSS will be *ad hoc* in the foreseeable future.

For the computer-to-computer interfaces, the standards are too numerous and detailed to list in the PIR. The ESS data objects have been used explicitly, but most other standards will affect only lower levels of the taxonomy than are now defined. The ITS standards are predominately concerned with the data dictionaries and message set standards unique to the surface transportation applications. The WIST-DSS will use several of these, primarily under traffic management and traveler information. However, many of the standards are not finalized, and environmental information has not been included fully through users services in the National ITS Architecture. In any case, the ITS specifies no comprehensive set of data dictionary and message set standards for the WIST-DSS at this time.

For weather information generally, there are *de facto* standards established by the NWS (and from which the ESS standard is derived). Although these standards are not discussed in detail, they will apply to the products and communications channels indicated in the section on weather services. The Road Weather Management Program intends to pursue projects that will establish interfaces between the WFOs, surface transportation applications and the ESS observations. Since many RWIS products are now proprietary, open system standards are not predominate. The Internet is, however, growing in use. This does not address the data dictionary and message set standards. A combination of NWS and ITS data dictionary standards, with the Extended Markup Language (XML) syntax may evolve into a general standard for environmental information over the Internet. The Japanese have taken a lead in applying the XML syntax for use in Internet applications, and have devised a Road Weather Markup Language (RWML)[13] within XML. This is based on a set of data objects devoted to weather-related road conditions, and may be effective in creating a *de facto* standard for that category of information.

Broadcast or other dissemination protocols may remain diverse and proprietary, especially if they serve niche markets. NOAAPort broadcasts probably will persist for wide area dissemination of the central NWP products and sharing of the common observational database, but this is a published and *de facto* standard. The growth of digital radio, both broadcast and cellular packet, will be important for all kinds of wireless information dissemination in the ITS. These modes may evolve to a protocol standard, but still need a push to adopt data dictionary and message set standards. Like the application, the information infrastructure is evolutionary.

2.7 Data and Meta Data

The taxonomy lists data objects. The data objects are expected to be described as types that are handled uniformly by the DSS processes. However, the real information, or data, are carried by the attributes of the types. For instance, the wind speed data object carries the physical data of the wind speed as a numerical field, or possibly a discrete set of speed designators. Observations also typically carry “meta data”. These data describe the location of the observation, time stamp, instrumentation type, etc. Both data and meta data may be relevant to the processes. Logically, data and meta data are not different and both are intended to be implicit for the data objects of the taxonomy. In most cases, they will not be made explicit in this document. The various standards typically specify meta data in headers as part of the message set formats, and otherwise specify numerical or categorical data formats.

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[13] The current draft RWML may be found at www2.ceri.go.jp/eng/its-win/RWML.htm

The data objects concerned with environmental information, resource disposition, and transportation network states are embedded in physical space-time. Therefore, space-time coordinates are essential meta data for these. Geo-location and time (e.g., local versus UTC) standards will apply to the coordinates given. The space and time resolution of the information is implied by these coordinate meta data, both for observations and forecast grids. This is a vital aspect of the quality of the information, but it is not reflected in the taxonomy. It is up to the data filtering and fusion processes to select the relevant and most valuable information for the decision making process. The selection of sources with the best quality information is mostly a planning scale decision, reflected in the 3.2.5 type (communications network addresses) that identify the sources used.

The data and meta data in each type ultimately determine the communications and internal processing capacity required. This is not specified here. However, the bulkiest types are likely to be NWP grids, with their attribute values, three spatial dimensions and series of time horizons. This is why NOAAPort satellite broadcast is likely to continue as the preferred mode of communications for these data, and why a filtering function is necessary. There is contention between doing this filtering at the DSS, to ensure that all possible information is available, versus using products that perform the filtering upstream. This issue leads to considerations of how the processing of NWP data is organized. Information volume also affects the decision on how to deploy regional NWP modeling. National observation sets and any GIS-based products will be voluminous because of their physical dimensionality. Reducing this to network space on the highway grid increases relevance to the decision making and probably decreases data volume. The capacity across the interface is determined by what filtering, fusion and processing occur externally.

The National ITS Architecture contains current, predicted and archived data types at a high level in its logical data flows. The principle used here, of implicit meta data, does not recognize this typology in the taxonomy. As emphasized for the DSS, all decision support information is essentially predictive, whereas all observations and predictions must be made in the past of the decision. Scale is the key parameter. There is no logical difference between archived data (how long ago, and was it observed or forecast?), current observations (from how long ago and extended to what horizon?) and predictions (made how long ago and to what horizon?). The scale concept substitutes for the ambiguous concept of “real time”, because all decision making is in “real time” as demanded by the wide range of time leads for decisions to become effective. The *appropriate* data to use for a given *scale* of decision are determined by the DSS.

A harder decision for the taxonomy is the treatment of data on the reliability of source information. Such information is essential to WIST-DSS functions. The decision was made that statistics produced from ensembles of data within the data objects (or possibly across data objects) would be treated as meta data, and are implicit in the taxonomic types. Among the external sources, some product types (e.g., assimilated observations, the Model Output Statistics (MOS) or other ensemble products) are explicit in representing statistical results on data objects. This again illustrates why there may be different taxonomies externally and across the interface.

In any case, the important but implicit statistical attributes include:

- central values (mean, median, mode)
- dispersion values (variance, standard deviation, min-max)
- distributional values (percentiles)

It will be assumed that these data accompany any of the data objects. When they are not produced externally, but needed by the DSS, they will have to be produced by the Generate Scenario function. An example is the comparison of radar tracked precipitation versus ground observations to produce validations within the operational scale. The two sources could be fused in the DSS, but this is also a function that should be accomplished by an external source. The desire to allocate such functions to external sources is another reason why the ESS data should be open for integration with upstream weather information, and not stovepiped from source to DSS application.

3. Weather and Road-Condition Information

This section discusses issues of external environmental-information production. It identifies the important processes in delivering environmental information to the interface of the WIST-DSS, and how they might be improved.

3.1 Background on Information Sources

Figure 3.1.1 shows the important divisions and relations between weather and road-condition information.

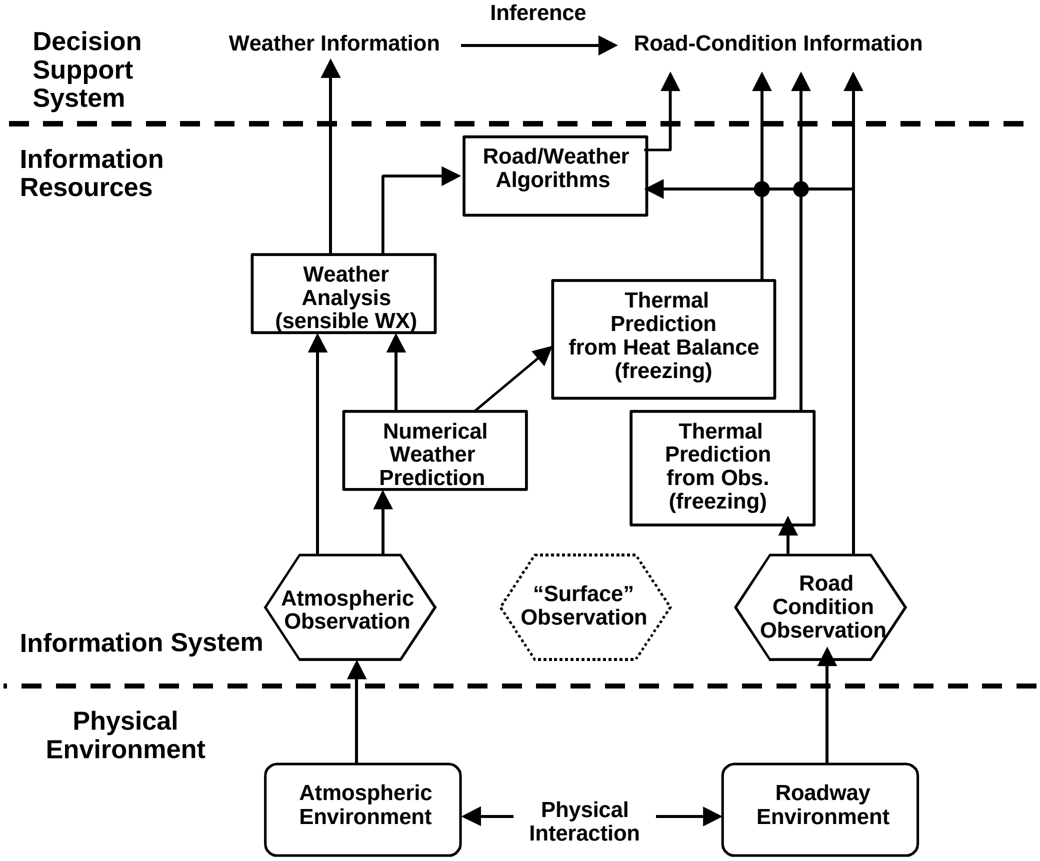

Figure 3.1.1: The Relation Between Weather and Road-condition Information

Weather and road condition constitute the two types of environmental information[14] considered here. There are essential differences between these types of information. The logical differences in the taxonomy reflect the difference in the physics of the atmosphere and the roadway, and the fact that the locations of interesting volumes in the atmosphere are different from the interesting linear segments of roadway. However, the physical interactions between atmosphere, surface physiography and vehicle operation, as well as the need to cope with informational deficiencies in either domain, create various ways for the weather and road-condition information to interact. This interaction should be mostly in the external information processing, but may be in the WIST-DSS functions.

Figure 3.1.1 starts in the physical environment (at bottom). The physical interaction is of weather affecting road condition, and road condition affecting the atmosphere. But there is an asymmetry of scale in this: Weather at any scale can affect road conditions. Conversely, roads affect the atmosphere mostly at micro scale. For instance, road heat affects local air temperature and water evaporation into the atmosphere while topographical contours created by road cuts, fill and structures affect winds. Even vehicles transfer heat, add gases and move air. This is well below the scale of normal weather analysis and prediction, but is often vital to road condition.

The physical conditions enter the information system by measurement instrumentation. Atmospheric observation is by numerous means and road conditions are measured by the ESS. There is an overlap in measuring “surface weather”, which in meteorological terms means somewhere above ground surface and preferably not where unusual artifacts like roads affect the measurements.

Weather services distinguish weather analysis from numerical prediction. Historically, analysis took point observations to infer air masses, fronts, precipitation, and other weather threats. Prediction was the manual extrapolation of analysis. The revolution of the 1950's was to introduce numerical weather prediction (NWP), that started to make prediction an automated function. However, the human meteorologist remains the weather analyst. Analysis is still the process of taking data, that arrives as text or graphical data displays, to infer weather phenomena and sensible weather–what the atmosphere will mean to people–at various future time horizons. The NWP data are called “numerical guidance” in this context. Weather analysis also requires decision support. Environmental context monitoring by transportation staff can be a collaborative decision with meteorological staff.

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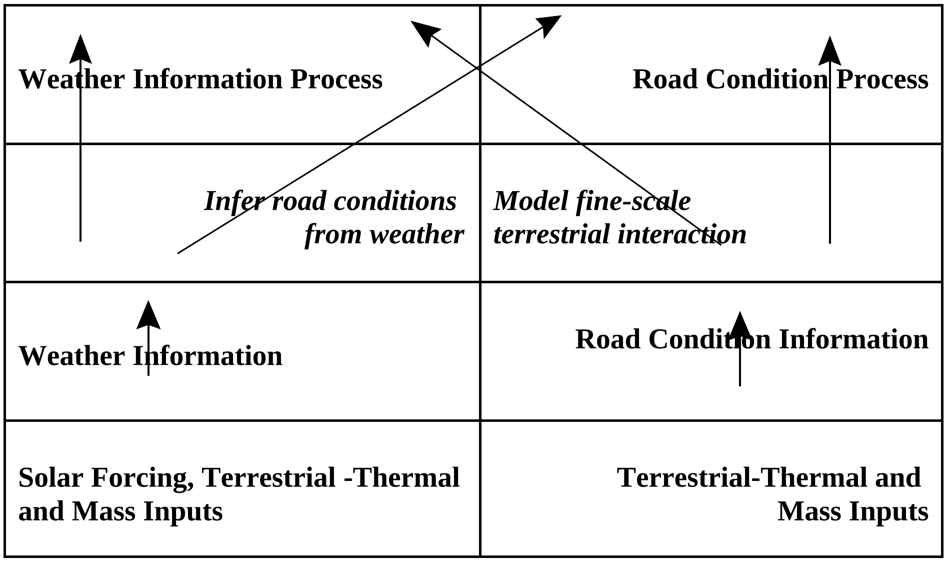
[14] Other data objects in the taxonomy are properly “environmental”. These include environmental consequences and sensitivities of treatment. The definition of “environmental” here is from the data objects in the ESS standard, that certainly includes weather, the condition of the road surface and near-road environment. Weather and road condition are taken as a broad dichotomy of “environmental”.

Figure 3.1.1 shows crossovers of weather and road condition information. The table below suggests the issues of why there is, and must be, an interchange between weather and road-condition information processes.

Table 3.1.1: Environmental Information Interactions



Weather Information Process	**Road Condition Process**
Infer road conditions from weather	***Model fine-scale terrestrial interaction***
Weather Information	**Road Condition Information**
Solar Forcing, Terrestrial -Thermal and Mass Inputs	**Terrestrial-Thermal and Mass Inputs**

Weather is driven, or “forced” by solar inputs. The atmosphere gets water from terrestrial sinks, mainly the oceans. The oceans, and to a lesser extent the land, are sinks for solar and geophysical energy. However, the state of the atmosphere by itself, with the diurnal cycle of solar input, is mostly sufficient for predicting the future state of the atmosphere. Atmospheric volume observations and surface point observations are the main input to weather analysis and prediction. Road conditions are a small and climatically biased part of terrestrial conditions. Heat and mass (especially dust and water) transfers to the atmosphere are negligible for most purposes, except for immediate road conditions (e.g., localized fogs). Winds, and consequently other weather attributes, are affected by surface topography (called orographic forcing). As the scale of weather analysis and prediction gets finer, small-scaled orographic features must be defined, and terrestrial heat and water become more significant. Still, roads are beneath the scale of any weather analysis and prediction now done. The crossover from road-condition information to weather processes is practically nil, except insofar as ESS observations are used as surface weather observations, or can be used to characterize more general terrestrial conditions. In both cases, there are concerns with the climatic bias of ESS sites. If ESS are sited to measure critical freezing, fog or wind locations on roads, those locations probably do not typify either the terrestrial or atmospheric environment.

Transportation decisions are based on both weather and road conditions. What occurs above a road (e.g., fog and precipitation affecting visibility or high winds) may be classed as weather but affects road condition. The taxonomy follows the ESS standard by specifying a "visibility" data object, but this will often correlate with weather objects. By affecting travel decisions and other road activities (like construction and maintenance) weather of all types can affect decisions. Winter road maintenance is unique in being concerned almost exclusively with the condition of the road surface, because that is what is treated, not weather or other near-road conditions. For this application, the interest in weather tends to be how it affects the road-surface condition.

The road-surface condition is driven by both solar and terrestrial thermal inputs, and is affected by terrestrial water (subsurface, condensed on surface, or flowing over). The thermal inputs include vehicle heat, and vehicles also provide mechanical stress to the roads, or what covers them. But other, and often dominant, factors in road condition are from weather. Thermal inputs from the Sun are via weather: Air transfers heat and weather includes cloud and other radiation-blocking effects. Winds and visibility effects are from weather. Snow, ice, and precipitation are weather. There is a vital flow from weather information to road surface processes. Except for the important issues of surface freezing and local fogs, weather determines road conditions absent consideration of prior road conditions. Further, it is usually preferable to infer road conditions from large scale weather information rather than from road condition observations that are limited in characterizing all the particular road segments.

The overall situation then is that weather is an input to road condition processes, and rarely conversely. Weather is a sufficient input in many cases. It is not sufficient primarily in predicting surface freezing and local fogs. In these cases, road condition observations may be sufficient for predicting road conditions. The input of road condition information to weather processes would be important at very fine scales of weather analysis and prediction. However, the economics of observation are crucial. Since surface weather observations are limited, there is some value in integrating all surface observation sources, for *both* weather and road-condition processes.

Figure 3.1.1then shows four processes providing road-condition information to a DSS. One is direct road condition observation. Two deal with road thermal predictions, one using the road-condition observations, the other derived from weather information, called heat balance modeling. Finally, there are the mixed cases, where some combinations of road-condition and weather information are fused for the purpose of deriving road conditions. For winter road maintenance, the latter are primarily concerned with the freezing and persistence of precipitated water on roads. This includes ice layers (black ice or frost) by themselves, or as a bonding layer under snow.

The dominant direction of information flow supports the view that RWIS is a recipient of weather information, but also that RWIS must be a combination of weather and road condition information. The possible combinations are what insist on an open system. Further, at the root of both information paths are observations that have the most utility when shared, in an open system. More insight on the processing of information is developed in the next subsections that treat the types separately, and then together.

3.2 Weather Information

The taxonomy in Appendix A1 should be consulted for the listing of what is considered "weather" under type 2.1.1. This subsection states the key characteristics of weather information relative to the supply of road-condition information.

Weather is in the atmosphere and concerns the state of the atmosphere or phenomena in the atmosphere. Strictly defined, there are six atmospheric state variables (and their implicit space-time dimensions) captured in fluid dynamic models for NWP. These are the scalars of temperature, humidity and pressure, and the three wind vectors. From these, weather analysis defines other sensible variables, mainly hydrometeors (precipitation), and the phenomena of clouds/fogs, lightning, air masses, fronts and storms. The atmosphere is driven predominately by solar energy inputs, that are also the primary thermal input at the terrestrial surface. Solar weather and the electrical environment are important for many purposes, including ITS operation. These are included by the taxonomy in "weather".

The atmosphere physically interacts with the terrestrial surface. However, the concern of weather practically stops at the atmospheric boundary layer, within a few meters of the ground surface where interactions with the ground cannot be neglected beside interactions strictly within the atmosphere. The term "surface weather" or "surface observations" refer to levels above the boundary layer. ESS and weather observation systems such as the Automated Surface Observing System (ASOS) both measure surface weather attributes that can be treated both as weather and road conditions. In NWP models, the lowest pressure layers considered can be hundreds of meters above ground surface. Apart from water and thermal inputs from the oceans and the Great Lakes, weather prediction considers terrestrial inputs only at very fine scales. Orographic forcing is important at synoptic and meso scales, and finer topographical databases are part of the advances in meso-scale NWP modeling.

The usual starting point in comparing weather information relative to road-condition information requirements is to criticize weather information as not sufficiently timely, relevant, or accurate. These general objections can be specified as follows:

Timeliness

Weather predictions are from, or based upon, the NWP models run by the National Centers for Environmental Prediction (NCEP) of the NWS. In the past, these models have been synoptic scale, and run twice daily based on the international synoptic cycle of observations. The results are for specified time horizons out to days. Currently, the Rapid Update Cycle (RUC) is the most frequently run model, and is run hourly. Weather analysis from the Weather Forecast Offices (WFOs) is scheduled for two full forecasts and two updates per day, although watches and warnings can be issued as necessary. The problem with timeliness is most likely based on differences between when environmental information is consulted, and the last forecast available. Or, it could refer to a horizon time of a decision compared to the stated horizon of a forecast. The difference could be hours. Observations can be disseminated more quickly, but age most quickly. A system geared to, at best, hourly reporting, and at worst the 12 hour synoptic cycle, is not geared to “information on demand”. The VAMS and RWIS fill a role for more rapid observational updates, including the ESS observations.

Relevance

This may refer to the attributes reported or the spatial specificity of weather information. As has been emphasized, weather is not road condition, and meaningful road conditions require road-segment specificity. The tailoring constraint has been used to keep the NWS away from road condition issues, although the PIR argues that this is a false argument when applied to environmental information as opposed to true decision support applications. The underlying technical problem is then one of observational sufficiency to support fine scales of prediction.

Taken together, ESS sites, ASOS sites, cooperative observing sites, and other environmental sensors (fire-weather, agricultural, etc.) do not fully cover the road network. Doppler radar is an important source for precipitation, wind and severe storm information over large air volumes, and resolves to 1 km. However, it is limited in near-ground sensing where there can be important orographic and precipitation phase-change effects. Remote sensing by geosynchronous satellite (necessary to give continuous coverage), resolves between 1 and 16 km, depending on spectral band and location. Higher resolution of low orbit satellites (down to 1 m visual resolution) is useful for periodic coverage in some applications. Analysis results from WFOs are commonly presented for watch/warning areas, that are county-sized.

The highest resolution NCEP NWP model, called Eta, runs at 32 km although local models down to 5 km are becoming common. Spatial resolution (and proximity to a location of interest) is limited by *in situ* observation sitings, and remote sensing resolution, as well as the computing power available for NWP. Operation of higher resolution NWP models has been limited to the VAMS and special applications in limited domains. Resolutions down to 1 km but in sub-state domains is now feasible. This still may not be adequate for full characterization of road segments, and processes to infer the road conditions from the weather information still must be developed. In summary, almost none of these weather-information sources resolve individual road segments, they usually do not cover to ground level, and weather attributes are not identical to road condition attributes.

Accuracy

Measurements of accuracy are not simply defined for space-time phenomena, and where validation is limited in any case. Meteorological validation, such as skill scores, deal with space-time aggregates equivalent to synoptic scale[15]. For road conditions, it is easier to relate to point errors, as in the start time of an event or errors for observation sites (e.g., road temperature at ESS sites). For events, it is relatively easy to set probability of detection and missed-event rates (e.g., 90% or greater and 10% or less), but this is time-horizon dependent, and when the spatial dimension of jurisdictions is considered, the problem gets back to defining what an "event" is. Similarly for point measurements of precipitation when the network of interest is not at a point. Road temperature may be characterized as an event-threshold value, for the freezing point of water, but that does not translate directly into a weather event. Road temperature validation at ESS observation sites is best documented [see STWDSR V1.0]. Measurement accuracies within $\pm 1^{o}$C s.d. are expected and even predictions within 24 hours are expected to be within $\pm 2^{o}$C s.d. But the issue still arises of how the performance extends spatially over the network. Any measurement has instrumental errors and any prediction has errors due to errors in the initializing data and the prediction model. Adequate accuracy can be defined only with respect to the decision payoff risks, and the cost of increments of accuracy. Neither of these is well defined. The risk has to be relative to spatial resolutions and time horizons for a decision, so that accuracy requirements are not generic.

All three deficiencies in weather information are related to the scale gap between weather and road-condition information. There is frontier of performance as defined simultaneously by resolution, accuracy and time horizon. The highest resolution predictions are effective to 6-12 hour time horizons, which covers many important transportation decisions. At decision time horizons out to 24 hours or more, effective resolution will deteriorate toward the conventional synoptic resolutions (above 32 km). At the shortest time horizons (0-2 hours), observations alone, or fused with NWP results should be used. This mixing of sources over scales is another important reason for connecting environmental information processes.

At short horizons and high resolutions, NWP models can be adaptively re-initialized. This replaces the batch initialization cycles of several hours with more continual use of observations, especially where weather is rapidly changing.

Rather than demanding a particular accuracy, it is better to accept available information with some meta data about its risks. While accuracy is a matter of validation after the fact, there are means to generate the statistics of information *a priori*. One means is to run a distribution of predictive models in an ensemble. There are inherent limits to NWP resolution, accuracy and time horizon, and their tradeoff is partly a matter of the computer power employed. But there is a point where use of computer power to run an ensemble to get an average prediction with an idea of its risk will be more useful to decision support than devoting the computer resource to

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[15] It is planned to publish material originally intended as appendices to this document that will further describe issues of ESS and weather information performance, especially the relations of accuracy, resolution and time horizon for NWP models.

predictions of high resolution but unknown risk.

Predictive accuracy almost always deteriorates with time horizon (an exception being road temperature, or other cases where there may be diurnal cycles in predictability due to stabilization of conditions). Closing the current scale gap between weather and road conditions probably has less to do with customer demands for weather information than with the inherent desire of meteorologists to measure and predict the atmosphere at finer scales as the means to do so are made available. In this case, programmatic attention by road interests should be more on road-condition information sources and their fusion with available qualities of weather information.

There is, however, a strong mutual interest between weather and road interests in observing systems. *In situ* (fixed point) observations still play their traditional role at reporting stations in characterizing “current conditions”. These are reported as if for cities, even when the observations are at a point, often at airports. This localization, and possible bias is similar to the problem with ESS. For weather analysis, and especially numerical guidance, the in situ observations are becoming less relevant (except for climatic time series) compared to remote sensing.

Remote sensing observations, at geosynchronous and finer resolutions, might be better adapted to surface transportation purposes. This is being pursued in the NASA/RSPA program for applications of remote sensing (meaning by satellite) to surface transportation. It is unlikely that road-condition requirements will determine technology deployment or development. However, there is potential in better applications and institutional arrangements in the use of existing data. This includes any ‘snapshot” applications (e.g., thermal mapping) for high resolution, low orbit, satellite and aerial sensing. Terrestrial-based remote sensing (e.g., sounders, radar or lidar) is still important, and perhaps most directly applicable. Road-condition applications might play a role in joint investment decisions for these terrestrial systems and the software that does their signal processing. In the case of precipitation characterization from Doppler radar, there is a significant conjunction of meteorological and road-weather interests. A similar case may be made for atmospheric moisture through ground-based Differential Global Positioning System (DGPS) signals. This is particularly pertinent since the DGPS program is largely under USDOT auspices (with Coast Guard and FAA components).

The current scale of weather information has had significant institutional implications. Weather information tends to be centralized, and this corresponds to synoptic scales of weather for which national jurisdictions are the minimum feasible ones. As a result, there are national weather services. In the U.S. this complements a tight inter-federal coordination between the NWS and other federal agencies that are weather-information users or producers, especially with the military and the FAA as airspace operator. The OFCM has mediated inter-federal projects, of which joint observing systems like ASOS and the NEXRAD Doppler radar are significant examples. The FHWA has not been a part of these ventures because it is not an operating agency, and the road interests have been diffused at the smaller scales of the state and local operators. High resolution NWP models in small domain tend to promote decentralized jurisdictions and the consumer-vendor relations of the RWIS. But as finer scales in weather promote a greater integration of the air/land/ocean environment the existing institutional arrangements will change. NCEP may well progress to a national domain for a 5 km resolution model, and/or there may be decentralization among the WFOs and NWS regions.

In the meantime, high resolution NWP modeling is becoming part of RWIS on a decentralized, non-uniform and customer-vendor basis. As long as there are multiple sub domains needed to cover the highway system, problems of coordination, in terms of assimilated initializations, boundary conditions, reconciliation at model boundaries, quality assurance, availability, and ensemble modeling will exist. This suggests some hierarchical organization, if not a centralized one. In any case, an exchange of information between model domains will become important.

3.3 Road Condition Information

Road conditions can be defined broadly as any measurable attribute of a roadway, including the traffic on it, its structural integrity, and anything that affects its traffic. As used here, and as a subset of “environmental conditions”, road conditions will mean those attributes defined under the Roadway Environment terminator of the National ITS Architecture, and measured by the ESS. This includes the road surface conditions caused by weather, other weather that affects road operation or use, and environmental effects of road operation (particulates, exhaust emissions, and runoff). For operational-scale treatment decisions, the road conditions that result from weather threats can be narrowed further, to those that are mitigated by ice treatment, snow removal and related cleanup (e.g., of incidental blowdown or meltoff flooding). Snow drifting is subject to snow removal. Snow fencing to prevent drifting, or highway location and design decisions are at the planning scale. The planning scale will use climatic forms of most of the environmental conditions cited for operational decisions.

The scale difference between weather and road condition has been mentioned. However, a more careful distinction has to be made for weather information supporting operational-scale decisions in highway operation. The relevant spatial object for physical effects is a road segment as defined by climatic differences in thermal, wind and drainage characteristics. This is necessarily the “atomic” level of road-condition information. However, operational-scale winter maintenance decisions typically are made for jurisdictions and sets of treatment beats. In this case, the spatial scale differences are not that great, but the problem of translating weather into road conditions still is. The finest scale applies to warning decisions. These will be made by travelers based on observational information, either directly by the traveler/vehicle or at fixed sites, as in fog-hazard areas. For treatment trucks, it is expected that driver perception and mobile sensing on the trucks is necessary for treatment control. Spot ice-hazards (e.g., on bridges) are best treated by fixed sprayers under automatic control. An operational-scale DSS typically does not work with micro-scale information because it is not reliable at the necessary prediction horizons. There is an analogy with how NWP uses aggregates of point observations through assimilation. Operational-scale decisions must consider some risk of threats not at specific points, but over some space and time aggregates where not every point is directly observed.

Whatever the scale of physical effects in weather versus on road objects, they are fundamentally different in topology. A road segment is practically a linear object, and not an area under a grid, nor a cubic volume, so it is hard to make comparisons between weather resolution and the resolution of road segments. Thermal effects due to topography and road/subgrade structure can be differentiated well under 1 km. Orographic effects at similarly small scales are significant to winds and therefore to snow drifting. Small water bodies and small scale topography are significant to fogs and flooding. The same factors that create small-scaled climatic differences dictate that there is no unique dimension to the scale of interest. In flat areas with road on grade, segments of many kilometers may be homogeneous up to the relevant weather scale. In rugged terrain with steep elevation changes, there will be climatic differences between elevations and relative to shading by the topography well within scales of weather change.

It is nearly correct to say that for winds and local visibility threats that are in the warning scale, and not usually treatable, the only useful weather scale is micro. At this scale, almost all weather information comes directly from local observation. For road-surface freezing (e.g., black ice or condensation frosts), conditions can be quite local and information also has to be micro-scaled. This results in the strategy of placing ESS at critical freezing spots, and the need to infer treatment decisions at larger scale. Surface freezing, by itself or as an ice-bonding layer under snow, are the conditions dominated by the thermal dynamics of the road surface and subsurface. These are simpler and more sluggish than atmospheric dynamics. For flooding, resultant road conditions are spatially micro, but the dependence on precipitation and the time constants of terrestrial hydrology can put prediction usefully into the operational scale, with the exception of "flash" flooding situations. Other precipitation effects, especially snow that is treatable, are primarily at operational scale because of both the atmospheric time constants involved and the relative homogeneity of the precipitation and surface areas being covered.   Large-accumulation snow storms are synoptic in scale. Small and violent convective storms can occur in winter, but are mostly a non-winter threat. Nonetheless such convective winter storms would be of critical interest and are well into the meteorological meso scale, best characterized by radar observation, and a challenge in NWP modeling. Very light snows will be more like surface freezing, with micro spatial scales of differences in threat where it melts, sticks or drifts.

Since the interest here is in the road conditions that interact with weather, a systematic list of attributes is created by considering weather threats to road operation and use. Threats (stated as road conditions adversely affecting highway system) are indicated in the table below, with the causal atmospheric conditions.

Table 3.3.1: Threats to Surface Transportation Performance

Performance Threat	Road Condition	Atmospheric Condition
Threats most relevant to winter road maintenance treatment:		
Loss of traction	frozen precipitation on surface surface freezing (black ice)	temperature humidity precipitation (type, rate) winds/stability cloud cover insolation
Impaired plowing	snow/ice bonding (incl. surface freezing)	(all factors in surface freezing) precipitation (type, especially liquid content)
Lane obstruction	snow accumulation snow/freeze-related blowdown, slides and meltoff	winds severe storms precipitation (type, rate, history) icing (trees, wire lines) temperature (change rates, history)
Treatment chemical dispersion	surface washing winds	precipitation (rate, history) winds
Impairment to treatment truck operation	See other threats to highway use	
Other treatment-resource impairment	Conditions affecting crew health/safety Conditions affecting stock usability Conditions affecting communication and control	temperature extremes severe storms lightning solar storms/flares icing (trees, wire lines) humidity (affecting communications) air layers/inversions (refraction affecting communications)
Threats relevant to other surface transportation decisions:		
Loss of traction	wet surface	precipitation (type, rate)

Performance Threat	**Road Condition**	**Atmospheric Condition**
Loss of maneuverability or stability (other than loss of traction)	high winds, gusts flowing water	winds severe storms precipitation (rate, accumulation) temperature (meltoff) water level, wave height
Lane obstruction	fallen objects blown debris flooding avalanche and washout debris	winds severe storms precipitation (type, rate, history) icing (trees, power lines) temperature (meltoff and history) water level, wave height
Road damage	road washout road buckling frost heaves pavement failure structural failure sign/barrier destruction	winds severe storms precipitation (type, rate) temperature (history, change rate) water level, wave height
Loss of communications and control	power outage communication failure circuit damage	lightning icing winds severe storms solar storms/flares humidity (affecting communications) air layers/inversions (refraction affecting communications)
Vehicle damage	falling objects blown vehicles	precipitation (hail) severe storms icing
Loss of visibility	reduced road-level visibility	precipitation (rate, type) fog winds (dust, snowdrift) visibility, ceiling air layers/inversions (refraction)
Vehicle emissions	cold starts hot soaks	temperature (history)

Performance Threat	Road Condition	Atmospheric Condition
Emissions reaction and transport	exceeding air quality standards for CO, NOx, ozone, PM	winds air stability insolation cloud cover precipitation
HAZMAT dispersion	spills plumes	precipitation winds temperature/insolation (for evaporative plumes)
Threat to work crews	heat cold wetness falling/blowing objects winds	temperature extremes humidity (heat index) winds (wind chill index) precipitation (rate, cumulative) severe storms
Threat to work materials	heat cold wetness falling/blowing objects winds	temperature extremes precipitation (rate, accumulation) humidity winds severe storms

For road conditions that are related to weather, weather is rarely the exclusive cause. The resultant threat to road performance is some combination of the weather with the road and traffic characteristics. Therefore, although the effect of road conditions on weather is *mostly* negligible, the relevant threats are a more even combination. The relevant physical road and traffic characteristics include:

- Road temperature
- Topography local to the road (surrounding landscape and cut/fill/grade level of the road)
- Local physiography and biota (dust sources, windbreaks, shading, water bodies)
- Wayside human-operated (“anthropogenic”) processes (stack plumes, etc.)
- Road drainage
- Road structures (any local overhanging or elevated structures)
- Road design (grades, curves, widths, lane separations etc., that affect the outcomes of visibility, traction and stability impairment)
- Traffic volume (relative to road design and as a source of heat and mechanical stress on the road)
- Traffic weight limits (mechanical stress)

Of these, road temperature has been a particular focus of the RWIS and ESS. The physics of road temperature are qualitatively different from the atmospheric physics, and this stipulates a lot for the processing of the road condition information. The important differences are:

- Road temperature has localized climatic variation, at a scale below meso scales of weather.
- Road temperature and weather are driven mostly by insolation. Weather affects its own energy transfer, as well as that to roads, but the latter is also modulated significantly by local orography and other shading/reflection.
- The energy transfers of road temperature drive diffusion dynamics, that are approximately one-dimensional, and very different from the essentially three-dimensional hydrodynamics of the atmosphere.
- Road surfaces and subgrades have widely varying thermal parameters, relative to the homogeneity of air.
- The ground is a thermal reservoir with large inertia relative to air.
- Besides insolation, terrestrial heat transfers (adjacent heat reservoirs, running water, vehicles, thermal activity, surface water phase change, chemical reaction/phase change) cannot be ignored in road conditions.
- The early-AM period is a critical time for road freezing. Since it is also a period of no insolation and air stability, it tends to be least critical and most homogeneous for weather (calling ground fogs surface- more than weather-conditions).

Some of the road condition threats from weather, e.g., related to precipitation, are causally dominated by weather. However, the ice and snow threats treated by winter road maintenance are significantly affected by road temperature, and specifically temperature that falls below the phase change of water to ice. This affects surface icing (that affects tractability) and the formation of a bonding layer of ice beneath snow (that affects snow removal and residual tractability after snow removal). The critical temperature varies because the molal freezing point of water can be depressed by dissolved chemicals, as is the purpose of pretreatment by chemical application. Therefore, a *range* of temperatures at and below 32^{o}F/0^{o}C is critical to prediction for treatment. Fresh chemical applications can maintain very high chemical concentrations and therefore very low freezing points. However, the more critical prediction cases may be after chemical dilution/dispersion, and with10% chemical concentration freezing points are down to about 20^{o}F or -5^{o}C. It must also be noted that chemical solution can be endothermic or exothermic (cooling or heating). In this case, there is not one critical temperature threshold to identify over a road network, but a range of many degrees. Treatment decisions must consider a distribution of temperatures over a road network along with the possible distribution of residual chemical. Both of these are affected by weather history.

The physics of road temperature is both an advantage and disadvantage to information supply. Thermal inertia means that *persistence* (prediction=observation) is a useful prediction model for time horizons of a few hours, and this includes many decision-time horizons. The diffusion model for heat transfer, along with the thermal time constant that represents thermal inertia, means that even longer time horizons can be predicted simply and reliably from observations restricted to the road surface and subgrade. Time series of surface temperature combined with clock time (for the diurnal cycle of solar insolation) are reasonably accurate out to 24 hours *at the point of the observational data*. This is sufficient for most of the operational-scale winter road maintenance decisions, where the constraining treatment time horizon generally is between 12 and 20 hours[16]. Such models have to perform best when the critical temperature range is reached. For surface freezing, a fortunate fact is that the most critical time is within a few hours of sunrise. When the sun is not up, all variations in insolation are irrelevant (being captured in the observable subgrade temperature profile). Although cloud can still affect radiative cooling, at this time the air tends to be stable so that convective variations are minimum. For this reason, predictive accuracy for road temperature is best around this time, better even than shorter-horizon prediction during daylight. The downside for road temperature is its climatic variability along roadways. ESS location has rightly focused on measuring the critical locations, that are most likely to freeze and most threatening to traffic safety. This automatically creates a climatic bias with respect to weather, and hence the issue of integrating ESS and surface weather observations.

Thermal mapping has great utility in identifying the critical locations, and in giving some correlation between the observations at the critical locations and surrounding road segments. Thermal mapping is the surface-temperature measurement of some large portion of the road network. Thermal mapping should measure both a spatial distribution of temperatures at climatically comparable times, and across times that represent different shading effects over the cold period of the year. The virtue of thermal mapping is that it can be done on a snapshot basis, and does not require constant monitoring. How many snapshots are needed over a sseason is a question that is affected at least by topography. Thermal mapping and the selected placement of ESS should be very effective for predicting ice treatment needs as a function of road temperature. Good guidance on the number of ESS stations with thermal mapping is not available, and, of course, road conditions depend on more than road temperature.

Neither the ESS nor surface weather observation sites have enough spatial coverage for most road-condition applications. There are about 1200 ESS locations (defined as RPU sites) in the U.S. A total of 993 ASOS sites are planned, mostly covering the CONUS, with 569 deployed by the FAA and therefore mostly at airport sites[17]. There are about 4 million route miles in the public road network of the U.S., and 160,000 route miles of the National Highway System (NHS). There is a 5-50 rule of 5% of the route mileage (approximately the NHS) carrying 50%

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[16] Assuming staff shifts of 7AM to 3PM, if there is only one shift, a schedule splitting decision should be made prior to 7 AM. If two shifts are operated normally, the splitting decision would be made before 3 PM. The predictive lead times for freezing assume that about 3 AM is the critical time for reaching the critical temperature range.

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

vehicle miles traveled (VMT), and conversely for the last 50% of route miles carrying only 5% of the VMT. Therefore, the NHS and "everything else" is a practical dichotomy of the network in terms of impact on mobility and safety. Treatment cost, dependent both on the miles of road treatment and VMT, cannot be so dichotomized. However, for just the NHS, the number of ESS RPUs comes to one for every 133 route miles. This probably is insufficient to monitor road temperature reliably. Development of extensive mobile sensing in the ITS is important.

There are advantages and disadvantages to the various observational strategies. *In situ* observations are limited, but are locally specific. Terrestrial radar/lidar remote sensing has fair resolution and large volume-coverage, but not to ground level. Satellites have ubiquitous coverage but lower resolution, and are limited in ground coverage at various spectral bands. What is most important is to combine the advantages of each strategy. To define a requirement on any observational deployment requires an overall strategy, including the type and quality of downstream processing to derive road conditions. Figure 3.3.1 summarizes challenges to road-condition information.

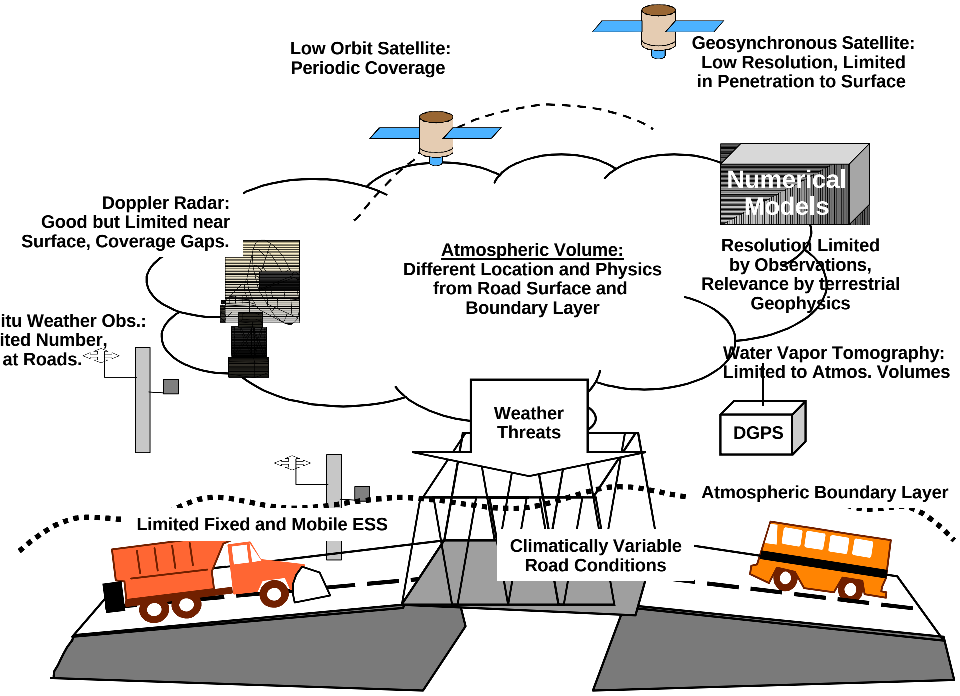

Figure 3.3.1: Challenges to Deriving Road-Condition Information From Weather Information

3.4 Integrating Weather and Road-Condition Information

The differences between weather and road-condition information can be summarized as:

- Institutional responsibility. There is a traditional division between supply of "weather" information by the NWS and the "tailoring" of this into road conditions by the RWIS, and with separate observational systems. New information processing capabilities, and a limitation of true tailoring to decision support applications will shift the division.

- The thread of information processing. Except for possibly autonomous road-temperature information, road-condition information is mostly produced from weather information.

- Information geometry. Weather is concerned with atmospheric volumes, sometimes sliced into two-dimensional layers, mostly along pressure contours that have variable relation to the terrestrial surface. Weather phenomena follow track lines, also with arbitrary relations to the terrestrial surface. Road conditions are defined on the discrete network of lines (road segments) and points (places, nodes). Mapping from the atmospheric space to the network is an issue of the scale of the information (how many discrete points of weather information there are) and where the discrete points of interest (grid points versus nodes) are defined in either case.

- Observed data and prediction models. The ESS and surface weather observations overlap for surface-weather data types. Otherwise, road surface and atmospheric state variables have to be observed by different instrumentation at different locations, in terms of altitude and climatic bias. Remote sensing is relatively more feasible for weather than for road conditions, while at the same time being economically attractive as a substitute for intensive *in situ* ESS location. Models incorporate entirely different physics for the road versus the atmosphere.

- Asymmetry in interaction. Weather affects road conditions to the finest scales, in combination with fine-scaled terrestrial effects. Roads affect weather perhaps at the micro scale, but not at scales of most meteorological interest.

- Ensemble statistics. For road temperature, continuous time-series prediction inherently generates statistics, but other road conditions rarely generate statistics. In weather information, statistics are generated mostly for synoptic scale NWP models and are least available for the regional NWP models.

- Scale. This is the single most important difference. Scale defines the gap in the technical and economic frontier of weather space/time/accuracy relative to road condition requirements. It leads to the institutional and observational differences as well.

At first glance, the differences might argue for keeping weather and road information separate. But the differences also make the information types complementary, or necessary substitutes in many cases. Figure 3.4.1 is a more detailed look at the interactions between the information.

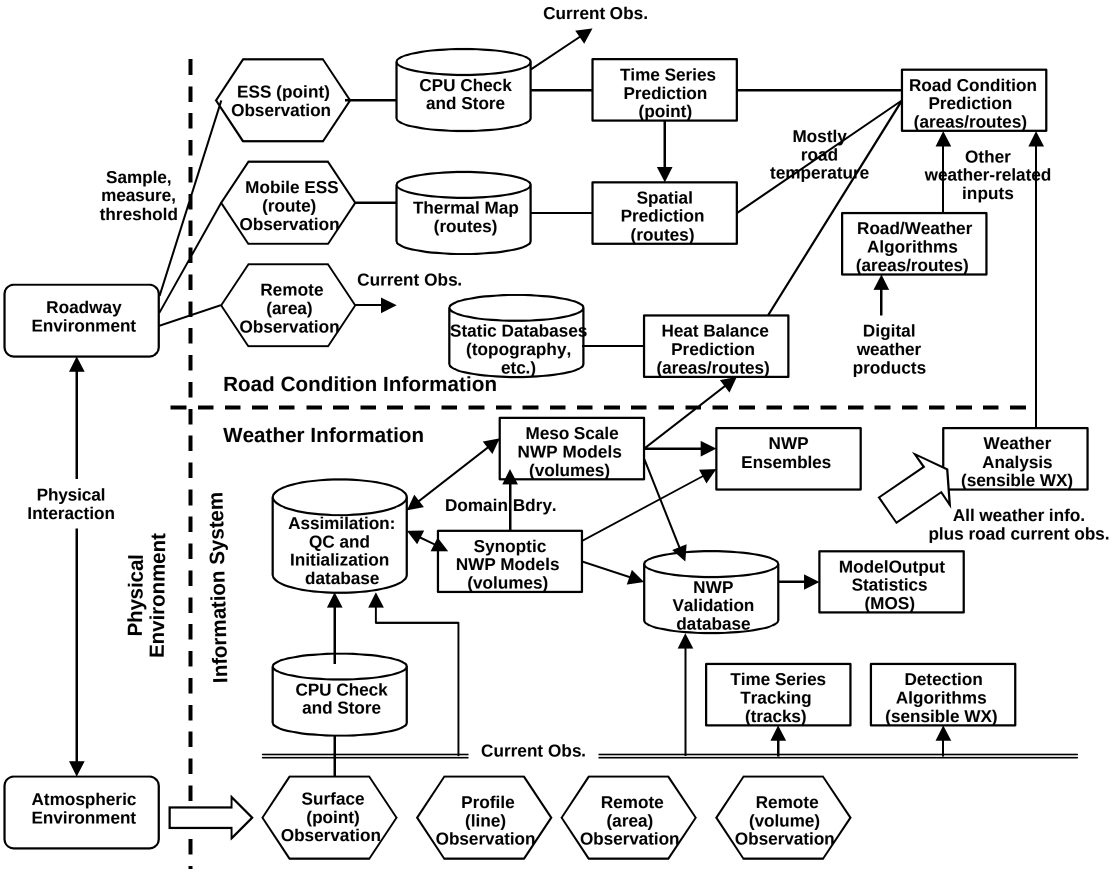

Figure 3.4.1: Processes in Weather and Road-Condition Prediction

The figure shows the physical environment on the left. It is ambiguous where to separate the information system into road conditions and weather. The physical environment does not make the distinction. The distinction is really made according to the threats that cause decisions on behalf of performance goals. In the case of winter road maintenance, what has to be known is what is treatable, and that is not the weather. In between the physical environment and the decision support, in other words in the supply of environmental information, there are many possibilities of process and data fusion.

One of the potential areas for information fusion is in data assimilation, shown where it is now, on the weather information side. Assimilation produces a smoothed (error-corrected) set of observations, used as the initialization grids for NWP models. Since this was first oriented toward synoptic models for hemispheric and larger domains, it naturally became a process centrally conducted with the largest possible scope of observations. The process of cross-comparing data, and with previous NWP fields, also argues for the largest available collection of data. This produces weights on the data as they go into initializing the next NWP run, but it also indicates the reliability of the individual data. Over some sample, quality control (QC) information is generated on the data and by implication on its instrumentation. This in itself could be valuable to the ESS.

On the road condition side, three types of measurement are shown. These are the point and mobile ESS, and remote sensing specific to road conditions (e.g., active infrared scanning, CCTV monitoring, etc.). These can make an important contribution by expanding the area covered by reliable, fixed equipment, especially for surface freezing detection. However, the current practice is that the set of observations is not assimilated, nor even put into a common database. This is due to the decentralization of RWIS services, and the local scale of most ESS observation. This, more than any characteristic of the data, is what now starts the divide between the information processing threads. This begs the question of what would happen if the divide were kept closer to the decision support interface.

Surface observations for weather are limited by the same economic factors that limit ESS sitings, and there is not much incentive for a great expansion in preference to remote sensing. The NWS depends primarily on the 993 ASOS sites for frequent and complete surface observations. There are other sources, but the most numerous are about 10,000 cooperative observation sites, manually providing partial surface information from volunteers. The ESS observations are another potential source, and are even now used for validation and auxiliary inputs to analysis at the WFO level. Assimilation of all surface observations is desirable to achieve mutual benefits. The benefit is probably more on the side of using other surface weather to quality-control the ESS. Because the ESS observation can be climatically atypical, there is hesitation in including them for weather purposes. Assimilation will determine what ESS observations are valuable to weather and the climatic bias inherent in ESS placement can be filtered out in the process. However, ESS along with other specialized *in situ* observations clearly multiply the available ASOS observations, and become significant as NWP requirements demand more observational data. What is less clear is how much of this demand can be served strictly by remote sensing. Meso scale NWP modeling practice presently relies on “mesonets” that include all available *in situ* sensors. The role of *in situ* sensors in validation of various products also is important.

Having the ensemble of observations in assimilation gives statistics useful in downstream processing, including determination of a reasonable initialization variation for prediction ensembles. The assimilated database as a whole, combining many types of observations, becomes a "nowcast" predictor. Because assimilation uses information about atmospheric dynamics (through use of previous NWP fields as the "first guess" field for assimilation) the assimilated data base represents value added over pure point observation. This enables an effective resolution improvement over the density of the physical measurements. In principle, adding road thermal-prediction models to the process would also improve the assimilation process.

The barrier of climatic bias in ESS data, if ESS sites are located at critical (freezing) points, can be mitigated if their location is based more on meteorological considerations. At such time as ubiquitous mobile ESS data are available, the problem becomes less acute. In the meantime, the best siting and density strategy for ESS is still an open question. Another project of the Road Weather Management Program is beginning to address the question in FY 00. Small gains to the assimilated data pool from less bias in the ESS siting may not balance the need for monitoring critical road segments, that *are* climatically biased, by a limited set of ESS.

For road-condition data, past time series of the point data are used for thermal prediction (and sometimes other predictions). The use of observational time series is less frequent in meteorology which is dominated by using the assimilated observations (a spatial ensemble) at each initialization time, and letting the dynamical NWP models generate the prospective time series. There are other processes that directly use the observational data. This currently applies mostly to the remote sensing, atmosphere-volume data.

Weather phenomena can be spatially tracked from radar and satellite imaging. Tracking is a time series filtering process similar to that used in road temperature time series. This commonly applies to cloud features in satellite imagery or cells of convective activity in radar or infrared radiometry. This is an important technique for weather prediction in the 0-2 hour horizon range. Combined with this it is necessary to identify discrete cells and to characterize precipitation in the cell. This is the focus of various algorithms using radar and multi-spectral data, and is a very vital area of research and practice. It will deliver useful resolutions for road conditions, but only at the short time horizons.

Weather observations are the basis of all weather analysis and forecasting prospectively, and validate those products retrospectively. This is the basis of learning in the information system, as described for the WIST-DSS learning mode. The process of learning selects parameters from the information system that correlate with the best validation. An operational form of this practice is the Model Output Statistics (MOS) product. This is based on regression analysis of NWP model outputs against observed conditions, so that the product is not the direct NWP output, but rather the predictor of weather from the regression with the model output as in the input variable to the regression. This also illustrates a use of ensembles, of different cases of model outputs and weather conditions. The approach requires a good historical sample of a stable model, and so is applied only to older NWP models at NCEP. The consistent historical sample is a problem for newer, continuously developing, high-resolution models. With the regression, prediction-reliability statistics are also generated, so the MOS approach is an important source for statistical information into any DSS.

Most of the weather information system shown in figure 3.4.1 is concerned with NWP production. The features shown are the production of the larger scaled, synoptic models that provide the boundary conditions for meso models in smaller domains. Any NWP model can be used to generate ensembles of predictions, by varying the initializations or parameters in a number of model runs within the forecast production cycle. This requires using additional computer time in a tradeoff against higher resolution (where justified by initialization data), larger domains, longer time horizons, or shorter production cycles. These tradeoffs tend to be more critical on meso-scale models and ensembles typically have been more available for the synoptic models. But there is no reason why growing computer power cannot be used for ensembles at the smaller scales. The advantage of ensembles is that central statistics are more reliable predictors, and the ensembles also give the error bounds and risk limits on the predictions.

The end product of weather information is weather analysis to predict the occurrence of sensible weather effects. The focus of analysis in the NWS is now the Advanced Weather Interactive Processing System (AWIPS) deployed in the WFOs. This is a DSS to the decision of “what the weather will be”. In terms of environmental context monitoring the AWIPS is excellent, but it is designed to support analysis by skilled meteorologists. Despite the rise in NWP use, the goal of automated analysis (effectively automated decision making about the weather) is still elusive, and the human meteorologist is very much in the loop. The AWIPS technology is key to making the NWS more graphical-product oriented. The primary products of the WFO analyses are still narrative forecasts, watches and warnings. But since graphical products that fuse many sources are the basis for the narrative products, the question naturally arises of why the graphical sources are not also disseminated. A server at the WFOs, outside the firewall, is being provided by the Local Data Acquisition and Dissemination (LDAD) system. The WFOs can also become hubs for local data assimilation and numerical modeling through the Local Analysis and Prediction System (LAPS). This makes the WFOs more powerful contenders for environmental information fusion, and disseminators of products. The AWIPS could be the basis for partially-automated collaboration between weather and transportation decision support.

The problem of keeping decisions and DSS in series is that the weather and following decisions may be responding to entirely different and contradictory risk criteria. For instance, the maintenance manager may be more concerned with missed alarms and the forecaster with false alarms. Or, there may be different payoffs to early versus late event-start predictions in either case. Because weather analysis remains a human and subjective decision, there can be a wide variation in relative risks between particular forecasters and particular managers using the results.

Relative risk bears on some of the general criticisms of weather information, including perceived accuracy and relevance of the disseminated information versus the much richer supporting information. The perceived accuracy is not good. The failed forecasts tend to be remembered more than the good ones, probably because of the higher cost of missed alarms to operations. This is a motivation for reaching farther back into the weather information stream for interfaces with the DSS, raising the problem of fusion, and the equivalent of weather analysis, in the DSS. The DSS should not put the surface transportation decision maker in the role of a trained meteorologist. But neither should operational decisions depend on subjective assessments of weather risk by someone unassociated with the operational decision. Quantitative statistics to reflect risk is an important strategy for tailoring the weather information for operational decisions. It can supplant the human-to-human collaboration that the NWS is limited in doing, and what VAMS often do. The DSS is the tool to enhance this collaboration above narrative exchanges. When this occurs, a link to the AWIPS could be as viable as links to VAMS analyses.

Assuming that no highway DSS does independent weather analysis, there is only one thread that can cross back over into weather information from road-condition information. That is current observations from ESS. There are five processing threads shown going into road-condition prediction, three of which are from weather information. These are:

1. Weather analysis (i.e., the typical NWS products that are publicly disseminated).

2. Algorithms that tailor weather information (generally digital products further upstream from analysis) into road-condition information.

3. Road thermal predictions from heat balance models, requiring NWP models (preferably high-resolution).

4. ESS point measurements, used for time-series prediction (aka filtering, e.g., Kalman filtering) of thermally-related road conditions (especially surface freezing) and sometimes other conditions.

5. The spatial prediction (aka extrapolation or correlation) of the point ESS observations and predictions via thermal mapping of the road network.

What is called RWIS can include any or all of these threads. Typically, heat balance modeling for road-thermal predictions is competitive and mutually exclusive with the ESS-based methods. Heat balance modeling uses weather prediction to infer road temperature, and of course the other weather effects come along with this. Both the heat balance models and other road-condition algorithms are kinds of “post processors” needed to convert NWP results to road conditions. The heat balance approach has been a primary motivation for use of higher-resolution NWP models.

Thermal mapping and the heat balance models both require initial survey data, so the tradeoff between the two is more in the investment in ESS versus the meso scale modeling. This tradeoff may have a different balance of capital versus operating costs as well. The post processing that is involved (filtering and spatial prediction for ESS, the heat balance models for the NWP grids) is also comparable in investment, and comparably proprietary under the VAMS. The desire to avoid more extensive ESS investment, or if ESS are bought, to avoid the expenses of the heat balance approach, is one reason that the two are not much combined. However, there is good reason to use ESS observations of road temperature in the initialization of the heat balance models.

Heat *balance* refers to the net input and output of thermal energy to the road surface that, with the diffusion equations, determines temperature. The energy flows include to/from the subgrade (conduction), the air (boundary layer conduction, convection and radiation), water phase changes at the surface (energy from condensation, energy to evaporation), and radiation in from the sun or surrounding objects that re-radiate or reflect solar energy. But road temperature is both the result of these processes and a major determinant of the heat transfer to and from the road. Therefore, like any weather state variable that is both initializing and predicted, it makes sense to put road temperature into the heat balance model as an observation as well as extracting it as a prediction. How to reinitialize the heat balance models efficiently with sparse data is subject to further study. Some European practice (e.g,Denmark[18]) uses the reinitialization process. In any case, some combination of the ESS-based and heat-balance techniques probably is superior to either alone. It is a matter of finding their most economic balance.

Within each thermal prediction technique there are also tradeoffs that have yet to be studied thoroughly. The most efficient density and placement of ESS with respect to thermal mapping or heat-balance modeling is one issue. And while higher resolution in the NWP models is always better, it has to be supported by observations, and what is the best mix of observation types? Over varying time horizons, and possibly at various locations, what weight should be placed on what prediction technique? This is a data fusion issue that must use all sources and reliability statistics on them. In general it is expected that as time horizon increases, the reliance goes from observations (persistence), to simple filtering of observations, to more complex predictive algorithms and NWP models. What is relied on in a particular location is then affected by observation coverage, including the *in situ* and remote sensing instrumentation.

The “one environment” axiom suggests that fine scaled environmental products, using all available information sources, should be provided in the information infrastructure as common to many applications. But if there is only a limited market in specific applications, the information is effectively “tailored” for the DSS applications. The NWS could move into the finer scales of integrated environmental information, which would define it as a common resource, but there is also much latitude here for the VAMS.

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[18] Sass, Bent H., Forecasting of Winter Time Road Conditions Using a Numerical Model, pp. 10-12, 15th International Conference on Interactive Information and Processing Systems, 1999, American Meteorological Society.

The apex of figure 3.4.1, for the DSS most interested in threats to road condition, is the box labeled Road Condition Prediction (areas, routes). Although weather information is criticized for its spatial aggregation, an important part of any road-condition post processing is to translate a spatially-distributed risk into decision criteria that are over aggregates of jurisdictions, or at least treatment beats. The spatial aggregate of the decision also goes along with the longer time leads for larger jurisdictions. The inherent uncertainty, and spatial aggregation of the environmental information, means that even if point information is available, it is applied in operational-scaled decision criteria as statistics and the consideration of risk in committing resources. At the longer time leads, the issue is whether the probability of some event of some magnitude is great enough to split crews and ready resources. At shorter time horizons, it is how to dispatch a beat, not to treat every predicted point of threat, but so that any given beat will encounter a reasonably dense distribution of threat over the beat. For large storms that will be fairly uniform in the spatial threat over a jurisdiction, timing is more essential than the spatial element (as indicated in the responses analyzed for the OCD). For spotty black ice, the risks are in missing predictions not just at ESS sites, but over a whole beat. Knowing the risks, in order to make decisions, requires contributions from all the environmental information processes. Conversely, fusing the information is also a matter of weighting the sources according to reliability risks, and the risks are a function of time and space for different sources. In short, a DSS must be designed to use the best mix of information, from weather and road-condition observational sources, for particular decisions. Without the statistics on the sources, the best mix cannot be known.

At present, the information infrastructure must be open to potential mixes of processes that will be demanded by DSS applications. Over time, and if the risk statistics are available (or equivalently, statistics on performance from the learning mode), some threads of information processing may become standard “best practice”. If some of these threads serve many DSS applications, they are not “tailored”. For those DSS applications that continue to mix a variety of information sources, according to particular decision needs, the tailoring is limited to the DSS application. Lacking the experience to define either case well, it is unwise to define any part of environmental information processing as tailored now.

3.5 Regional Responsibilities

The public/private division of responsibility for environmental information has been discussed, and is an open issue for many processes. Another important issue is the geographical allocation of information processes.

The axiom of open systems creates easy exchange of information regardless of the geographical location of processes. However, if there is one environment, it has geographical continuity. Geographical regions for information processing emerge because there are cross-inferences between data that are spatially nearby, and processes should exploit this. Also, since most decisions are in spatial jurisdictions, products have to be spatially presented in regions. The size of a region chosen has to do both with the decision jurisdiction and the characteristics of the information processing.

Decision jurisdictions for winter road maintenance generally are from county to state size. In information processing, the operation of NWP models at various resolutions is a key factor in defining regions. In the NWS we see a geographical hierarchy of services, with central offices, like NCEP, supporting the local WFOs and River Forecast Centers (RFCs)[19] over the U.S. for regional service. In the Southern Region of the NWS, meso-scaled NWP models are being installed at several WFOs, with some integration at the regional office. In road weather, regional service centers are forming around NWP models and associated mesonets of observations. Important examples are Foretell (IA, MO and WI), the Advanced Transportation Weather Information Center (ND, SD, MN and part of MT), the plains states mesonet around Salt Lake City, UT, and the Washington State road weather program.

What is emerging is a geographical partitioning of the U.S. for the delivery of environmental information applied to road conditions. Regardless of whether the NWS or VAMS ultimately operate the regional NWP models, the geographical partition should avoid overlaps and gaps in coverage, while assuring quality, and integrating information across regions as necessary.

Regional NWP modeling creates a scale-hierarchy of information. High resolution NWP models are run in national subdomains. This is dictated partially by limited areas with appropriate observations, and by the allocation of limited computing power in the resolution/time horizon/cycle time tradeoff of numerical guidance production. At present, the finest national scale resolution produced by NCEP is a 32 km grid. Examples mentioned above are going below 10 km grids, below 5 km is readily feasible in domains about state-sized, and 1 km grids are being produced in sub-state domains. NCEP may be producing a 5 km grid over the nation in the not-distant future. In any case, the boundary conditions in small NWP domains must be established by larger-scaled NWP models. NCEP is the accepted source for this, and some NWP models also nest their own grids within the NCEP boundary conditions. If the NWS adheres to its policy of keeping NWP modeling centrally in NCEP, then any finer-scaled modeling will necessarily be outside the NWS. As well as the ability to achieve higher resolution in smaller domains, a focus on a region can also improve numerical guidance by using regional climatological skill.

There are scale economy arguments for regionalizing into relatively few environmental information service centers. However, the converse argument is that more centers, and the dissociation of various information processes from real geographical centers into the virtual

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[19] The latest inventory counts 124 WFOs, including 5 planned and 3 to be allocated a location. There are 13 RFCs. Source, NWS file extracted 8/22/00 at www.nws.noaa.gov/pub/modernize/facility.txt

space of open communications, could promote innovation and synergies of overlapping information.

The 124 WFOs are probably too numerous to do regional modeling efficiently. They are there as appropriate allocations of human weather analysis. The 13 RFCs are a more likely number. There is an analogy with the Center Weather Service Units, that serve aviation weather needs in the 21 Air Route Traffic Control Centers in the U.S. As a concept, a national hierarchy of weather/road condition prediction would have the NCEP supporting several regional service centers, of number probably between 10 and 30.

Once there is a tier of centers below the national level, the issue of coordination arises. There are needs to reconcile possibly different information at regional boundaries, and to extract value from the synergy of multiple approaches to generating the information over a region. The latter includes the ensemble approach, where multiple processes for the same information produce an average that is better than the individual products, and also generate the risk statistics necessary for DSS.

France[20] has faced the problem of having national subdomains of NWP operation, and found it necessary to apply some coordination to alleviate the boundary discrepancies at the model domains. This approaches the problem of collaborative decision making. A single large scale boundary grid is not sufficient to ensure that subdomains create the same predictions at their boundaries. But unless the synergy of multiple predictions is exploited in some way, the reconciliation can be a force fit that does not improve overall performance. Where models overlap, ensembles can be created. Multiple predictions of some boundary domain may allow a more reliable average to be used, that can then be smoothed back into the internal model domains. The problem is similar to observational assimilation. The approach also represents what can be done in parallel computing, effectively creating one big domain out of many coordinated ones. Alternatively, the area of overlap can be greatly expanded, so that each area is covered by multiple models that approach a true ensemble in one domain. In either case, there is something to be gained by sharing of information.

The coordination involved could be achieved under one agency. But the open system concept equally supports an information exchange among different institutions. A true hierarchical system would consist of an agreement for information exchange, but otherwise autonomous operation of the regional centers. This is more analogous to the operation of the NHS.

The provision of environmental information is, of course, not restricted by the spatial constraints of NWP models. There are issues of how observational data is collected and assimilated. At

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[20] Benichou, Patrick, Overview of the Meteo-France Experience in Graphical Interaction on the SYNERGIE Workstations, pp. 434-437, 14th International Conference on Interactive Information and Processing Systems, 1998, American Meteorological Society.

present, the main model is the NWS. All observational datasets are distributed through NOAAPort, now mainly to support the AWIPS in the WFOs and RFCs. The addition of ESS data to the assimilated observational database suggests keeping a central database under the NWS. An alternative is local assimilation, following the LAPS model, where the data are used locally in NWP and other processes. There are tradeoffs in doing this. One is the reduction of communications costs by keeping data more local to its use, versus having national assimilation. Communication technology mostly favors a larger, centralized, dataset. If most data are from remote sensing anyway, and transmitted through the NOAAPort satellite broadcast, the loading from any number of in situ observations will be relatively small. The greater problem is the transmission of NWP grid products from many, fine-scaled, subdomains. These weigh more toward decentralized fusion, possibly with a center-to-center communications network rather than the centralized broadcast of NOAAPort.

There will be many kinds of processes tied into the application network for environmental information. If there are geographical service centers of some sort, these should not restrict the innovation and use of processes. Rather, they become a market for the processes. In the future, most processes, such as prediction filters for ESS time series, will not stand alone in serving DSS applications. Assuming that most environmental information fusion moves out of DSS applications into an information infrastructure, individual processes will have to find the synergies with other processes in service centers, or over an open system. Relatively few service centers may accrue scale economies, but also form a small market for innovation. Inevitably, centers tend to stovepipe internally and resist alteration to their systems. This is a tradeoff between some geographical focusing of processing, and leaving it entirely in the virtual space of an open system (and open market) for processes.

Looking ahead, there will almost certainly be some coalescence of regional services, and a need for an appropriate hierarchical coordination. The more centralized the system, the more that measures must be taken to ensure evolution that adapts to technology and needs through ongoing innovation. The current stovepiping serves neither appropriate regional organization nor innovation, and that applies to both private and public services in environmental information. How the structure of environmental information to decision support develops is partly a matter of inter-federal coordination, partly a matter of federal-local public coordination, and partly a matter of the market. The system will evolve, because it is doubtful that it can be planned at any one scale.

4. Weather Services

This section details the products and processes for weather information. The National ITS Architecture defines the terminator “weather services” as providing all current, predicted and archived weather information. This section describes products from the National Weather Service and other weather information providers, and identifies improvement issues.

4.1 The Process for Products

Figure 4.1.1 shows the general scheme for producing public products of weather analysis.

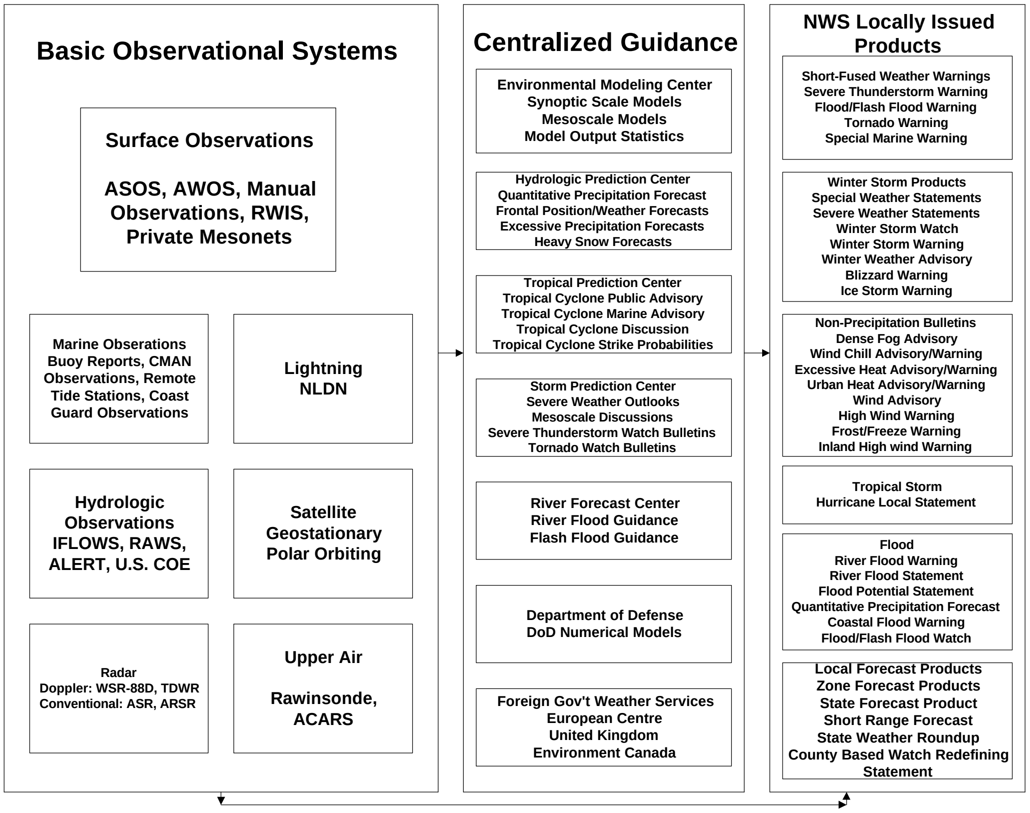

Figure 4.1.1: General Weather Services Information Elements

The products on the left are NWS products because these are the best documented. They are produced by analysis in the WFOs and River Forecast Centers (RFCs) and therefore incorporate local and human meteorological expertise. The centralized guidance includes NWP modeling and larger scaled or specialized analysis. This and the local products are all supported by environmental observation. The weather information supplied to the interface of the WIST-DSS is from any of the three general steps, not just the locally issued products. The latter tend to be the narrative statements, including watches and warnings that are appropriate for public dissemination but harder to incorporate in automated DSS. The following subsections describe in more detail the information items shown in figure 4.1.1.

4.2 Observations

Basic to the weather services' products are the observed meteorological variables. These are listed in table 4.2.1 with the right column giving the observational system that produces the observations. Tables 4.2.2 and 4.2.3 give more detail of the observational sources.

Table 4.2.1: Observed Meteorological Variables

Basic Observational Elements		
Data Element	**Description/Remarks**	**Available From:**
Ambient Temperature	"dry bulb" temperature of the air approximately 6 feet above the surface (of the ground or water)	ASOS, AWOS, Manual Observations, ESS, Private Mesonets, Buoy Reports, CMAN Observations, Coast Guard Observations, RAWS , Upper Air Observation
Dew Point Temperature	Used to determine saturation of the airmass for humidity calculations, fog formation, precipitation state (via wet bulb value) and low temperature forecasts	ASOS, AWOS, Manual Observations, ESS, Private Mesonets, Buoy Reports, CMAN Observations, Coast Guard Observations, RAWS , Upper Air Observation
Relative Humidity	Derived value from air temperature and dew point. Directly available from some platforms	ESS, Private Mesonets, Coast Guard Observations
Cloud Height and Amount	Important for fog and obscuration of higher terrain	ASOS, AWOS, Manual Observation
Visibility	Horizontal visibility along the surface.	ASOS, AWOS, Manual Observations, ESS, Coast Guard Observations

Present Weather	Description of observed hydrometeors (such as rain, snow or ice) plus intensity	ASOS, AWOS, Manual Observations, ESS, Coast Guard Observations
Pressure (both surface and corrected to Mean Sea Level, MSL)	Used to determine pressure gradient for winds and movement/evolution of weather systems	ASOS, AWOS, Manual Observations, Private Mesonets, Buoy Reports, CMAN Observations, Coast Guard Observations, RAWS , Upper Air Observation
Light Sensor	Sensor that relays percentage of possible sunshine	Some Manual Observations and Private Mesonets
Wind Direction/Speed and Character (Gusts)	2 meter to 10 meter above ground wind measurements	ASOS, AWOS, Manual Observations, Private Mesonets, Buoy Reports, CMAN Observations, Coast Guard Observations, RAWS , Upper Air Observation
Liquid Precipitation Accumulator (rain gage)	Some gages (such as on ASOS) use a heated lid to allow liquid equivalent accumulations during below freezing conditions	ASOS, AWOS, Manual Observations, Private Mesonets, RAWS
Thunderstorm Detection	Some ASOS systems are now equipped with single site lightning detection systems. Some FAA ASOS systems use a national lightning detection system called ALDARS. NWS is about to deploy a “smart” algorithm that combines radar, lightning data and model information for thunderstorm detection around airports.	ASOS
Status of Road Surface	Determination of the state of the road surface (wet, dry, etc)	ESS
Road Surface Temperature	Temperature of the road surface from any lane or ramp	ESS
Bridge Surface Temperature	Temperature of the bridge roadway surface from any lane	ESS
Subsurface Temperature	Temperature of the soil below the surface. Used for depth of frost layer.	ESS

Applied Chemical Factor	Determination of the chemical applied to the road or bridge surface.	ESS
Water Temperature	Important when air flow becomes modified by over water trajectory, when the temperature of the water body modifies nearby land areas and for phenomena such as lake effect snow	Some Private Mesonets, Buoy Reports, some CMAN Observations, Remote Tide Stations, Coast Guard Observations
Water Level	Can be observed tide levels or levels of rivers	Remote Tide Stations, IFLOWS, RAWS, ALERT, COE
Wave Height	Can be used for coastal flood and lowland inundation potential	Buoy Reports
Radar Data	All radars report reflectivity. Only Doppler systems report velocity information.	NWS via NIDS or NOAAPORT, FAA, DoD
Lightning Data	National detection network senses cloud-to-ground data. Single site sensors detect both cloud-to-ground and cloud-to-cloud. Lightning data is available only from private vendor	Global Atmospherics, Inc and their "LightningStorm" Service or through third party vendors
Satellite Data	Geostationary and Polar orbiting satellites provide multiple channels of data (i.e. visible, infrared, water vapor)	NESDIS, Dod, foreign governments

Table 4.2.2 lists the observational sources under the operating institution.

Table 4.2.2 Observational Sources and Operators

NWS Observational Products	
	ASOS Surface Observations Rawinsonde Observations (Mandatory and Significant Level data) WSR-88D Radar Data (once the NIDS contract expires) Oceanic Buoy Reports Coastal Observation Reports (CMAN Observations)
National Environmental Satellite Data and Information Service (NESDIS)	

	Visible Satellite Imagery (GOES) Infrared Satellite Imagery (GOES) Water Vapor Satellite Imagery (GOES) Polar Satellite Imagery (POES) Differential GPS
National Oceanic Service (NOS)	
	Coastal observations from remote tide stations with weather instrumentation PORTS tide prediction data
Federal Aviation Administration (FAA)	
	Air Route Traffic Control Radar Data Terminal Doppler Weather Radar (TDWR) Airport Surveillance Radar (ASR) Air Route Surveillance Radar (ARSR) Aircraft Communications Addressing and Reporting System (ACARS) commercial aircraft observations
Global Atmospherics, Inc	
	National Lightning Data Network (NLDN)
Department of defense (DoD)	
	ASOS Military Surface Observations Manual Military Surface Observations Defense Meteorological Support Program (DMSP) Satellite data Numerical Guidance (Navy NOGAPS, NORAPS) Military operated WSR-88D radar data
Coast Guard	
	Coast Guard Station Observations Relay of Marine Observations
U.S. Army Corps of Engineers	
	River/Rainfall Remote gage data
Private Collectors of Weather Data	

	Automated Weather Source (mesonets across the country) Power Utility Mesonets University Mesonets Companies that solicit/collect and disseminate marine observations Many airlines collect observations from their aircraft (other than ACARS) State sponsored AWOS (automated weather observing system) networks State sponsored Road Sensor System networks Private Satellite data IFLOWS rainfall and river gage data from State Emergency Operations Centers RAWS western states forest-fire remote observing systems ALERT remote river gage systems
Non-U.S. Weather Data	
	European Centre ECMWF model forecasts and observations United Kingdom UKMET model forecasts and observations Environment Canada SEF/GEM model forecasts and observations

Table 4.2.2 further describes the observing systems.

Table 4.2.2: Meteorological Observation Systems

Basic Observational Systems	
Surface Observations	**ASOS** (Automated Surface Observing System) - This data flow originates in the basic observational systems function. ASOS provides basic observational elements including (but not limited to) temperature, dew point, winds, pressure, visibility and present weather in a “METAR” encoded format. Limited lightning detection capability (called ALDARS) is being implemented. Some larger airports continue to have human augmentation. Organizations that provide and disseminate ASOS observations include NWS, FAA, DoD
	AWOS (Automated Weather Observing System) - This data flow originates in the basic observational systems function. AWOS is similar to ASOS but typically contains less observational capability and failsafe redundancy. AWOS provides basic observational elements including (but not limited to) temperature, dew point, winds pressure, visibility and (in most cases) present weather in a “METAR” encoded format. AWOS can have human augmentation. Organizations that provide AWOS observations include state DOT’s, counties and some private airports. NWS typically collects and disseminates this information.

	Manual Observations - This data flow originates in the basic observational systems function. A human uses his/her own senses and instrumentation to report current conditions including (but not limited to) temperature, dew point, winds, pressure, visibility and present weather in a "METAR" encoded format. DoD sites still make extensive use of and disseminate manual observations.
	ESS (Environmental Sensor Stations) - This data flow originates in the basic observational systems function. A network of strategically placed sensors that provide (but are not limited to) roadway surface temperatures at different lanes or ramps at a specific location, bridge temperatures, subsurface temperatures, air temperatures, relative humidity, wind, visibility, occurrence of precipitation, road surface state (wet, ice covered) and type of chemicals on the road surface. Some ESS networks are not disseminated due to contractual agreements. Some are made public through the internet or third party providers.
	Private Mesonets (dense, localized network of remote weather stations) - This data flow originates in the basic observational systems function. Networks are operated by private companies, power utilities, universities and some government entities. Exposure and calibration of the data is not necessarily certified according to official regulations. The networks provide (but are not limited to) air temperature, dew point (or humidity), winds, pressure and rainfall accumulation. Some networks are not made public. Those that are in the public domain can be accessed via internet, collection by the NWS or through a third party.
Marine Observations	**Buoy Reports** - This data flow originates in the basic observational systems function. NWS and NOS operate both near shore (coastal, bay and lake) and oceanic data collection platforms providing (but are not limited to) air and water temperature, dew point, winds, pressure, wave height and period. The NWS is the principal disseminator of this information.
	CMAN Observations (Coastal Marine Automated Network) - This data flow originates in the basic observational systems function. CMAN observations are remote limited-observing platforms found along the coast that provide (but are not limited to) air temperature, dew point (or humidity) and winds. Some CMAN's are located on piers and provide water temperatures. CMAN observations are principally collected and disseminated by the NWS.
	Remote Tide Stations - This data flow originates in the basic observational systems function. The tide stations are remote limited-observing platforms found spaced along the coast and major inland bays and tributaries providing tide levels. Some of the stations are equipped with a meteorological package that provides basic observational elements. The tide stations are operated by NOS. Both NOS and NWS collect and disseminate the information.
	Coast Guard Observations - This data flow originates in the basic observational systems function. Some Coast Guard stations provide a limited surface observation including (but are not limited to) air temperature, water temperature, winds, pressure and visibility. Coast Guard observations are typically disseminated by NWS.

Hydrologic Observations	**IFLOWS** (Integrated Flood Observing and Warning System) - This data flow originates in the basic observational systems function. IFLOWS consists of remote platforms with a rain gauge and/or river gauge (depending on location). Most IFLOWS networks are owned by states and counties in the eastern U.S. and are administered by the NWS.	
	RAWS (Remote Automatic Weather Stations) - This data flow originates in the basic observational systems function. RAWS are remote weather observing platforms principally found in the western U.S. and are a prime tool in fire weather forecasting. Data includes (but is not limited to) air temperature, dew point (or humidity), and winds. The networks are owned and maintained by both state and federal agencies. RAWS information is available via internet from the NWS.	
	ALERT System (Automated Local Evaluation in Real Time System) - This data flow originates in the basic observational systems function. The ALERT system consists of remote platforms that radio observations to centralized computers and principally contain rain and river gauges. ALERT systems are used by the NWS, U.S. Geological Survey, Army Corps of Engineers, Bureau of Reclamation, numerous state and local agencies, and international organizations.	
	U.S. Corps of Engineers (COE) operated remote platforms - This data flow originates in the basic observational systems function. The COE operates and maintains remote platforms that measure river gage readings, pool elevations and flood stages. Information is available via the internet.	
Radar	**Doppler Radar**	**WSR-88D** (Weather Surveillance Radar - 1988 Doppler) - This data flow originates in the basic observational systems function. The WSR-88D is a tri-agency network (NWS, DoD, FAA) of Doppler weather radars that covers the majority of the Continental U.S. Data are available directly through NIDS Vendors (NEXRAD Information Dissemination System) and via the internet.
		TDWR (Terminal Doppler Weather Radar) - This data flow originates in the basic observational systems function. TDWR provides high resolution reflectivity and Doppler coverage in the vicinity of major airports. The data complements the WSR-88D. The system is operated by the FAA and disseminates data to the NWS.
	Conventional Radar	**ASR** (Airport Surveillance Radar) - This data flow originates in the basic observational systems function. The ASR provides primary radar surveillance of aircraft out to an instrumented range of 60 nautical miles and secondary radar coverage up to 120 nautical miles and is maintained and operated by the FAA.

		ARSR (Air Route Surveillance Radar) - This data flow originates in the basic observational systems function. The ASR provides primary radar surveillance of aircraft out to an instrumented range of 60 nautical miles and secondary radar coverage up to 120 nautical miles and is maintained and operated by the FAA.
Lightning	**NLDN** (National Lightning Detection Network) - This data flow originates in the basic observational systems function. Global Atmospherics is a commercial enterprise that maintains and operates a national network of lightning sensors. Data is available via vendors and the internet.	
Satellite	**Geostationary Satellites** - This data flow originates in the basic observational systems function. Geostationary satellites provide hemispheric coverage from a fixed point above the earth. Different data channels are available including (but not limited to) visible, infrared and water vapor imagery. U.S. geostationary satellites are operated by NOAA. European and Japanese governments also operate geostationary satellites with coverage over U.S. territory. Data are widely disseminated via vendors and internet.	
	Polar Orbiting - This data flow originates in the basic observational systems function. Polar orbiting satellites rotate around the earth from pole-to-pole as the earth revolves below. Coverage is more limited in areal extent but resolution can be better due to the lower earth orbit. As with geostationary satellites, numerous data channels are available. Polar satellites are operated by NOAA and DoD. Data are widely disseminated via vendors and internet.	
Upper Air	**Rawinsonde** - This data flow originates in the basic observational systems function. Rawinsondes, more commonly known as radiosondes or “weather balloons” carry instrument packages to the top of the atmosphere via helium or hydrogen filled balloons. The NWS routinely sends up rawinsondes from 75 locations twice per day to obtain atmospheric profiles. Data are widely disseminated via vendors and internet.	
	ACARS (Aircraft Communications Addressing and Reporting System) - This data flow originates in the basic observational systems function. ACARS is a system where commercial aircraft transmit real-time observations to a centralized collection point. The program is managed by Aeronautical Radio, Inc and is in partnership with NOAA’s Forecast Systems Laboratory. The data may not be freely redistributed, but is available to government agencies in support of forecast operations.	

4.3 Centralized Guidance Products

Weather services operate central organizations for some kinds of products and support to field offices. The NWS operates the National Centers for Environmental Prediction (NCEP) responsible for NWP operation and national analysis. The NCEP and other central functions are listed in table 4.3.1.

Table 4.3.1: Centralized Guidance Products

Centralized Guidance		
NWS/National Centers for Environmental Prediction (NCEP)	**Environmental Modeling Center (EMC)**	**Synoptic Scale Models** - This data flow originates in the centralized guidance function. The EMC collects data from the basic observational systems function and runs numerous atmospheric simulations on national and hemispheric scales. The models include (but are not limited to) the ETA, NGM (Nested Grid Model), MRF (Medium Range Model) and RUC (Rapid Update Cycle) model. Output can be in grids or graphics and are widely available via vendors, universities or internet.
		Mesoscale Models - This data flow originates in the centralized guidance function. Mesoscale models cover a smaller domain and temporal span than synoptic scale models in exchange for a higher resolution. Mesoscale models are available from NOAA, some universities and private companies. Examples of such models include the RAMS (Regional Atmospheric Modeling System), MM5 (Mesoscale Model 5) and SAIC's Omega model. Distribution may be proprietary from private vendors...but NOAA and most university model output is available via internet.
		MOS (Model Output Statistics) - This data flow originates in the centralized guidance function. Several of the NOAA models create alphanumeric output called MOS that attempts to describe forecasted parameters such as (but are not limited to) temperature, humidity, winds and rainfall. MOS is widely used as a first guess in weather forecasting and is available via vendor and internet.
	Hydrologic Prediction Center (HPC)	**Quantitative Precipitation Forecasts** (QPF) - This data flow originates in the centralized guidance function. QPF's are forecasts of actual accumulation amounts of rain or (liquid equivalent of) snow. NOAA's HPC provides QPF forecasts both in alphanumeric and graphic formats and are widely available from vendors and internet.
		Frontal Position/Weather Forecasts - This data flow originates in the centralized guidance function. HPC creates narratives and graphics depicting the position of weather systems, fronts and precipitation every 6 hours through 48 hours. Additional daily graphics extend out to 3 days. These data are widely available from vendors and internet.

		Excessive Precipitation Forecasts - This data flow originates in the centralized guidance function. HPC creates narratives and graphics depicting areas where forecast precipitation accumulation will exceed the ability of the water to be absorbed into the soil. The runoff may induce flooding or flash flooding. These data area widely available from vendors and the internet.
		Heavy Snow Forecasts - This data flow originates in the centralized guidance function. HPC creates narratives and graphics depicting areas where heavy snow (from storms, orographics or lake effect) will occur. These data are widely available from vendors and the internet.
	Tropical Prediction Center (TPC)	**Tropical Cyclone Public Advisory** (TCP) - This data flow originates in the centralized guidance function. The TPC (known internationally as the National Hurricane Center (NHC)) provides a clear, narrative bulletin providing plain text information about the movement, strength and extent of tropical cyclones (tropical storms and hurricanes). These data are widely available from vendors and the internet.
		Tropical Cyclone Marine Advisory (TCM) - This data flow originates in the centralized guidance function. The TCM elaborates on the TCP by providing exact coordinates of forecast movements and storm strengths. These data are widely available from vendors and the internet.
		Tropical Cyclone Discussion (TCD) - This data flow originates in the centralized guidance function. The TCD is a plain language discussion from the forecaster’s perspective about current conditions associated with a cyclone and its forecast movement and uncertainties. These data are widely available from vendors and the internet.
		Tropical Cyclone Strike Probabilities - This data flow originates in the centralized guidance function. TPC generates strike probabilities to allow emergency managers to assess the risk of a tropical cyclone moving to within 50 miles of specific coastal landmarks. These data area widely available from vendors and internet.
	Storm Prediction Center (SPC)	**Severe Weather Outlooks** (SWO) - This data flow originates in the centralized guidance function. The SPC issues “day 1" and “day 2" severe weather outlooks for the continental U.S. several times per day. Both in narrative and graphic form, the data focus on the potential for general thunderstorm activity and the risk (slight, moderate or high) of severe thunderstorm development. These data are widely available from vendors and the internet.
		Mesoscale Discussion (MCD) - This data flow originates in the centralized guidance function. SPC issues MCD’s for 1) severe convection, 2) excessive precipitation and in winter 3) for heavy snow. The products are focused on explaining why the severe weather is expected in narrative form. These data are widely available from vendors and internet.

<table>
<tr><td rowspan="2"></td><td rowspan="2"></td><td>Severe Thunderstorm Watch Bulletins - This data flow originates in the centralized guidance function. These products are issued by the SPC describing the areal extent, duration and threat produced by the potential for severe thunderstorm development. Typically, the watch is issued well in advance of the severe threat and covers a large area. Typical time extent: 4 to 6 hours. (Note: Future NWS plans may allow local offices to issue localized, county based watches.) These data are widely available from vendors and internet.</td></tr>
<tr><td>Tornado Watch Bulletins - This data flow originates in the centralized guidance function. Issued by the SPC describing the areal extent, duration and threat produced by the potential for severe thunderstorm development that have a potential for tornado development. Typically, the watch is issued well in advance of the severe threat and covers a large area. Typical time extent: 4 to 6 hours. (Note: Future NWS plans may allow local offices to issue localized, county based watches.)</td></tr>
<tr><td rowspan="2">NWS/River Forecast Center (RFC)</td><td colspan="2">River Flood Guidance - This data flow originates in the centralized guidance function. Forecasts of river stage levels and potential flood conditions (times of crests, flow rate, etc) can be obtained from RFC river flood guidance products. Products are updated daily and more frequently if conditions warrant. Data are widely available via vendors or internet.</td></tr>
<tr><td colspan="2">Flash Flood Guidance (FFG) - This data flow originates in the centralized guidance function. FFG attempts to give users an understanding of how much precipitation will be able to fall before the soil conditions become saturated and additional precipitation will runoff potentially producing flooding conditions. FFG is updated daily and is widely available from vendors and internet.</td></tr>
<tr><td>Department of Defense (DoD)</td><td colspan="2">DoD Numerical Models - This data flow originates in the centralized guidance function. The DoD (principally the Navy) maintains and operates several synoptic scale models (such as the NOGAPS and NORAPS) to support defense operations. Much of the data is available through universities and the internet.</td></tr>
<tr><td rowspan="3">Foreign Government Weather Services</td><td colspan="2">The European Centre for Medium Range Weather Forecasts (ECMWF) - This data flow originates in the centralized guidance function. The European Consortium runs a weather center that operates the ECMWF model which covers the northern hemisphere. Much of the data is available through universities and the internet. However, some of the fields are restricted for government use or is available for a fee.</td></tr>
<tr><td colspan="2">The United Kingdom Meteorological Office (UKMET) - This data flow originates in the centralized guidance function. The UK Meteorological Office operates the UKMET model which covers the northern hemisphere. Some of the data is available through universities and the internet.</td></tr>
<tr><td colspan="2">Environment Canada - This data flow originates in the centralized guidance function. Environment Canada maintains and operates several models (such as the GEM and SEF models) which covers North America. Some of the data is available through universities and the internet.</td></tr>
</table>

4.4 NWS Locally-Issued Products

In the U.S., the NWS focuses most of its weather analysis and public dissemination at the local level, through WFOs and RFCs for the flood products. The NWS modernization program has established[21] 121 WFOs (with 3 additional planned) and 13 RFCs, to be equipped with the Advanced Weather Interactive Processing System (AWIPS) to support the local analysis. The AWIPS will be accompanied by the Local Data Acquisition and Dissemination (LDAD) system that will be the interface for data into the analysis and product dissemination. The Local Analysis and Prediction System (LAPS) enables local data assimilation and regional NWP modeling to support the analysis. Table 4.4.1 lists local products, that are mostly textual narratives for watch and warning areas. These are the products shown on the right of figure 4.1.1. AWIPS and LDAD will, in the future, support more graphical products. Table 4.4.2 gives more detail on products.

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[21] Current listing found at www.nws.noaa.gov/pub/modernize/facility.txt

Table 4.4.1: Local Product Acronyms

Short-Fused Severe Weather Warnings	
	SVR Severe Thunderstorm Warning FFW Flood/Flash Flood Warning TOR Tornado Warning SMW Special Marine Warning
Severe Weather Guidance	
	SPC Day 1 Severe Weather Outlook (graphic) SPC Day 2 Severe Weather Outlook (graphic) SPC Severe Thunderstorm Watch Statements SPC Tornado Watch Statements WFO County Redefining Statements for SPC Watches FFA Flood/Flash Flood Watch
Winter Storm Products	
	SPS Winter Storm Potential Statement SVS Severe Weather Statement WSW Winter Storm Bulletin Used for: Winter Storm Watch Winter Storm Warning Winter Weather Advisory Blizzard Warning Ice Storm Warning NPW Non-Precipitation Warning Used for: Dense Fog Advisory Wind Chill Advisory/Warning Excessive Heat Advisory/Warning Urban Heat Advisory/Warning Wind Advisory High Wind Warning Frost/Freeze Warning
Tropical Cyclone Products	

	TCP Public Tropical Cyclone Advisory TCM Tropical Cyclone Marine Advisory TCD Tropical Cyclone Discussion SDF Tropical Cyclone Strike Probabilities HLS Hurricane Local Statement
Flood Products	
	FLW River Flood Warning FLS River Flood Statement ESF Excessive Precipitation Potential Outlook FFG RFC Flash Flood Guidance (Amount of precipitation before flooding starts) QPF Quantitative Precipitation Forecasts (WFO Based precipitation amounts) CFW Coastal Flood Watch/Warning
Local Products/Forecasts	
	ZFP County based Zone Forecasts (thru day 5) SFP Consolidated State Forecasts (thru day 5) HRR Hourly Weather Roundup of current conditions
General Guidance (used in WFO analysis)	
	NCEP 6 hour QPF graphics NCEP Day 1 - 3 QPF graphics (rainfall/snowfall) NCEP Day 1 - 5 Front/Precipitation graphics NCEP Numerical Forecasts & Model Output Statistics Products(NGM, ETA, AVN, MRF)

Table 4.4.2: Local Product Descriptions

<table>
<tr><th colspan="3">NWS Locally Issued Products</th></tr>
<tr><td rowspan="4">Short-Fused Severe Weather Warnings</td><td colspan="2">Severe Thunderstorm Warnings (SVR) - This data flow originates in the ‘NWS locally issued products’ function. Warnings associated with thunder-storms producing 3/4 inch diameter or greater hail and/or winds at or above 58 mph. Greatly reduced visibilities usually accompany these storms. Typical time extent: 15 minutes to 1 hour. These data are widely available from vendors and the internet.</td></tr>
<tr><td colspan="2">Flood Warning (FFW) - This data flow originates in the ‘NWS locally issued products’ function. Warnings associated with excessive precipitation, rapid water runoff or snow melt. Time scale can be over hours and can be associated with inundation of small streams, road beds and low lying areas. May produce mud slides and erosion of roadways. Typical time extent: 2 to 6 hours. These data are widely available from vendors and the internet.

Flash Flood Warning (FFW) - This data flow originates in the ‘NWS locally issued products’ function. Same as Flood Warning but is associated with a much more sudden, rapid rise in water levels. This sudden rise may result in catastrophic loss of structures such as low water bridges and the rapid inundation of low lying areas and ravines. Typical time extent: 1 to 4 hours. These data are widely available from vendors and the internet.</td></tr>
<tr><td colspan="2">Tornado Warning (TOR) - This data flow originates in the ‘NWS locally issued products’ function. Warning associated with radar detection or visual spotting of a tornado funnel reaching the ground. The warning focuses on storm motion (direction and speed) and does not typically indicate the relative strength (Fujita Scale) of the tornado. Typical time extent: 15 minutes to 1 hour. These data are widely available from vendors and the internet.</td></tr>
<tr><td colspan="2">Special Marine Warning (SMW) - This data flow originates in the ‘NWS locally issued products’ function. Warning associated with hazards to mariners typically within bay or coastal waters, but may be germane to roadway conditions when the warning includes large span bridges or causeways. Typical conditions that warrant this warning include winds above 39 mph (35 knots), hail and frequent cloud to ground lightning. Typical time extent: 15 minutes to 2 hours. These data are widely available from vendors and the internet.</td></tr>
<tr><td rowspan="3">Winter Storm Products</td><td colspan="2">Special Weather Statements (SPS) - This data flow originates in the ‘NWS locally issued products’ function. The SPS product is used as a “Winter Storm Potential Statement” narrative that attempts to give extended lead time to potential winter events. It is also used to elaborate on short range conditions. These data are widely available from vendors and the internet.</td></tr>
<tr><td colspan="2">Severe Weather Statement (SVS) - This data flow originates in the ‘NWS locally issued products’ function. The SVS is used to elaborate on potential or occurring severe conditions such as a blizzard. These data are widely available from vendors and the internet.</td></tr>
<tr><td>Winter Storm Bulletin (WSW)</td><td>Winter Storm Watch - This data flow originates in the ‘NWS locally issued products’ function. A winter storm watch is typically issued 24 to 48 hours in advance of the onset of winter storm conditions. These conditions are regionally determined depending on climate and orographics. These data are widely available from vendors and the internet.</td></tr>
</table>

		Winter Storm Warning - This data flow originates in the 'NWS locally issued products' function. A winter storm warning is typically issued when winter storm conditions (such as heavy snow or significant ice) are imminent or have a high probability of occurrence. These data are widely available from vendors and the internet.
		Winter Weather Advisory - This data flow originates in the 'NWS locally issued products' function. An advisory can be issued if forecast wintry conditions will be hazardous, but do not meet warning criteria (as in light snow or sleet). These data are widely available from vendors and the internet.
		Blizzard Warning - This data flow originates in the 'NWS locally issued products' function. Blizzard warnings are issued only for severe winter storms which typically include prolonged heavy snow, winds above gale force (35 knots), greatly reduced visibilities and drifting. These data are widely available from vendors and the internet.
		Ice Storm Warning - This data flow originates in the 'NWS locally issued products' function. An ice storm warning can be issued when significant ice accumulations are expected. This accumulation will likely cause tree and power line damage and extremely hazardous driving conditions. These data are widely available from vendors and the internet.
	Non-Precipitation Weather Bulletin (NPW)	**Dense Fog Advisory** - This data flow originates in the 'NWS locally issued products' function. A dense fog advisory is issued for widespread occurrence of low visibilities (less than a quarter mile). Product duration is typically 1 to 3 hours. These data are widely available from vendors and the internet.
		Wind Chill Advisory/Warning - This data flow originates in the 'NWS locally issued products' function. Wind Chill products are issued according to regional and climatic criteria (i.e. wind chill values of -25F for an advisory and -40F for a warning). Product duration is typically 12 hours. These data are widely available from vendors and the internet.
		Excessive Heat Advisory/Warning - This data flow originates in the 'NWS locally issued products' function. Excessive heat products are issued according to regional and climatic criteria (i.e. heat index values of 105F for an advisory and 115F for a warning). Product duration is typically 12 hours. These data are widely available from vendors and the internet.
		Urban Heat Advisory/Warning - This data flow originates in the 'NWS locally issued products' function. Excessive urban heat products are issued according to regional and climatic criteria and the makeup of the urban area (such as large areas of inner city dwellings without air conditioning). Heat index values of 100-105F can be used for an advisory and 105-110F for a warning. Product duration is typically 12 hours. These data are widely available from vendors and the internet.

		Wind Advisory - This data flow originates in the 'NWS locally issued products' function. A wind advisory is issued when winds of 39 mph are expected for several hours. This can cause tree and power line problems and hazardous conditions for high profile vehicles. Product duration is typically 12 hours. These data are widely available from vendors and the internet.
		High Wind Warning - This data flow originates in the 'NWS locally issued products' function. A high wind warning is issued when wind gusts could reach or exceed 58 mph for several hours. More widespread tree/power line damage can be expected than in an advisory. Product duration is typically 12 hours. These data are widely available from vendors and the internet.
		Frost/Freeze Warning - This data flow originates in the 'NWS locally issued products' function. A frost/freeze warning is issued for agricultural interests (such as for nurseries and for people with tender vegetation) when there is a premature end to the growing season, or in the spring after a period of warm weather which allows flowers to bloom. Product duration is typically 12-14 hours. These data are widely available from vendors and the internet.
		Inland High Wind Warning for Tropical Storms/Hurricanes - This data flow originates in the 'NWS locally issued products' function. This is a specialized high wind warning product used to describe potential tropical storm and/or hurricane force winds for inland areas (away from the danger of coastal storm surge, etc). Typical duration is 12-18 hours. These data are widely available from vendors and the internet.
Tropical Storm	**Hurricane Local Statement** (HLS) - This data flow originates in the 'NWS locally issued products' function. The HLS is issued by local NWS forecast offices to elaborate on potential effects from tropical storms. The HLS acts as a summary product and supercedes the issuance of separate warnings (such as flash flood, coastal flood, heavy surf advisories, high wind, etc). Products are updated routinely every several hours once a threat exists. These data are widely available from vendors and the internet.	
Flood	**River Flood Warning** (FLW) - This data flow originates in the 'NWS locally issued products' function. FLW's are issued when gaged rivers stage levels are at or forecast to be above flood stage. Crest levels and times are also included. Products are updated routinely when a threat exists. These data are widely available from vendors and the internet.	
	River Flood Statement (FLS) - This data flow originates in the 'NWS locally issued products' function. FLS's are issued when a river flood warning has been discontinued or to indicate unusual flow or stage conditions. Products are updated as needed when conditions warrant. These data are widely available from vendors and the internet.	
	Flood Potential Outlook (ESF) - This data flow originates in the 'NWS locally issued products' function. A Flood Potential Outlook is issued to give an extended lead time (on the order of days) of a potential flood producing event. Products are updated as conditions warrant. These data are widely available from vendors and the internet.	

	Quantitative Precipitation Forecast (QPF) - This data flow originates in the 'NWS locally issued products' function. QPF's are issued daily (and on special request from river forecast centers) and indicate forecast precipitation amounts in 6 hour periods through 24 hours. These data are widely available from vendors and the internet.
	Coastal Flood Warning (CFW) - This data flow originates in the 'NWS locally issued products' function. A CFW is issued when coastal inundation is possible (such as from tropical storms or a prolonged wind fetch which pushes water up a river). Product duration is typically 12-24 hours. These data are widely available from vendors and the internet.
	Flood/Flash Flood Watch (FFA) - This data flow originates in the 'NWS locally issued products' function. A Flood Watch is issued when there is the potential for rainfall (and/or snow melt) to cause inundation of small streams, creeks and low lying areas. A Flash Flood Watch is issued when water ponding or rises are expected to be rapid. Typical duration is 3 to 12 hours. These data are widely available from vendors and the internet.
Local Forecast Products	**Zone Forecast Product** (ZFP) - This data flow originates in the 'NWS locally issued products' function. The ZFP is a county-based alphanumeric forecast product that provides a 5 day forecast (broken down into 12 hour segments for the first 2 days and 24 hour segments for days 3-5). The product is routinely updated 4 times per day and more often in changeable weather conditions. These data are widely available from vendors and the internet.
	State Forecast Product (SFP) - This data flow originates in the 'NWS locally issued products' function. The SFP is a summary forecast for a specific state (using the zones as its basis) which extends out for 5 days. The product is routinely issued 2 times per day and more often in changeable weather conditions. These data are widely available from vendors and the internet.
	Short Range Forecast (NOW) - This data flow originates in the 'NWS locally issued products' function. The NOW is a short range narrative forecast used to update zone forecasts with high detail. Product duration is typically from 1 to a maximum of 6 hours. Updates vary by office and weather conditions. These data are widely available from vendors and the internet.
	State Weather Roundup (SWR) - This data flow originates in the 'NWS locally issued products' function. The SWR is a plain language summary of a state's weather conditions. Typical parameters shown are current weather, temperature, humidity, winds and pressure. The product is automatically generated and distributed near the top of each hour. These data are widely available from vendors and the internet.
	County Based Watch Redefining Statement (SLS) - This data flow originates in the 'NWS locally issued products' function. The SLS is issued when SPC issues a severe thunderstorm watch or tornado watch. Each NWS weather forecast office takes the SPC watch and breaks it down (redefines) the areal coverage of the watch to county components. The product duration is for the extend of the SPC watch. These data are widely available from vendors and the internet.

4.5 NWS Dissemination Services

The National Weather Service (NWS) disseminates hydrometeorological and other environmental data and information to protect life and property from natural hazards. To this end there are ten dissemination services they provide, whose content is the central and local products described in the subsections above:

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

These services were described in detail in the STWDSR V1.0 document. These services generally are available as channels to the WIST-DSS. Only the National Warning System (NAWAS) is strictly limited to emergency managers. Other users may receive services as do the Information Service Providers (ISPs) or as does the general public. Where a service does not go through to public entities on the left, it is generally used internally within the NWS, or no public dissemination is currently established.

Most of the services began with the intent of dissemination to sophisticated users who needed more than the weather reports from the broadcast media. The broadcast media, as ISPs, and others using weather information for operational decisions would get the products, listed in previous subsections, directly. The NOAAPort satellite broadcast system is used by ISPs and VAMS, but is intended primarily for communicating the central products within the NWS. It is the source of the nationally assimilated observations and NWP model products.

Most of the channels are pre-Internet, but the Internet now allows the general public to access a large range of graphical products. This was initiated by the EMWIN. Now the NWS effectively acts as an ISP for its own information through the Interactive Weather Information Network (IWIN)[22]. This is disseminated from the National Weather Service Headquarters in Silver Spring, Md. It obtains raw data from a telecommunications gateway, satellites, and other multilayered redundant links. Many private ISPs distribute free and subscription products over

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[22] On the Internet at http://iwin.nws.noaa.gov/iwin/graphicsversion/bigmain.html

the Internet.

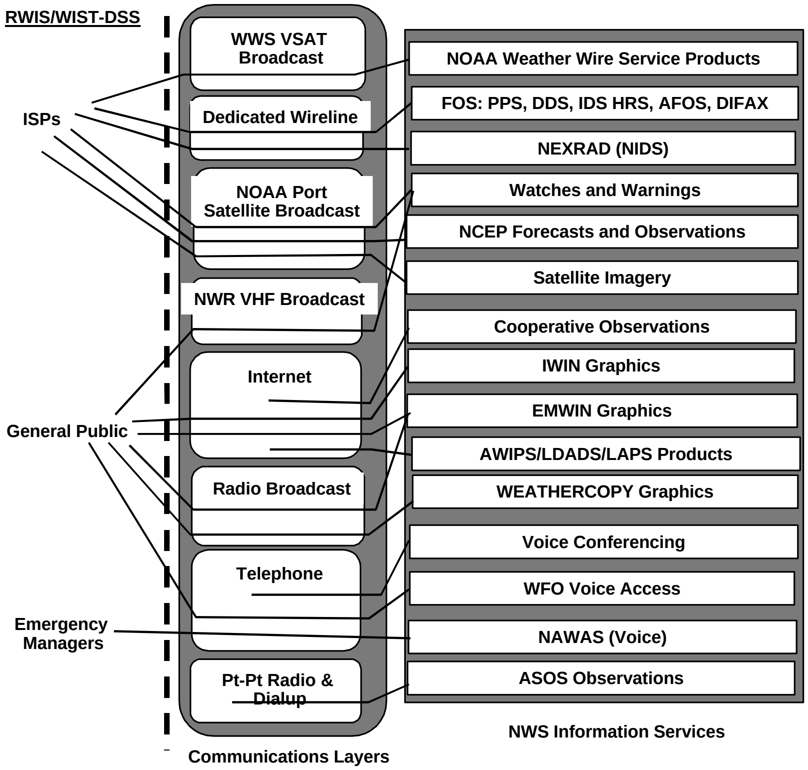

Figure 4.5.1: NWS Information Services and Dissemination Channels

4.6 Weather Information for Road Conditions

Comparing the WIST-DSS information taxonomy with the products of the weather services generally shows an adequacy of information types. The observational data requirements were based on the ESS data objects, and for surface weather these are consistent with the observational products listed above. Remote sensing observations are provided under the NEXRAD/NIDS products, other radars, and for satellites via the NESDIS products. The predicted versions of the weather data objects are provided by tracked remote-sensing observations and the NWP products are among the centralized guidance (a more detailed list of the NCEP models is in STWDSR V1.0). The statistical version of the data objects are represented by MOS products. Other kinds of ensemble products are not available.

Narrative watches and warnings are among the local analysis products. From the weather services' viewpoint, these narrative end-user products receive much more emphasis than numerical data and graphical products that are mostly internal. This is changing with the dissemination technology (e.g., Internet) and the demands of automated DSS applications. Further dissemination channels and open system interfaces will become an issue. Practically, the Internet and NOAAPort satellite broadcast will meet most of the needs for numerical and graphical data. The main question is how the servers for computer-to-computer communications will be organized. The old wire and fax services will give way to IWIN-type systems. For the NWS and users, the issue is how much of that will remain centralized, and how much will exploit the local capabilities of the WFOs and RFCs with the LDAD interface. It is a question of where the filtering of large data domains occurs and the communications capacity implied. Not every WFO/RFC product of local interest need be nationally disseminated. The problem of how local data are to be disseminated would be more acute if the WFOs were to use LAPS to generate dense NWP grid products. Similarly, if local mesonets are ingested by LAPS the question is whether the assimilated databases should be broadcast nationally or kept locally for client-server access. These are issues that the NWS must determine, but also where customer demand will be influential.

If weather information is mostly categorically available, the question is still qualitative. The demand for more timely, accurate and relevant data has to be treated in the context of great improvement in weather information. The state of the art and science of weather observing and forecasting has made great strides during the last half century. Increasing understanding of the physics of the atmosphere, the power of numerical models and the computers that run them, and the vast array of remote sensors has pushed forecast capabilities to new frontiers.

However, much of the focus on remote sensing and forecasting during the latter half of the 20th Century has been on regional (mesoscale) and larger (synoptic) scales which are occasionally too coarse to recognize small-scale perturbations and predict their evolution. It is this smaller scale that requires a higher density of observations and a finer grid for numerical models that will ultimately create higher resolution forecasts. The ability to make accurate predictions down to sub-community and roadway scales is what will eventually satisfy road maintenance decision support needs.

In the mean time, the WIST-DSS information needs can be summarized to a few types that occur with a high frequency and that involve weather. These needs include both observed and forecast conditions of the following:

precipitation type	air temperature and trends
precipitation accumulation (amount)	dew points
precipitation rate	wind speed and direction
precipitation state	surface visibility
precipitation onset time	road/bridge surface temperatures
precipitation duration	road/bridge wind effects
snow cover and drift potential	road/bridge icing

There is also a stated need to supply an accurate assessment of the occurrence and impact of a potential ‘next’ storm.

In addition to having observational data and prognostic guidance, there were several needs described requiring an archive and retrieval capability. Specifically, these were:

- Archive current conditions across the road maintenance district
- Retrieve a previous day’s weather observations
- Retrieve a previous storm’s precipitation impacts
- Retrieve a previous storm’s cost to the district
- Retrieve storm histories from similar previous events
- Retrieve meteorological case studies for comparison with current conditions or forecasts

Of the general types of information needed, not all are achievable given the current state of the art of meteorology. This applies specifically to the road conditions implied by weather. The other atmospheric attributes are provided, and with ESS information, the types are sufficiently provided for DSS operation. The remaining question is data quality versus current weather services’ performance. Since quantification of requirements is lacking on the DSS side, quantified improvement needed on the weather side cannot be defined. However, by examining the production of weather information, it is possible to identify processes and operations where there is a mutual meteorological and road-condition interest in improvement. The following table identifies more than a dozen potential improvements that could provide significant benefit to winter road maintenance supervisors.

Table 4.6.1 Weather Information--Potential Improvement List

1. Model Resolution & Microclimate	
	Numerical models should strive to have: 1.1 A high enough resolution (i.e. small spacing between model grid points) to provide information of high quality about weather affecting different roads and land features. Depending on terrain differences, grid spacings may need to be reduced to below 10 km. 1.2 A cycle refresh rate high enough to support road maintenance operations and decision makers. 1.3 A large enough domain so that a sufficient region surrounding the road district can be covered for model initialization and the propagation and tracking of approaching weather systems without sacrificing grid density. 1.4 Knowledge of specific microclimates within the domain of the model grid. This includes high resolution terrain data and knowledge of surface albedo, bodies of water and their temperature, urbanization (heat island effects) and other local weather features (i.e. such as cold air damming or a high frequency of freezing precipitation).
2. Model Ability to Predict Small-Scale Disturbances	
	Numerical models should strive to have: 2.1 The ability to quantify, identify and propagate small-scale disturbances which produce significant weather over the road maintenance district. The disturbances can range from sub-grid perturbations in the mid and upper troposphere to near- surface gravity waves and convectively induced outflow boundaries. 2.2 The ability to accurately predict any number of hazardous weather events produced by these small-scale phenomena such as the initiation of convection to localized bands of “whiteout” snow conditions from Conditional Symmetric Instability (CSI).
3. Model Ability to Accurately Predict Precipitation Type, Start Times and Duration	

	Numerical models need to have: 3.1 The ability to accurately predict precipitation state (liquid, freezing or frozen) at any time during the life cycle of a storm. This includes state changes due to upward vertical motion variations, accounting for evaporative cooling, adiabatic up glide, terrain (anabatic vs katabatic), conduction (temperature modification due to contact with the ground), advection (horizontal movement of an airmass), and contact with large heat sources/sinks (such as bodies of water). 3.2 The ability to accurately predict the starting and stopping times of the precipitation event to within an hour. In addition, during the precipitation event, the model must be able to display accumulation/accretion rates and the potential for drifting (if frozen precipitation is involved).
4. Adequate Backup for Model Generation	
	4.1 In the event of a failure of the computer(s) that either pre-processes data or the computer that runs the model, adequate backup must be available. 4.2 In the event of a communications failure between the computer center and the client sites, an alternate means of data transmission must be available.
5. Environmental Sensors that can Measure Snow and Ice	
	5.1 Develop and distribute one or more sensors that can monitor snow conditions. This includes (but is not limited to) snow accumulation, snow drift and liquid equivalent. 5.2 Develop and distribute a sensor that can monitor icing conditions. This includes (but is not limited to) visibility, ice accretion, sleet accumulation and liquid equivalent.
6. Maintenance and Calibration of Remote Sensors	

	6.1 Develop a policy so that a wide range of remote environmental sensors can be *maintained* to high standards to preserve quality in the data that is ingested into numerical models and decision support systems. 6.2 Develop a policy so that a wide range of remote environmental sensors can be *calibrated* so that a uniform quality data set can be obtained.
7. Radar Issues	
	7.1 Weather radar systems need to be able to discriminate between precipitation state (liquid/freezing or frozen) so that algorithms can automatically utilize correct Z-R relationships for precipitation accumulation output and severe weather processing algorithms (i.e. dual polarization). 7.2 Radar systems need to be able to effectively account for beam blockage in algorithms from terrain, structures or atmospheric refraction. 7.3 Radar algorithms need to be able to account for loss of returned signal due to beam attenuation (either through hydrometeorological targets or accretion on the radar dome). 7.4 The operational practice of scan cycles in weather radars should give adequate emphasis to near-ground coverage, including technologies to reduce clutter effects near to ground surface.
8. Adequate Radar Backup	
	8.1 Adequate backup radar should be available in the event that the main weather radar system is taken out of service. This includes the ability to utilize conventional and Doppler systems from other agencies (such as the FAA or DoD) and to compensate for the loss due to either a lack of coverage or beam heights of the backup radars being too high over the maintenance district.
9. Satellite Remote Sensing Capabilities	

	9.1 Satellite sounding capabilities need to be refined to be able to report near-ground conditions (such as precipitation, temperature and winds) regardless of cloud cover. 9.2 Snow accumulation/height survey data from satellite would be a good tool for initializing model data and for distributing surface resources.
10. Adequate Satellite Backup	
	10.1 Timely satellite backup should be available in the event that the main observing platform is taken out of service. This includes the ability to move existing resources and to utilize polar and geostationary assets of other agencies and nations.
11. Density of Surface Stations	
	11.1 The number of maintained and calibrated ESS units should be increased to properly cover the microclimates associated with roadways throughout each maintenance district. 11.2 Each ESS should be equipped with all meteorological equipment necessary to observe conditions in its local climate (i.e. snow drift sensors are less likely in the deep south). 11.3 Each ESS observation should be properly formatted and transmitted so that it can be included in current observational collectives and be made available for model updates.
12. Ability to Collect and Process Data from Proprietary Networks	
	12.1 Some ESS networks are proprietary, where archived and current data are not available to other federal agencies such as the National Weather Service. These data sets should be made available for use in analysis and forecasting. 12.2 Some private organizations maintain networks of ESS's (such as around power stations). These data sets should be made available for use in analysis and forecasting.
13. Ability to Archive and Retrieve Storm Histories	

	13.1 The ability to archive current weather conditions, model forecasts and status of the road maintenance district (personnel, resources, budget). 13.2 The ability to retrieve archived weather conditions, model forecasts and status of the road maintenance district. 13.3 The ability to retrieve archived meteorological case studies of significant weather events that affected the district to compare with a forecast event.
14. Dissemination and ITS	
	14.1 The NWS information architecture should be integrated with the National ITS Architecture to take advantage of developing information dissemination capabilities to mobile and stationary users. 14.2 The NWS should increasingly disseminate graphical products to the public, as generated by AWIPS and other processes, through the Internet and other open system channels to the ITS.

5. ITS/ESS Data Elements

This section describes the ITS and the ESS within the formal architecture that will be used to describe the WIST-DSS interfaces. This describes data flows within the ITS that are equivalent to, or finer levels of, the information taxonomy for the WIST-DSS.

5.1 The National ITS Architecture

The STWDSR V1.0 contains an extraction from the National ITS Architecture, Version 2.2, of weather-related information elements. Since that time, version 3.01 has become available[23]. This was reviewed to find any modification to the earlier extraction. The main differences found were the addition of the Archive Data User Service (ADUS), and further tracing of environmental sensor data. The modified diagram of the weather-related information flows is below.

Figure 5.1.1 shows the logical architecture with process specifications (pspecs) as numbered entities and the data flows to and from them. Each heavy-bordered entity is a physical subsystem to which the pspec is assigned. Outside of the physical subsystems are terminators (entities external to the ITS) that terminate data flows. In the physical National ITS Architecture, the data flows are aggregated into “architecture flows”.

Most of the physical subsystems are as extracted for the STWDSR V1.0. The Archive Data Management Subsystem (ADMS) was created in response to the ADUS. A Construction and Maintenance terminator also has been added. Since work is proceeding on a Maintenance & Construction Operations user service, the terminator does not yet reflect requirements for that user service. As such, the data flows of primary interest to the STWDSR cannot be considered as definitive in the ITS at this time.

Data dictionary listings are found in various standards associated with the National ITS Architecture. The ESS standard and the Traffic Management Data Dictionary (TMDD) are the primary sources for the standardized data elements. It should be noted that final versions of the applicable standards are not yet available.

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[23] Source: http://www.odetics.com/itsarch/
Hypertext Architecture Version 3.01 generation date 3/24/2000 from the Logical Architecture dated 11/08/99 and the Physical Architecture dated 11/12/1999

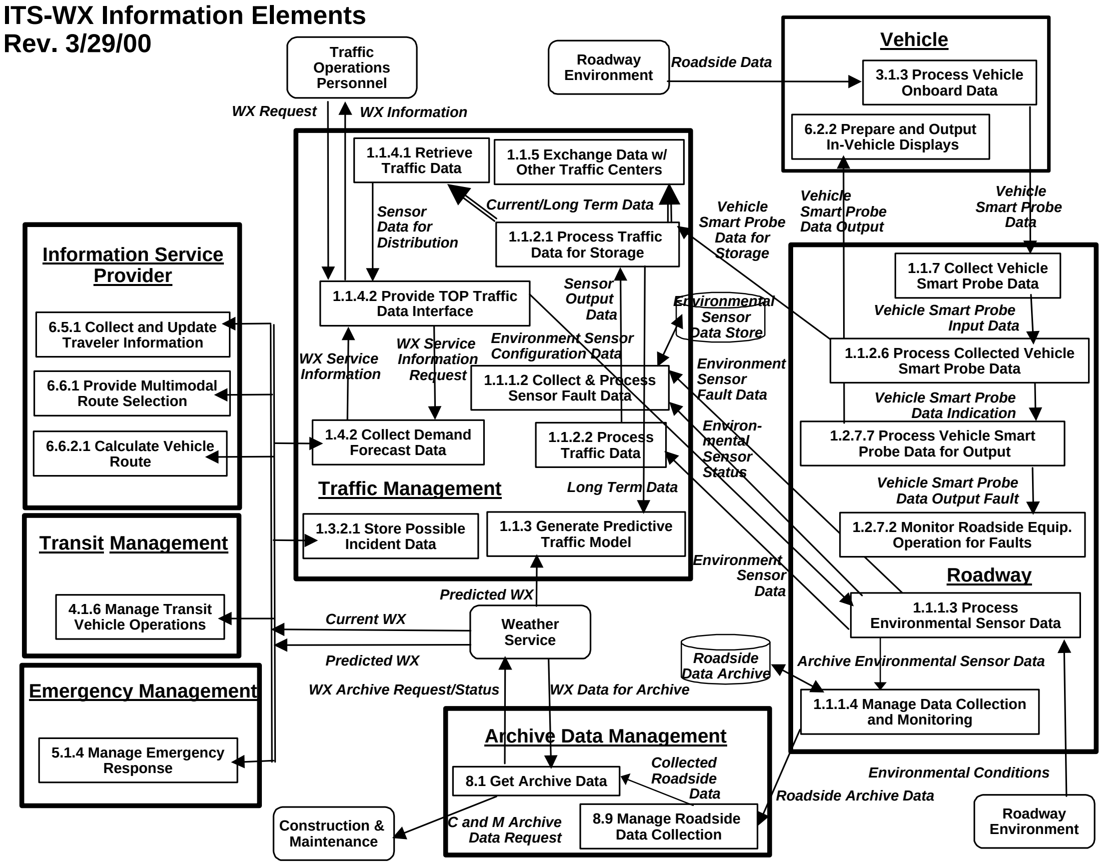

Figure 5.1.1: Weather Information in the National ITS Architecture

Modifying the National ITS Architecture is a controlled process that this document cannot undertake by itself. Use of the National ITS Architecture to assist in structuring any system is specified in a proposed USDOT rule[24]. The rule also must be consulted by agencies using federal aid for eventual WIST-DSS deployment.

The implications of the present National ITS Architecture for WIST-DSS interfaces will be

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[24] Federal Register, Vol. 65, No. 102, pp. 33994-34000, May 25, 2000. Part V, Department of Transportation, Federal Highway Administration, 23 CFR Parts 655 and 940, Intelligent Transportation System Architecture and Standards; Proposed Rule.

developed in sections below. The ESS data object standard is a primary reference for the surface weather and road-condition observation types of the taxonomy. There are many other data object and message set standards that will affect the WIST-DSS interface. Except for the ESS data objects, this document generally will stay at the level of the logical data flows from the National ITS Architecture.

5.2 ITS Weather-Related Data Flows

The ITS will be the immediate source of all information to the WIST-DSS. The weather and ESS data flows are described in detail. Other data, such as traffic flow, are described briefly in a later subsection, and using traffic management as the reference function.

The table below organizes weather-related data flows under major groupings. Some data flows are in a hierarchy of aggregate and primitive data flows. The table shows the data flow name from the architecture and the text description of the data flow. The affected pspecs may be taken from figure 5.1.1.

Table 5.2.1: ITS Weather-Related Data Flows

Data flows to/from Weather Service terminator	
fws_current_weather (fws= from Weather Service)	This data flow is sent to the Manage Traffic function and the Provide Driver and Traveler Services functions. It contains details of the current weather conditions, e.g. temperature, pressure, wind speed, wind direction, humidity, precipitation, visibility, light conditions, etc.
fws_predicted_weather	This data flow is sent to the Manage Traffic and Provide Driver and Traveler Services functions. It contains details of the predicted weather conditions, e.g. temperature, pressure, wind speed, wind direction, humidity, precipitation, visibility, light conditions, etc.
fws_weather_archive_data (aggregate)	This data flow from the Weather Service terminator to the Manage Archived Data function contains a catalog and details of weather data that may be of interest to the archive data users systems that cannot be obtained directly from ITS functions. This data flow contains the following items each of which is defined in its own DDE: weather_archive_catalog + weather_data_for_archive.
weather_archive_catalog	This data flow is used to provide the description of the data contained in the collection of weather data from the Weather Service terminator that has been made available for the Manage Archive Function. The catalog may include descriptions of the schema or structure of the data, a description of the contents of the data; e.g. time range of entries, number of entries; or sample data products.

weather_data_for_archive (aggregate)	This data flow is sent by the Weather Service terminator and contains weather information that may be of interest to archive data users systems along with the meta data that is necessary to describe the imported data to the Manage Archived Data function. This data flow contains the following items each of which is defined in its own DDE: weather_data + weather_data_attributes.
weather_data	This data flow is sent by the Weather Service Provider and contains weather information that may be of interest to archive data users systems.
tws_weather_archive_status	This data flow is sent from the Manage Archived Data function to the Weather Service terminator. It is the status returned when weather archive data is sent from the terminator to the Manage Archived Data function.
weather_data_attributes (aggregate)	This data flow is used to provide meta data included with weather data for release to the archive. Items of meta data may include attributes that describe the source and quality of the data. This meta data may also include flags to identify the presence of privacy sensitive information. Other meta data attributes such as class names, data type, and data concept identifiers may be present when a standard data dictionary or message set template is used as in IEEE P1489 and P1488. This data flow consists of the following items each of which is defined in its own DDE: quality_control_attribute + data_reductions + data_aggregation + collection_conditions + security + error_handling + owner_entities + authorization_to_use + date_created + date_published + date_archived + methods_applied + personal_identification_status + collection_equipment + equipment_status + data_concept_identifier + perishability_date + data_revision + data_version + record_size + standard_data_attribute + standard_message_attribute. [these subflows are not further described here.]
tws_weather_archive_ request	This data flow from the Manage Archived Data function to the Weather Service terminator contains the request for data collected and stored by the terminator that may be of interest to archived data users systems that is not included in data from sources within the ITS functions. This data flow includes request for a catalog of the information available as well as the request for the data itself. This data flow consists of the following items each of which is defined in its own DDE: weather_archive_catalog_request + weather_archive_data_request.
weather_archive_catalog_request	This data flow from the Manage Archived Data function to the Weather Service contains the request for a catalog of the data held by the terminator. The request for a catalog may include either or both the description of the types of data the archive is interested in or a time frame over which the requested information may be available.
weather_archive_data_request	This data flow from the Manage Archived Data function to the Weather Service contains the request for the data held by the terminator. The request for data may include either or both the description of the data required or a timeframe over which the requested information may be available.
Data flows to/from Construction and Maintenance terminator	

tcm_c_and_m_archive_ request (aggregate)	This data flow from the Manage Archived Data function to the Construction and Maintenance terminator contains the request for data collected and stored by the terminator that may be of interest to archived data users systems that is not included in data from sources within the ITS functions. This data flow includes request for a catalog of the information available as well as the request for the data itself. This data flow consists of the following items each of which is defined in its own DDE: c_and_m_archive_catalog_request + c_and_m_archive_data_request.
c_and_m_archive_catalog_request	This data flow from the Manage Archived Data function to the Construction and Maintenance Terminator contains the request for a catalog of the data held by the terminator. The request for a catalog may include either or both the description of the types of data the archive is interested in or a time frame over which the requested information may be available.
c_and_m_archive_data_request	This data flow from the Manage Archived Data function to the Construction and Maintenance terminator contains the request for the data held by the terminator. The request for data may include either or both the description of the data required or a time frame over which the requested information may be available.
Data flows within Archive Data Management	
collected_roadside_data (aggregate)	This data flow is contains the roadside collected by the Manage Roadside Data Collection function. It includes the data as received from the roadside along with meta data describing any processing that was performed on the collected data. This data flow is made up of the following items each of which is defined in its own DDE: roadside_archive_catalog + roadside_data_for_archive + collected_roadside_data_attributes.
roadside_archive_catalog	This data flow is used to provide the description of the data contained in the collection of roadside data that has been stored and made available for the Manage Archived Data function. The catalog may include descriptions of the schema or structure of the data, a description of the contents of the data; e.g. time range of entries, number of entries; or sample data products.
roadside_data_for_archive	This data flow is sent from the Manage Traffic to the Manage Archive Data function. It is used to provide detailed data collected from the roadside. This data flow consists the following items each of which is defined in its own DDE: sensor_data_archive_input + sensor_data_attributes + archive_environmental_sensor_data + environment_sensor_attributes + fault_data + fault_data_attributes + sensor_status + sensor_attributes.

collected_roadside_data_attributes	This data flow is used to provide meta data included with the collected roadside data for release to the archive. Items of meta data may include attributes that describe any methods related to aggregation or quality control that was applied to the data as it was collected. Other meta data attributes such as class names, data type, and data concept identifiers may be present when a standard data dictionary or message set template is used as in IEEE P1489 and P1488. This data flow consists of the following items each of which is defined in its own DDE: quality_control_attribute + data_reductions + data_aggregation + collection_conditions + security + error_handling + owner_entities + authorization_to_use + date_created + date_published + date_archived + methods_applied + personal_identification_status + collection_equipment + equipment_status + data_concept_identifier + perishability_date + data_revision + data_version + record_size + standard_data_attribute + standard_message_attribute. [these subflows not further described here.]
Data Flows associated with Road Way Environment terminator (fixed sensors)	
fre_environmental_conditions	This data flow is sent from the roadside environment to the Manage Traffic function and contains analog data. This data is used by sensors within the function to determine environmental roadside conditions such as air temperature, wind speed, humidity and precipitation, fog, ice, snow, rain, etc. that are affecting the road and highway network served by the function.
environment_sensor_configuration_data	This data flow is used within the Manage Traffic function to provide environmental sensor control commands. It consists of the following data items each of which is defined in its own DDE: [none–listed as primitive element]
environment_sensor_data (aggregate)	This data flow is used within the Manage Traffic function and contains a set of outputs from individual environment sensors. It consists of the following data items each of which is defined in its own DDE: list_size + list_size{station_id + sensor_identity + environment_sensor_output}.
environment_sensor_output	This data flow contains the raw data collected from a single sensor. This data flow could include data pertaining to wind, temperature, humidity, precipitation, radiation (sun), visibility, and pavement sensor information .
sensor_identity	This data flow contains an identifier of the sensor managed by a sensor station. The identifier would be a code which describes the type of the sensor (e.g. wind, temperature, precipitation, etc).
environmental_sensor_status (aggregate)	This data flow is used within the Manage Traffic function to report the status of an environmental sensor. By monitoring this data flow, the receiving process can monitor the health and current status of field equipment. It consists of the following items each of which are defined in its own DDE: list_size+ 1{station_id+ sensor_identity}list_size.
environment_sensor_fault_data	This data flow is used within the Manage Traffic function to show that an environment sensor has developed a fault that means it is not operating correctly. The fault will have been found by a process that is local to the sensor itself.

environmental_sensor_data_store (aggregate)	This data store is used within the Manage Traffic function to store the state of current fault state of all sensors. The data flow contains the following data items each of which is defined in its own DDE: environment_sensor_fault_data + environmental_sensor_status + sensor_fault_data + ftop-sensor_fault_data_input + fcm-sensor_fault_data + tcm-sensor_fault_data + ttop-current_sensor_faults.
roadside_archive_data (aggregate)	This data flow is sent from the Manage Traffic function to the Manage Archive Data function. It contains the roadside archive data stored in the Manage Traffic function along with the meta data describing the data as collected from field equipment. It consists of sensor data which includes the status of the sensors and detection of sensor faults. This data flow is made up of the following items each of which is defined in its own DDE: roadside_archive_catalog + roadside_data_for_archive.
roadside_data_archive (aggregate)	This data store is used within the Manage Traffic function to hold data that is to be archived by the Manage Archived Data function. This data store includes information collected from sensors, such as environment data, fault data, and sensor status. The data store contains the following data items each of which is defined in its own DDE: sensor_data_archive_input + sensor_data_attributes + archive_environmental_sensor-data + environment_sensor_attributes + fault_data + fault_data_attributes + sensor_status + sensor_attributes.
archive_environmental_sensor_data (aggregate)	This data flow is used within the Manage Traffic function to collect environmental sensor data and environment sensor fault data from the roadside to send to the archive data function. It consists of the following data items each of which is defined in its own DDE: environment_sensor_data + environment_sensor_fault_data + environmental_sensor_status.
Data flows to/from Traffic Operations Personnel terminator	
weather_service_information_request	This data flow requests weather information from the Provide Driver and Traveler Services and Manage Traffic functions. The data requested will provide weather conditions for the Provide Traffic Operations Personnel Traffic Data Interface.
weather_service_information (aggregate)	This data flow consists of weather information that is provided by the Provide Driver and Traveler Services and Manage Traffic functions and is sent to the Provide Traffic Operations Personnel Traffic Data Interface. It contains the following items that will be organized by geographic area to allow for local variations and each of which is defined in its own DDE: fws-current_weather + fws-predicted_weather.

current_data (aggregate)	This data store is used within the Manage Traffic function to hold data about the current state of traffic on the road (surface street) and freeway network served by the function. It is a sample of the traffic at a single instant in time and is updated periodically from data collected by other processes within both this and other ITS functions. The data flow contains the following data items each of which is defined in its own DDE: current_other_routes_use + parking_lot_storage_data + processed_data + traffic_flow_state + traffic_management_storage_data + traffic_video_image_data + vehicle_smart_probe_stored_data + wide_area_pollution_data + sensor_output_data + stored_incident_data. [not all these subflows further defined here].
sensor_data_for_distribution (aggregate)	This data flow contains raw and processed sensor data. The data flow consists of the following data items each of which is defined in its own DDE: sensor_output_data + roadway_environment_conditions.
roadway_environment_ conditions (aggregate)	This data flow contains processed environment sensor information which provides a summary of environment conditions referenced to a link. It consists of the following items each of which is defined in it own DDE: link_list +1{link_environment_conditions}link_list.
sensor_output_data (aggregate)	This data flow is used within the Manage Traffic function and contains information obtained from data analyzed by traffic sensors. It is sent to the process traffic data store for current and long term data. This data flow consists of the following items each of which is defined in its own DDE: environment_sensor_data + traffic_sensor_data + traffic_video_image + hri_sensor_data.
Data flows associated with Roadway Environment terminator (mobile sensors/smart probe)	
fre_roadside_data	This data flow is sent by the roadway environment to the Provide Vehicle Monitoring and Control function. It contains analog data from which sensors on-board the vehicle can determine the physical conditions such as fog, ice, snow, rain, etc. at the road or highway.
vehicle_smart_probe_data	This data flow contains data which provides information about conditions in the vicinity of the smart probe. These conditions, which may be the indication of a hazard on the road or freeway that has been detected by sensors on-board the vehicle. The type of information measured could comprise but not be limited to such things as, temperature, fog, ice, snow, and road condition (e.g. wet, icy, dry). The data may be provided as distinct elements with actual measured values (e.g. temperature) or it could provide conditions from a list of codes.
vehicle_smart_probe_data_ output	This data flow contains the data obtained from vehicle smart probes, processed and formatted for output to vehicles as they pass by.
vehicle_smart_probe_data_for _storage	This data flow is used within the Manage Traffic function. It contains the processed vehicle smart probe data collected from a roadside unit, which in turn have received data output by suitably equipped vehicles as they pass by. The data flow consists of the following data items each of which is defined in its own DDE: vehicle_smart_probe_data_source + vehicle_smart_probe_data_indication.

vehicle_smart_probe_input_ data	This data flow is used within the Manage Traffic function. It contains the raw data obtained from vehicle smart probes, with the identity of the roadside unit that received the data. The data flow consists of the following data items each of which is defined in its own DDE: vehicle_smart_probe_data_source_identity + vehicle_smart_probe_data.
vehicle_smart_probe_data_ indication	This data flow contains the data from a vehicle mart probe, processed to provide an indication of the type of hazard that the vehicle found on the road or freeway. The indication may include: bridge down, i.e. broken, or in some way hazardous to traffic; earth or mud slide; fog, smoke or mist reducing visibility; the road surface is icy; road covered by a liquid, e.g. oil, which makes it hazardous to traffic; obstacle on road, e.g. fallen tree, telegraph pole, etc.; road subsidence, i.e part of the road surface has fallen away. .
vehicle_smart_probe_data_ output_fault	This data flow contains an indication that the output of vehicle smart probe data is faulty. This may be due to data not being received for output, or that the output process itself is at fault.
vehicle_smart_probe_data_ source (aggregate)	This data flow is used within the Manage Traffic function. It contains the identity and location of the roadside unit that has collected a particular vehicle smart probe data. The data flow consists of the following data items each of which is defined in its own DDE: vehicle_smart_probe_data_source_identity + vehicle_smart_probe_data_source_location.
vehicle_smart_probe_data_source_identity	This data flow is used within the Manage Traffic function. It contains the identity of the roadside unit that has collected a particular vehicle smart probe data. The data flow consists of the following data item which is defined in its own DDE: unit_number.
vehicle_smart_probe_data_source_location	This data flow is used within the Manage Traffic function. It contains the location of the roadside unit that has collected a particular vehicle smart probe data. The data flow consists of the following data item which is defined in its own DDE: location_identity.
location_identity	This data element is used by many of the ITS functions to communicate the location of any transportation feature, entity, or event in an unambiguous and mutually understandable way. The Society of Automotive Engineer's Information Report SAE J2374 describes a suite of alternative location referencing interface profiles for use in Intelligent Transportation Systems. The location referencing interface profiles included in J2374 are in varying states of development and will continue to evolve as ITS user requirements and results of computer and field tests become available. The current set of interface profiles includes: - Geometry Profile - Geographic Coordinate Profile - Grid Profile - Linear Referencing Profile - Cross-streets Profile - Address Profile The profiles, when incorporated into relevant standards, will provide a common language for the expression of location between the different elements of an integrated transportation system.

5.3 Terminator Descriptions

The following terminator descriptions are taken from the physical view of the National ITS Architecture.

Table 5.3.1: Terminator Descriptions in the National ITS Architecture

Terminator	**Description**
Weather Service	This terminator provides weather, hydrologic, and climate information and warnings of hazardous weather including thunderstorms, flooding, hurricanes, tornadoes, winter weather, tsunamis, and climate events. It provides current and forecast weather data that is collected and derived by the National Weather Service, private sector providers, and various research organizations. The interface provides formatted weather data products suitable for on-line processing and integration with other ITS data products as well as Doppler radar images, satellite images, severe storm warnings, and other products that are formatted for presentation to various ITS users.
Roadway Environment	This terminator represents the physical conditions surrounding the roadway itself. These may include emissions, fog, ice, snow, rain, etc. which will influence the way in which a vehicle can be safely operated on the roadway.
Traffic Operations Personnel	This terminator represents the human entity that directly interfaces with vehicle traffic operations. These personnel interact with traffic control systems, traffic surveillance systems, incident management systems, work zone management systems, and travel demand management systems to accomplish ITS services. They provide operator data and command inputs to direct systems' operations to varying degrees depending on the type of system and the deployment scenario. All functionality associated with these services that might be automated in the course of ITS deployment is modeled as internal to the architecture.
Construction and Maintenance	This terminator represents the information systems that are used to manage and track construction and maintenance of the roadway infrastructure. These Construction and Maintenance systems are used by roadway maintenance personnel, roadway construction personnel, or other work crew personnel assigned to highway construction and maintenance. Coordination with these systems allows the ITS Architecture to rapidly correct deficiencies noted through its advanced surveillance capabilities and also improves the quality and accuracy of information available to Travelers regarding closures and other roadway construction and maintenance activities.

5.4 Environmental Sensor Station (ESS) and Object Definitions

Figure 5.4.1 locates the ESS data objects, and the weather data flows in a simplified abstract from the National ITS Architecture (version 3.01).

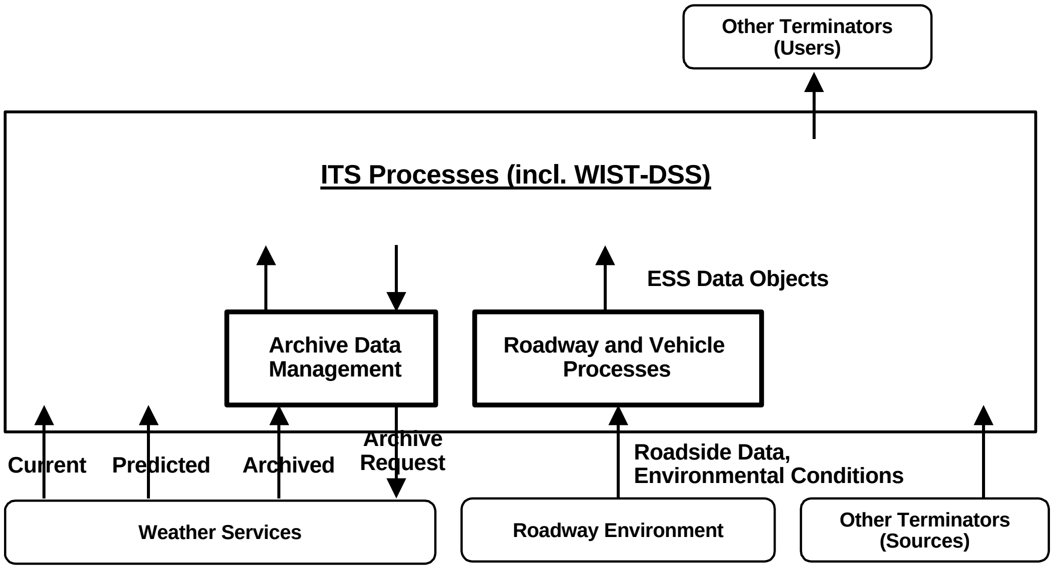

Figure 5.4.1: ESS and Weather Data Objects in the National ITS Architecture

The ITS terminator Weather Service is here made plural to emphasize the variety of weather information providers. The three kinds of weather information specified by the National ITS Architecture are current, predicted and archived. The lack of a reverse data flow except for archive request implies that ESS observations do not pass back to weather services, and that the current and predicted information is not requested in the same way as archive data. It is unclear if this is intended to represent broadcast, as opposed to client-server or other requests, for these data.

As contained in the ESS standard[25] , the ESS consists of processes associated with remote processing units (RPUs) and ESS data objects created by the RPUs and sent to central processing units (CPUs). In the National ITS Architecture, the roadway environment is a terminator that is

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[25] Joint AASHTO/ITE/NEMA Standards Publication TS 3.7-1998: National Transportation Communications for ITS protocol (NTCIP) Object definition for Environmental Sensor Stations (ESS), draft version 98.01.12, September 28, 1998.

the physical source of measurements. The RPU is associated with roadway and vehicles processes inside the ITS and the data objects are data flows in the ITS. ESS data from the roadway subsystem (fixed ESS sensors) and from vehicles (mobile sensors generating "smart probe" data) take separate paths in the National ITS Architecture. For the purposes here, use of ESS data can apply to either source. The source will be identified as meta data, and may relate to reliability for assimilation and other processing. Mobile source location will be used in tracking treatment vehicle location. Separate processing through the vehicle is relevant to in-vehicle use of ESS data (generally at warning scale, such as for spreader control), but this is not necessarily captured in the National ITS architecture yet.

ESS data objects have been defined in the protocol that covers the communication between the RPU and the CPU, also referred to as an information management subsystem (IMS) that processes and distributes the sensor data. While the CPU/IMS may correspond to other processes that produce road-condition and weather data types, it will be assumed that the ESS data objects are among the data types available to the WIST-DSS. The ESS standard covers the format and contents of data sent from fixed and mobile sensors and is based in part on World Meteorological Standard (WMO) standard for Binary Universal Form for the Representation of meteorological data (BUFR). The standard defines ESS to include devices that follow both NTCIP and BUFR standards (i.e., observing stations that may be operated by weather services or by transportation agencies). A list of the data objects from the standard is summarized below in indent format (in the standard the indices are preceded by 3 since that is the section number of the standard in which they appear):

1 Header Information
2 Identification Objects
3 Data Instrumentation Objects
4 Location Objects (fixed and mobile)
5 Station Elevation Objects
    5.1 Reference height
    5.2 Pressure (sensor) height
    5.3 Wind sensor height
    5.4 Atmospheric pressure
6 Wind Data Section
    6.1 Average wind direction
    6.2 Average wind speed
    6.3 Spot wind direction
    6.4 Spot wind speed
    6.5 Wind situation
    6.6 Maximum wind gust speed
    6.7 Maximum wind gust direction
7 Temperature Data Objects
    7.1 Number of temperature sensors
    7.2 Temperature sensor table

    - 7.2.1 temperature sensor index
    - 7.2.2 temperature sensor height
    - 7.2.3 air temperature
    - 7.2.4 wet-bulb temperature
    - 7.2.5 dew-point temperature
    - 7.2.6 maximum temperature
    - 7.2.7 minimum temperature
- 8 Humidity and Precipitation Data Objects
  - 8.1 Relative humidity
  - 8.2 Water depth
  - 8.3 Adjacent snow depth
  - 8.4 Roadway snow depth
  - 8.5 Roadway snow pack depth
  - 8.6 Precipitation indicator
  - 8.7 Rainfall or water equivalent of snow
  - 8.8 Snowfall accumulation rate
  - 8.9 Precipitation situation
  - 8.10 Ice deposit thickness
  - 8.11 Precipitation start time
  - 8.12 Precipitation end time
  - 8.13 Total precipitation past one hour
  - 8.14 Total precipitation past three hours
  - 8.15 Total precipitation past six hours
  - 8.16 Total precipitation past twelve hours
  - 8.17 Total precipitation past twenty-four hours
- 9 Radiation Objects
  - 9.1 Total sun
  - 9.2 Cloud cover situation
- 10 Visibility data objects
  - 10.1 Visibility parameter (distance)
  - 10.2 Visibility situation
- 11 Pavement Sensor Objects
  - 11.1 Number of pavement sensors
  - 11.2 Pavement sensor table
    - 11.2.1 pavement sensor index
    - 11.2.2 pavement sensor location
    - 11.2.3 pavement type
    - 11.2.4 pavement elevation
    - 11.2.5 pavement exposure
    - 11.2.6 pavement sensor type
    - 11.2.7 surface status
    - 11.2.8 surface temperature
    - 11.2.9 pavement temperature (2-10 cm below surface)

    - 11.2.10 surface water depth
    - 11.2.11 surface salinity
    - 11.2.12 surface conductivity
    - 11.2.13 pavement freezing point
    - 11.2.14 surface black ice signal
    - 11.2.15 surface sensor error
  - 11.3 number of sub-surface sensors
  - 11.4 sub-surface sensor table
    - 11.4.1 sub-surface sensor index
    - 11.4.2 sub-surface sensor location
    - 11.4.3 sub-surface type
    - 11.4.4 sub-surface sensor depth
    - 11.4.5 sub-surface temperature
    - 11.4.6 sub-surface moisture
    - 11.4.7 sub-surface sensor error
- 12 Mobile Platform Objects
  - 12.1 Mobile friction
  - 12.2 Mobile observation for the state of the ground
  - 12.3 Mobile state of the pavement
- 13 Pavement Treatment Objects
  - 13.1 Number of treatments
  - 13.2 Pavement treatment table
    - 13.2.1 pavement treatment index
    - 13.2.2 treatment product type
    - 13.2.3 treatment product form
    - 13.2.4 percentage of treatment type in mix
  - 13.3 Treatment amount
  - 13.4 Treatment width
- 14 Air Quality Parameters
- 15 Water Quality Parameters

This represents a comprehensive list of road-conditions of interest to maintenance and other decision makers. It is not mandatory that all ESS provide all data objects, and the standard specifies mandatory and optional conformance groups. The mandatory groups are basic ESS identification and configuration objects. The types of physical observations included are optional, but *when* a type of observation is included the applicable data objects generally are mandatory to meet the standard. In other words, an ESS *may* measure pressure, wind, temperature, etc., according to sensor equipage. But reporting observations from a particular sensor by an RPU *must* be according to the object standard. Therefore the standard does not guarantee what data will be obtained from an ESS, only that the data objects, when measured, will be standardized in format and content.

The contents of the standard for each data object will not be quoted here. However, the conformance groups are also categorized as basic, standard, enhanced and emerging. These suggest the corresponding equipage of an ESS according to the level of investment, and also over time as technology improves. These categories give some indication of what can be expected from ESS observations, with basic roughly corresponding to "any" ESS, standard to "prevalent" ESS, enhanced to "special" ESS, and emerging to "more common over time". A "staffed station" category also indicates observations that are most feasible when done manually. Therefore the categories can be used as a rough hierarchy of availability of observational data from the ESS (mostly without discrimination of whether these will be from fixed or mobile stations). This hierarchy is tabulated below:

Table 5.4.1: ESS Data Object Priorities

Level/Group	Data Objects
Mandatory	
Configuration	(in TS 3.4)
Time management	(in TS 3.4)
ESS Configuration	category, description, type of station
ESS Location	lat, lon, height
Basic (or not categorized and assumed basic)	
Pressure	pressure height and atmospheric pressure
Wind data	sensor height, direction, speed, max gust speed, max gust direction
Mobile wind data	wind situation (strength categories), direction and speed
Temperature	air temperature, max and min temperature
Precipitation	yes/no
Solar radiation	solar radiation (intensity), total sun (time)
Visibility data	visibility, visibility situation (categories)
Pavement Treatment (when reported by treating vehicle)	treatment product type, form, mix, amount, width
Air quality (if measured)	CO, CO2, NO, NO2, SO2, O3, PM10
Water quality	(not yet in standard)

Standard	
Precipitation	rate, start time, end time
Pavement sensor data	surface status, temperature, sensor error (fault)
Sub-surface sensor data	depth, temperature, error
Enhanced	
Temperature	relative humidity, wet bulb temperature, dewpoint
Precipitation	1, 3, 6, 12 and 24 hour amounts, precipitation situation (categories)
Pavement sensor data	pavement type, elevation, exposure, surface water depth, surface freezing point, surface black ice detection
Sub-surface sensor data	sub-surface moisture
Emerging	
Precipitation	water depth, roadway snow depth, roadway snowpack depth, ice thickness, adjacent snow depth, snowfall rate
Mobile platform	vehicle speed, bearing, odometer, friction, spot wind speed, spot wind direction
Staffed Station	
	wind situation, water depth, snow depth, snow pack depth, ice thickness, adjacent snow depth, precip situation, cloud situation, visibility situation, mobile observation ground state, mobile observation pavement

5.5 The Structure of Weather and ESS Data Flows in the ITS

Figure 5.5.1 shows the data flows and pspecs taken from the National ITS Architecture, partitioned to show what corresponds to functions within the WIST-DSS application and what is at the interface to external information.

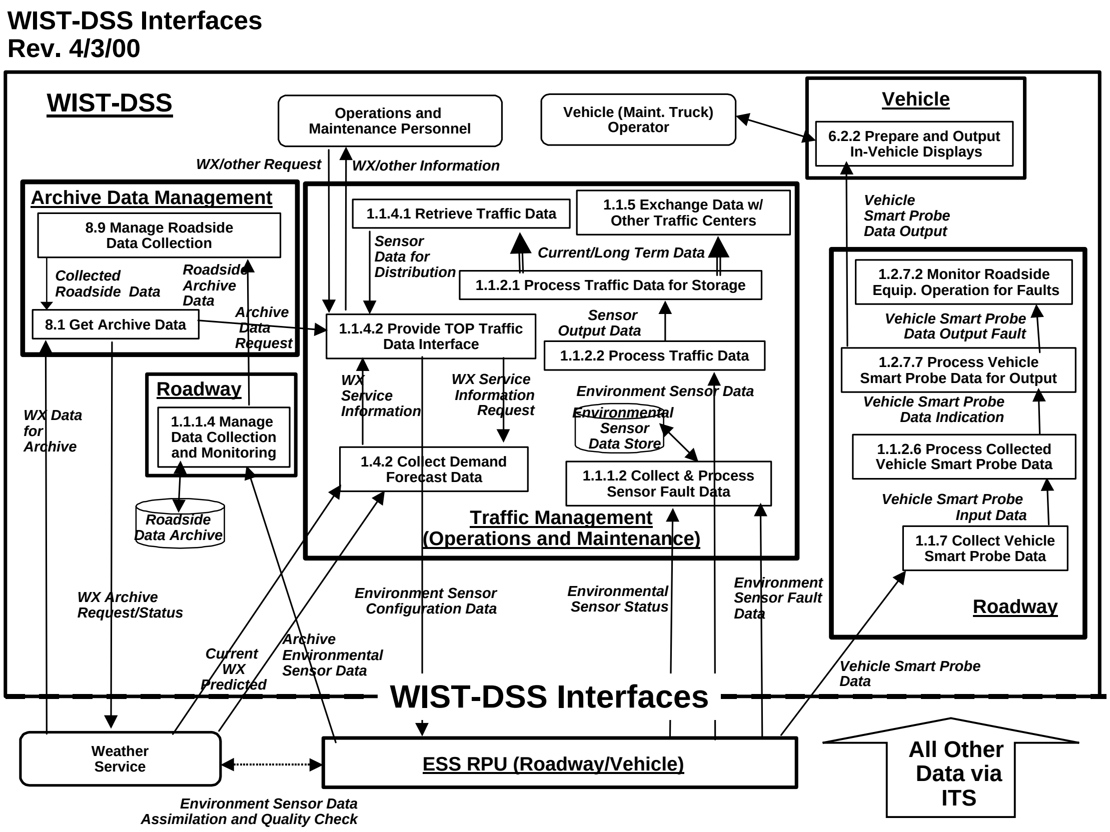


Figure 5.5.1: The WIST-DSS defined Within the National ITS Architecture

At the bottom are the three-way categorization of information sources initially defined for the WIST-DSS. The Weather Service(s) and the ESS RPU correspond to the sources of weather and road-condition information (collectively, environmental information). The ITS does not define an RWIS subsystem, but that is some part of the Weather Service(s) and the ESS. All other information in the WIST-DSS taxonomy will come from the ITS and is indicated as "all other data via ITS". The other ITS flows concern information that is not specifically weather-related but that flows to/from any of the pspecs shown.

The operational scale decisions covered in this document do not generally include decision made by vehicle operators. It is possible that some operational-scale decisions are made by managers in vehicles, but generally the environmental information processed as part of the "smart probe", or mobile ESS information thread will serve travelers and maintenance-truck operators at the warning scale. In either case, the smart probe information thread at the right of figure 5.5.1 is included to cover an expanded set of decisions for the WIST-DSS.

The other functions inside the WIST-DSS interface are as defined by the ITS, but can be mapped to WIST-DSS functions from the OCD. There are cases where some of these functions will be split between the DSS application and external processes. Most of the pspecs defined by the ITS and used here correspond to getting the external information (Select Context and Update Context as defined by the OCD) or passing the information to the human user (including the Generate Scenario, Monitor Conditions, Present decision and Make Decision functions). The users are represented by a Maintenance & Construction Operations Personnel and a Vehicle (Maintenance Truck) Operator terminators. There may be some functions assigned to these terminators that will be incorporated into the DSS, especially the information request delivery that is embedded in Monitor Context. Therefore these terminators are shown within the DSS. The purely human functions are outside the interface and served by the CHI. The CHI data flows therefore are taken as a subset of the data flow shown to the ITS terminators containing the users.

The National ITS Architecture does not yet have a Maintenance & Construction Operations (O&M) Personnel terminator in the position shown. Figure 5.1.1 showed the Construction and Maintenance terminator receiving information from Get Archive Data. Full representation of the O&M functions awaits completion of the O&M user service. However, the assumed O&M Personnel as WIST-DSS user is very analogous to the existing Traffic Operations Personnel (TOP) terminator. The structure in figure 5.5.1 is based on the data flows described to that terminator, which is a user of weather information. This means that the Archive Data Management to the Construction and Maintenance terminator has been re-assigned to pspec 1.1.4.2, consistently with how the “current and predicted” weather data flows are handled.

A rather circuitous thread can be traced for ESS data to the TOP terminator as well. For mobile ESS (smart probe) road-condition data, it can be argued that the flow to the Vehicle terminator should be extended to the TOP terminator as well. In that case, for operational-scale winter road maintenance management with the WIST-DSS, the Vehicle and TOP (here, O&M personnel) terminators should be merged to reflect the likely structure of information to the decision maker. Similarly, the pspecs assigned to the Vehicle and Roadway subsystems by the ITS might be in the (stationary) DSS.

Figure 5.5.1 addresses the environmental information flows to the WIST-DSS and the O&M Personnel user. It does not address the output data flow that would control winter road maintenance resources. Specifying those in the National ITS Architecture also awaits the O&M user service. But the WIST-DSS extends to decision support to many other users for many other decisions. Unless the WIST-DSS is specifically designated as a subsystem and/or pspec in the National ITS Architecture, it will have to be assumed that DSS involving environmental information and the supported decision outputs are distributed in existing entities. Weather and ESS information flows to several subsystems and processes as shown in figure 5.1.1. Each of these has to be examined to define what ITS entities are equivalent to WIST-DSS functions, as done in figure 5.5.1. The use of environmental information is perhaps best developed for the TOP terminator. Other users may not be so analogous to the TOP terminator, and it may be assumed that mapping WIST-DSS functions for other users will be awkward. These are some reasons for a review of the National ITS Architecture with respect to decision support involving environmental information. Some changes may make identification of DSS functions clearer to potential architecture users.

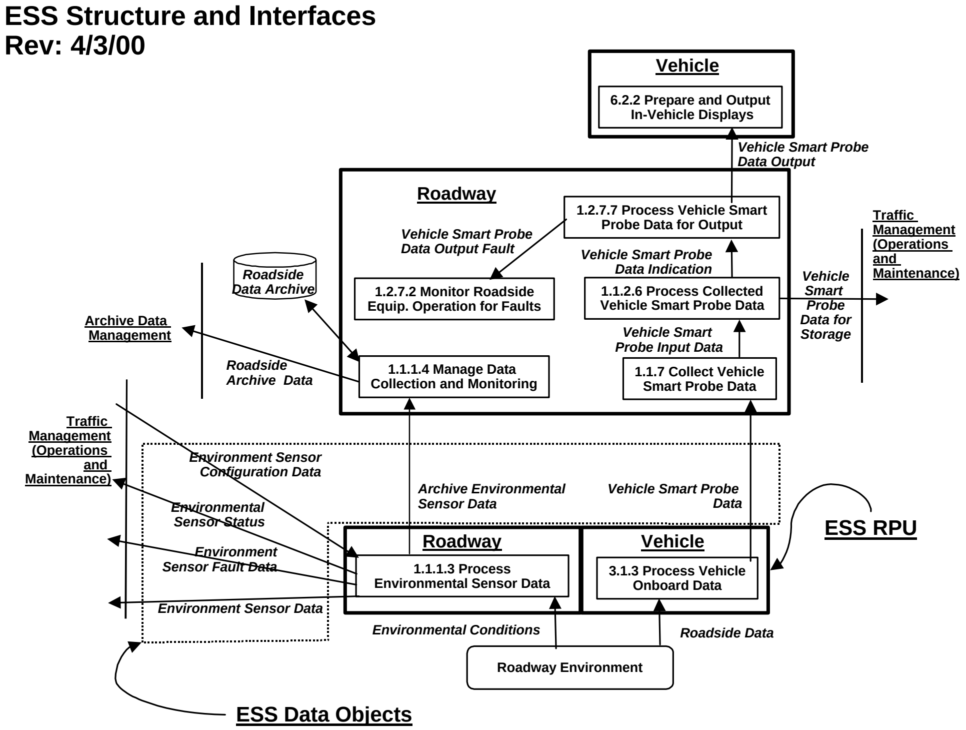


Figure 5.5.2: The ESS Interface to the WIST-DSS

Figure 5.5.2 details how the ESS RPU entity is constructed from the National ITS Architecture and leading to the data flows through the WIST-DSS. From figure 5.5.1, the WIST-DSS interface with the ESS is at the boundary designated as the ESS RPU. The RPU corresponds to two pspecs, one each in the Roadway and Vehicle subsystems for the fixed and mobile sensors. There are then six (6) data flows that correspond to the ESS data objects. The two data flows from the Roadway Environment terminator are within the ESS, but not in the data objects of the ESS standard. Physically, the *vehicle smart probe data*, the *environment sensor data* and the *archive environmental sensor data* will be what the sensors send to the RPU.

It is assumed that the RPU formats and transmits ESS data, and can remotely set the ESS configuration. The RPU does not do data checking and processing, that is largely within the WIST-DSS. An exception is shown on the WIST-DSS interface diagram. There, a data flow is inserted between the ESS and the weather service for data assimilation and quality checking. Alternatively, this function can be performed within the WIST-DSS (and therefore in another part of the ITS beside the ESS). This allocation issue will be tackled as part of WIST-DSS deployment considerations.

5.6 Other ITS Data Flows

In general, the most important information to the WIST-DSS, except for weather/road-condition, (and the mobile ESS data are taken to include maintenance-vehicle location) will be on traffic flow, to identify level of service (LOS) problems, to determine treatment effectiveness, to schedule treatment and as input to road-condition predictions. As the current National ITS Architecture shows, predicted traffic does depend on weather and road conditions. It certainly depends on road closure decisions, that may be made by the maintenance organization, traffic management or public safety patrols.

The ITS will also provide databases on the road network configuration and controls. Some of these will be at the planning scale, but others will be dynamic within the operational scale. This includes databases affected by road maintenance decision themselves. In the European “Road Master” concept, maintenance and traffic management function will be more integrated, so it is reasonable to project that any information on the state of the road system will be of interest to the WIST-DSS. Since information in the ITS that is part of the WIST-DSS information resources also goes to other applications in the ITS, their requirements cannot be determined solely by any one set of decisions served by the WIST-DSS. Only a full analysis of all decisions will determine the binding requirement on any information resource. Winter road maintenance management may not even be the binding requirement on the environmental information. Certainly, the operational scale does not stipulate the micro scale to be served by the ESS.

Not every possible data flow of interest will be traced here. The assumption is that the National ITS Architecture provides a high level framework for any application, and it will be up to each application to adapt and detail the architecture, subject only to control of interfaces by the architecture to other applications. However, the closest analog to a WIST-DSS architecture is contained currently in the Traffic Management subsystem, which is the focus of all road sensor (including ESS) data flows. The processes to support Traffic Operations Personnel are analogous to those in the WIST-DSS to support winter road-maintenance managers. It is therefore logical that the other ITS information of most interest to the WIST-DSS will be centered around Traffic Management, and this also suggests the functional integration between maintenance and traffic operations already embodied in the Road Master concept. Therefore, it is worthwhile to trace the Traffic Management data flows within the National ITS Architecture to identify data flows also of interest to the WIST-DSS.

Traffic data are centered in the Traffic Management subsystem (physical architecture). The corresponding processes and data flows in the logical architecture are under the Manage Traffic group at the first level. The associated lower level pspecs are listed below:

dfd Manage ITS 0
  dfd Manage Traffic 1
  dfd Provide Traffic Surveillance 1.1
  dfd Process Sensor Data 1.1.1
  pspec Process Traffic Sensor Data 1.1.1.1 (rs)
  pspec Collect and Process Sensor Fault Data 1.1.1.2 (tms)
  pspec Process Environmental Sensor Data 1.1.1.3 (rs)
  pspec Manage Data Collection and Monitoring 1.1.1.4 (rs)
  dfd Process and Store Traffic Data 1.1.2
  pspec Process Traffic Data for Storage 1.1.2.1 (tms)
  pspec Process Traffic Data 1.1.2.2 (tms)
  pspec Update Data Source Static Data 1.1.2.3 (tms)
  pspec Monitor HOV lane use 1.1.2.4 (tms)
  pspec Process Tag/AVL Data for Link Time Data 1.1.2.5 (tms)
  pspec Process Collected Vehicle Smart Probe Data 1.1.2.6 (rs)
  pspec Monitor Reversible Lanes 1.1.2.7 (tms)
  pspec Generate Predictive Traffic Model 1.1.3 (tms)
  dfd Display and Output Traffic Data 1.1.4
  pspec Retrieve Traffic Data 1.1.4.1 (tms)
  pspec Provide Traffic Operations Personnel Traffic Data Interface 1.1.4.2 (tms)
  pspec Provide Direct Media Traffic Data Interface 1.1.4.3 (tms)
  pspec Update Traffic Display Map Data 1.1.4.4 (tms)
  pspec Provide Media System Traffic Data Interface 1.1.4.5 (isp)
  pspec Provide Traffic Data Retrieval Interface 1.1.4.6 (isp)
  pspec Manage Traffic Archive Data 1.1.4.7 (tms)
  pspec Exchange data with Other Traffic Centers 1.1.5 (tms)
  pspec Collect Vehicle Tag Data for Link Time Calculations 1.1.6 (rs)
  pspec Collect Vehicle Smart Probe Data 1.1.7 (rs)

The pspec list indicates that the Traffic Management data flows are limited to those from ISPs, the Roadway Subsystem (RS) and internally. Traffic and road-condition information of course originate in the RS (which is also the processor of vehicle data from the terminator Roadway Environment), and the sensors for both traffic and other road-condition information are logically allied as well as physically coincident in many cases. For purposes of the WIST-DSS, the other ITS information can then pretty well focus on the TM and RS physical subsystems. Examining the third level indent of the logical TM processes gives the relevant structure of the traffic information processing (data flow diagram (dfd) items are composites with underlying pspecs):

dfd Provide Traffic Surveillance 1.1
    dfd Process Sensor Data 1.1.1
    dfd Process and Store Traffic Data 1.1.2
    pspec Generate Predictive Traffic Model 1.1.3 (tms)
    dfd Display and Output Traffic Data 1.1.4

As was seen in the architecture extract for weather and ESS information, the direct interface to Traffic Operations Personnel for all the traffic and weather data is a pspec under Display and Output Traffic Data: pspec Provide Traffic Operations Personnel Traffic Data Interface 1.1.4.2 (tms). This pspec has the following data flows:

Data Flows In	**Data Flows Out**
ftop_traffic_data_parameter_updates	environment_sensor_configuration_data
ftop_traffic_information_requests	operator_log_for_traffic_data
ftop_weather_request_information	request_traffic_map_display_update
map_data_for_traffic_display	request_traffic_operations_data
operator_log_for_traffic_data	sensor_configuration_data
retrieved_traffic_operations_data	traffic_data_media_parameters
traffic_video_image_for_display	ttop_traffic_control_information_display
weather_service_information	ttop_video_image_output
	ttop_weather_information
	weather_service_information_request

These data flows are also helpful in defining the analogous WIST-DSS interfaces. This then is the logical interface to the WIST-DSS for all of the external information elements identified in the interfaces taxonomy and via the ITS. The information taxonomy of WIST-DSS data flows does not necessarily follow the taxonomy of the ITS data flows. Among other differences, the WIST-DSS taxonomy subdivides the Weather Service terminator and its data flows differently. The ESS standard, incorporated into the WIST-DSS taxonomy already defines its data objects differently from the architecture data flows, although a mapping is maintained. The same can be said for the WIST-DSS information elements.

Of the pspecs feeding pspec 1.1.4.2, the one expected to have input from WIST-DSS outputs is pspec 1.1.3---Generate Predictive Traffic Model. This is also the focus of weather information.

The overview of this pspec reads:

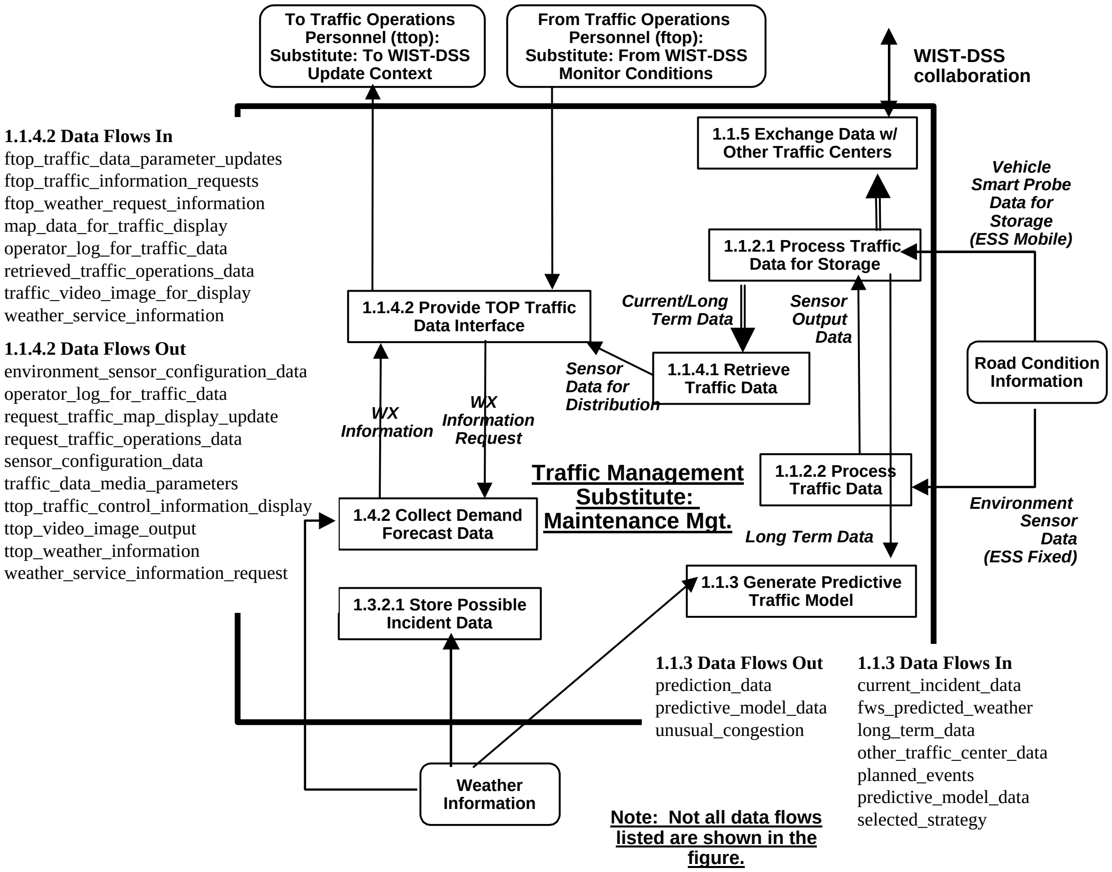
> This process shall be responsible for continually producing and updating a predictive model of the traffic flow conditions in the road or freeway network served by the Manage Traffic function that an instance of this process is allocated to. The prediction shall be based on current surveillance, historic traffic data and surveillance, current incidents, planned events, current traffic control strategy, data received from other Traffic Management Subsystems (TMS's) serving other geographic and/or jurisdictional areas, and current and predicted weather conditions. The predictive model of traffic flow produced by this process shall be used by processes in the Manage Traffic function and other ITS functions.

The “planned events” can include maintenance treatments. Data received from other TMS’s should be expanded to include “from O&M subsystems” as those are introduced. The current and predicted weather information should be augmented by “road conditions” as predicted from planned treatment activities. While predicted road conditions are not specified as data flows, they can be generated from ESS observations in the pspec 1.1.2.2 Process Traffic Data. This is just more awkward than having a consolidated ESS process. The WIST-DSS taxonomy argues that environmental prediction is an external process. Rather than assuming that various applications make predictions from ESS observations (or weather observations for that matter) it is probably desirable to include predictions in the ESS process.

The data flows for pspec 1.1.3---Generate Predictive Traffic Model are:

current_incident_data--In
fws_predicted_weather--In
long_term_data--In
other_traffic_center_data--In
planned_events--In
prediction_data--Out
predictive_model_data--in
predictive_model_data--out
selected_strategy--In
unusual_congestion--Out

The WIST-DSS outputs to the predictor will be analogous to other_traffic_center_data, planned_events and selected_strategy, if a “maintenance center” modifier is substituted for “traffic center”. The modified logical/physical architecture structure for the WIST-DSS interfaces, following the National ITS Architecture, will then appear as below:



1.1.4.2 Data Flows In
ftop_traffic_data_parameter_updates
ftop_traffic_information_requests
ftop_weather_request_information
map_data_for_traffic_display
operator_log_for_traffic_data
retrieved_traffic_operations_data
traffic_video_image_for_display
weather_service_information

1.1.4.2 Data Flows Out
environment_sensor_configuration_data
operator_log_for_traffic_data
request_traffic_map_display_update
request_traffic_operations_data
sensor_configuration_data
traffic_data_media_parameters
ttop_traffic_control_information_display
ttop_video_image_output
ttop_weather_information
weather_service_information_request

1.1.3 Data Flows Out
prediction_data
predictive_model_data
unusual_congestion

1.1.3 Data Flows In
current_incident_data
fws_predicted_weather
long_term_data
other_traffic_center_data
planned_events
predictive_model_data
selected_strategy

Figure 5.6.1: Other ITS Data Flows Relevant to the WIST-DSS

This figure suggests that either the Traffic Management processes can be used to interface with the WIST-DSS, or that a Maintenance Management subsystem can be formed, structurally and functionally very similar to Traffic Management. The choice depends partly on functional integration of maintenance and traffic management in the Road Master concept.

6. Recommendations

This section is based on all proceeding sections. It restates conclusions and makes recommendations on behalf of the objectives of an open information infrastructure, and information adequate to serve the interface taxonomy of the WIST-DSS. The Road Weather Management Program will decide which recommendations it will pursue, based on their importance and resources available.

6.1 Basic Structural Concept and Approach

Conclusion: All information-processing applications depend on an open information infrastructure.

1.1 Recommendation: The Road Weather Management Program must support ITS and other open system standards among the information resources important to the WIST-DSS. The role of the Program should focus on guidance to WIST-DSS users, deployers and vendors. The OCD and PIR are the basis for referring to relevant ITS and other standards in developing such guidance.

Conclusion: The OCD and PIR currently are limited to winter road maintenance, operational-scale, decision requirements.

1.2 Recommendation: Proceed to other user requirements in a phased program and maintain expandability in the DSS development program to include other requirements as they are analyzed. Launch an integration overview task to identify any critical expandability issues based on current requirements documentation and the pan-agency requirements effort of the OFCM JAG-WIST.

Conclusion: It is difficult, and currently not possible, to quantify requirements on external information resources. This is partly due to lack of validated experience in using information sources with advanced DSS, and the causal effects on surface transportation outcomes (goal performance), and partly due to lack of analysis on the benefits of combining various environmental information processes.

1.3 Recommendation: Longitudinal and end-to-end evaluations of DSS, such as being conducted for the Foretell program, should be promoted, which will also lead to the possibility of cross-sectional evaluations between projects. Full evaluation should accompany phases of WIST-DSS development. The FY 00 project for road-condition forecasting should be examined after a year to determine further efforts needed to address the organization and effectiveness of external information processes. The FY 02 research program should establish funding for extension and expansion of current projects.

Conclusion: In an open system, with multiple decisions dependent on information from one common environment, it is appropriate to define an environmental information infrastructure, and to limit the definition of "tailoring" to decision support applications.

1.4 Recommendation: The Road Weather Management Program should represent public surface transportation interests in legislative and regulatory matters affecting public versus private responsibilities in environmental information. The Program should devise a statement of principles to guide such representation. The principles should include supporting the ability of the NWS and other public agencies to maintain a high quality, integrated, environmental information system meeting the legislated mandates of those agencies. The principles should include supporting a vital private sector role in technical innovation, providing environmental information services where supportable by the market, and in providing true decision support applications within an open information system.

Conclusion: From qualitative analysis, there are apparent activities that are likely to improve the environmental information resources.

1.5 Recommendation: The Road Weather Management Program should ensure that the following activities are incorporated in its five-year plan:

- Pursue the goal of national assimilation of all observations for quality control and open-system access (primarily through the OFCM CIOS).
- Define and pursue opportunities for improved service from the NWS that are justifiable by its charter to serve commerce, the dissemination opportunities of the ITS, and appropriate limits on tailoring. This should be addressed through the OFCM JAG-WIST and bilateral projects with the NWS as part of WIST-DSS development.
- Define and pursue opportunities to exploit other existing weather services (e.g., military) and surveillance technologies (e.g., remote sensing) for environmental information and the public benefit of surface transportation. This should be done through the OFCM JAG-WIST, CIOS and the NASA/RSPA remote sensing program.
- Identify and promote advanced environmental observational and forecasting technologies, and operations, that are of unique interest to surface transportation, or that complement without duplicating meteorological and weather services' interests.

- Through the OFCM JAG-WIST, combine with other user communities (e.g., airspace operation, agriculture, etc.) in research and deployment programs, that leverage mutual interests.
- Define a strategy for the geographical organization of road/weather condition information production (e.g., regional centers to avoid duplication, ensure coordination and focus resources), and disseminate it for consensus, primarily through the OFCM JAG-WIST.

Conclusion: While most apparent initiatives for improved environmental information involve inter-federal coordination, the primary axis of WIST-DSS development and deployment is still through local transportation agencies and private vendors.

1.6 Recommendation: The FHWA must establish a stronger role in getting local-agency representation in federal activities and in guidance to local agencies relative to environmental information and decision support. The FHWA must focus on the public agency side of the user/vendor market. The STWDSR is only one tool, and must be accompanied by strong efforts of the Road Weather Management Program to interest and coordinate especially the state DOTs (AASHTO, the Aurora pooled fund, etc.) and local agencies (via APWA, NACO, etc.). Useful guidance via the FHWA technical assistance and professional capacity building programs, and based on a long-term research program, is essential to build the local constituencies.

Conclusion: VAMS concerns over their market and proprietary rights over ESS and other products continue to be a major institutional issue, sometimes wrongly impeding an open information infrastructure.

1.7 Recommendation: The Road Weather Management Program, allied with local agencies, should use every opportunity to engage the VAMS and promote the open system infrastructure in ways that demonstrate protection of proprietary rights over information, widening the market for products through promotion of new applications, and a shift of tailoring responsibilities from the information to decision support applications.

6.2 The Information Interface Taxonomy

Conclusion: The taxonomy enumerates the external information needed by the WIST-DSS for operational scale, winter road maintenance management decisions.
2.1 Recommendation: The taxonomy should be used as the STWDSR V2.0 baseline for control of interfaces to the WIST-DSS functions described in the OCD. Changes identified from modifications to the OCD or in further WIST-DSS development should be added in a controlled process.

Conclusion: The taxonomy was developed from detailed analysis only of winter road maintenance decisions at operational scale. The taxonomy probably serves many needs of other types of decisions.
2.2 Recommendation: Completeness of the taxonomy, and identification of requirements for other environmental information types, should be pursued through analysis of other decisions types, as prioritized by the Road Weather Management Program and in cooperation with the requirements process of the OFCM JAG-WIST.

Conclusion: The taxonomy is not a standard. Relevant standards for data objects (in ITS standards for data dictionaries and message sets) have not been identified relative to the taxonomy, except for the ESS data objects. Many relevant ITS standards are not finalized.
2.3 Recommendation: Further development of the WIST-DSS must follow applicable standards. The Road Weather Management Program should coordinate with the ITS, and other, standards activities to ensure that the practical experience from WIST-DSS development is incorporated into standards.

Conclusion: ITS data dictionary and message set standards extend to applications in end-to-end data communication. However, the ultimate end of this thread, the computer-human interface (CHI) has been least examined. There are many issues of appropriate CHI, including graphical iconology for environmental information, presentation of decision criteria, and the appropriate allocation of DSS functions between machine and human.
2.4 Recommendation: Development of the CHI component of DSS development must be bolstered. The Road Weather Management Program should pursue this on at least two tracks: One is consideration of graphical symbology as an extension of the MUCTD. The other is sponsorship of research in conjunction with other CHI efforts within the FHWA.

6.3 Weather and Road-Condition Information

Conclusion: There are important interactions between weather information processes and road-condition processes in the environmental information infrastructure. The concept of tailoring within the information infrastructure, as opposed to in the DSS applications, is largely an outdated artifact of stovepiping. The information infrastructure is itself a network of applications, that should interact to produce better environmental information for common use by many DSS applications.

3.1 Recommendation: The Road Weather Management Program should promote an open system, and resist artificial restrictions on services and development in an environmental information infrastructure. The FHWA's role in this is analogous to its role in coordinating connectivity and service of the NHS.

Conclusion: Technology and users needs are promoting an integration of environmental information. The separation of the air, sea and land in information processes due to observational, scale and technical limitations is diminishing. Terrestrial conditions, of primary interest to surface transportation, will come more into the mainstream of environmental information. Agency interests under NOAA will thereby merge with interests of other agencies.

3.2 Recommendation: The view of "one environment" (and many decision makers) should be promoted in inter-agency coordination, starting with the OFCM. Surface transportation interests should be active in promoting such an integrated view, including a USDOT statement of principle on environmental information services to transportation decision makers across the modes on land, sea and air. This is also appropriate for the National Science and Technology Council.

Conclusion: Improved resolution of environmental condition information has been considered necessary to relate to conditions on specific road segments. At least for operational-scale decisions, the appropriate focus is on jurisdictional aggregates, not individual road segments. At warning scale, direct and local observation likely will be the superior information source.

3.3 Recommendation: Priority for investment by surface transportation interests in improved environmental information must consider the appropriate allocation of functions between DSS and the external information sources. Appropriate fusion techniques within DSS, and requirements for matching types of information to the scale of decisions, should temper pursuit of arbitrary improvements in external information resolution.

Conclusion: Improved decision support can improve transportation system performance even with current environmental and other information resources. Over time, the environmental information resources will improve, and "tailoring" functions within DSS applications will shift more and more away from environmental information to applying that information to decisions.

3.4 Recommendation: Development of the WIST-DSS, focusing on true decision support functions, should proceed in parallel with programs to improve the external information resources. DSS development should anticipate external supply of environmental conditions, but should accommodate existing types and quality of environmental information. DSS development should include the fusing of various sources of environmental information according to relevance and reliability for decisions, but should consider inference of relevant environmental conditions, in lieu of external sources, as transient.

Conclusion: Numerical weather prediction (NWP) products are strongly looked to for improvements in the timeliness, relevance and accuracy of weather information for surface transportation decision support. The exact role of NWP is, however, not well defined with the production of road-condition information. The frontier of NWP performance is heavily limited by technical and economic factors, and dominated by meteorological interests. There are strong issues in the organization of multiple, sub-national domain, NWP modeling.

3.5 Recommendation: The Road Weather Management Program should not be involved in the technical development of meso-scaled NWP models, since this is primarily in the meteorological domain and driven mostly by meteorological interests. The Program should address the requirements for, use of and applications for advanced NWP models. The Road Weather Management Program should document and project NWP performance. Based on that, a strategy for institutional responsibility and geographical organization of meso scale NWP, for surface transportation purposes, should be devised. This should extend to the observational inputs necessary to achieve the desired level of NWP performance.

Conclusion: The common use of environmental observations strongly supports common assimilation and open distribution of observations.

3.6 Recommendation: The WIST-DSS development and other Road Weather Management Programs should define and promote common data assimilation and open distribution within the United States. This must use open system capabilities to address issues of data ownership.

Conclusion: Changing technology associated with the NWS modernization program will stress conventional institutional roles and the public/private division of the environmental information market. Road Weather Management Program activities to address this are strongly constrained by policy.

3.7 Recommendation: As detailed deployment requirements (e.g., for surveillance information on the National Highway System and for the ITS generally) develop, the Road Weather Management Program should adopt a policy on the supply of environmental information that specifically recognizes the legislated mandate and technical capabilities of the NWS. This policy should represent the interests of surface transportation as “commerce” in the NWS legislation, to promote use of NWS resources for environmental information, while promoting private sector innovation and decision-support application development. The basis of such a policy should be developed through testing of the WIST-DSS interfaces with NWS systems compared to other sources. This policy should also address the adaptation of narrative (e.g., watch and warning) and graphical NWS products that are the standard of public information on weather, to automated DSS applications and computer-to-computer communications.

Conclusion: The human judgment of meteorologists, whether in the NWS or as a VAMS, will continue to be a vital part of weather analysis and production of road-condition predictions. In the open system concept of a network of interacting applications, differences between DSS applications and environmental information applications are minimized. Collaboration applies as much between DSS and information source applications as between DSS. The idea of collaborative forecasting should be addressed in DSS development and interfaces, and raises important issues about the demarcation of tailoring.

3.8 Recommendation: The OCD should be reexamined with respect to collaborative functions in the production of what was defined as contextual environmental information. The communication of risk information on environmental predictions (and observations used as predictors) is one way to mitigate needs for collaboration and must be emphasized. However, alternative approaches involving two-way interactions between DSS and environmental information applications and/or users should be investigated.

Conclusion: Risk statistics are among the meta data least well provided at present. There are several intuitive cases to be made why the risk statistics are important, but there is little research on the use of risk information for surface transportation decisions. This could be extended to the CHI generally.

3.9 Recommendation: In addition to the CHI research recommended elsewhere, the production of information statistics should be promoted. This includes promotion of observational assimilation, dissemination of statistics for any time-series prediction (ESS filtering, weather cell tracking, etc.), operational-scale validation of predictions versus observations, extending MOS to additional NWP models, and running NWP ensembles as part of the organization of meso scale and sub-national domain NWP operation.

Conclusion: The role of ESS data in initializing (or adaptively updating) heat balance models is not well defined. The role strongly affects relative or complementary investment decisions in heat balance modeling, ESS and thermal mapping..

3.10 Recommendation: A research project should focus on this issue (it may be addressed in the FY 00 research program).

Conclusion: Thermal mapping in combination with ESS point observations is a valuable approach. It and the thermal surveys for heat balance models would benefit from remote sensing.

3.11 Recommendation: In lieu of adequate radiometric resolution in geostationary satellites, the use of low orbit satellites and aerial thermal mapping should be investigated and promoted. This includes identification of sensor technology research issues, affecting operational requirements and practices of existing and proposed platforms, and pursuing use of currently classified sources.

Conclusion: There is not enough fixed-site ESS coverage of the National Highway System (NHS), let alone the entire road network.

3.12 Recommendation: The Road Weather Management Program should be active in promoting mobile ESS deployment, not only on maintenance vehicles, but as part of the sensor/communications suites of private vehicles. The investment in fixed ESS sites remains a critical issue to be addressed in conjunction with other research. Technology development to make fixed ESS more cost-effective should be prioritized.

Conclusion: The USDOT has a strong role in DGPS deployment that affects the atmospheric tomography observations for water vapor.

3.13 Recommendation: The Road Weather Management Program should identify, in concert with meteorological researchers, any barriers to use of this technique, and should identify unique applications for surface transportation. The existing inter federal coordinating committee on DGPS as well as the OFCM CIOS should be used.

Conclusion: The USDOT encompasses both the FHWA and the FAA. Particular leverage can apply to using FAA weather capabilities for surface transportation purposes. This includes surface observations and radar remote sensing, and a joint interest in surface freezing conditions.

3.14 Recommendation: Form a USDOT task force to identify complementary activities in environmental information, and how best to leverage investments for service across the modes.

Conclusion: The information resource, like the DSS application, will evolve rather than being centrally planned, because of the diversity of parties involved and the effects of technology advances over time.

3.15 Recommendation: The spiral evolutionary mode for DSS deployment must be taken seriously. This includes a long term commitment to a sequence of research, test, commercialization and evaluation steps. This commitment should be made clear in strategy and program plans.

6.4 Weather Services

The conclusions here are summarized from the potential improvements in table 4.6.1, and recommendations are attached.

Conclusion: Model Resolution & Microclimate and Model Ability to Predict Small-Scale Disturbances. Numerical models should strive to have:

- A high enough resolution (i.e. small spacing between model grid points) to provide information of high quality about weather affecting different roads and land features.
- A cycle refresh rate high enough to support road maintenance operations and decision makers.
- A large enough domain to cover the maintenance jurisdiction with propagation and tracking of approaching weather systems, without sacrificing grid density.
- Knowledge of specific microclimates within the domain of the model grid.
- The ability to quantify, identify and propagate small-scale disturbances which produce significant weather over the road maintenance district.

4.1 Recommendation (similar to 3.5): The Road Weather Management Program should not be involved in the technical development of meso-scaled NWP models, since this is primarily in the meteorological domain and driven mostly by meteorological interests. The Program should address the requirements for, use of and applications for advanced NWP models. This should include monitoring the state-of-the-art (SOA) and the organization of regional modeling regarding its implications for regional road-condition prediction. The Program should coordinate national strategies and provide guidance to road operators for the deployment of SOA modeling, and sponsor research in the road-condition algorithms dependent on such modeling.

Conclusion: NWP models need to have:

- The ability to accurately predict precipitation state (liquid, freezing or frozen) at any time during the life cycle of a storm.
- The ability to accurately predict the starting and stopping times of the precipitation event to within an hour. In addition, during the precipitation event, the model must be able to display accumulation/accretion rates and the potential for drifting (if frozen precipitation is involved).

4.2 Recommendation: Part of the SOA characterization of NWP modeling should define its role with respect to observational data, and the weather analysis process generally, at different time horizons for precipitation characterization and timing. This includes the risk statistics and validation measures of performance appropriate to event prediction for a space-time distributed jurisdiction for decision making. Testing of DSS with SOA information should be done to refine quantitative requirements on the validated performance of the environmental information, and to trace these measures back to specific information process improvements.

Conclusion: Adequate backup for NWP model production:

- In the event of a failure of the computer(s) that either pre-processes data or the computer that runs the model, adequate backup must be available.
- In the event of a communications failure between the computer center and the client sites, an alternate means of data transmission must be available.

4.3 Recommendation: Backup recommendations should be applied to any strategy for regional NWP modeling. It should be assumed that NCEP modeling has appropriate backup criteria.

Conclusion: There are technical difficulties with current sensors that limit their performance in (among other capabilities):

- snow accumulation, snow drift and liquid equivalent.
- monitoring icing conditions, including visibility, ice accretion, sleet accumulation and liquid equivalent.

4.4 Recommendation: The Road Weather Management Program should ally with other interested parties (in meteorology and applications such as air traffic), to sponsor joint research and development in improved *in situ* sensors related to the surface incidence of precipitation, icing and related effects. The focus should be on cost effective technologies for widespread, reliable deployment, and communications back to centers. However, the overall role of *in situ* versus remote sensing in these applications should be defined (per other recommendations). The OFCM CIOS is an appropriate forum for raising this issue.

Conclusion: Maintenance and calibration of remote sensors is non-uniform, and often deficient.

4.5 Recommendation: Develop a policy so that a wide range of remote environmental sensors can be *maintained* to high standards to preserve quality in the data that is ingested into NWP models and decision support systems. Develop a policy so that a wide range of remote environmental sensors can be *calibrated* so that a uniform quality data set can be obtained. The Road Weather Management Program should collect policies of highway authorities that operate ESS and determine best practices. The Program should determine practical and economic levels of maintenance and calibration, related to ESS technologies and capital costs. The Program should promote a policy on maintenance and calibration in conjunction with opoerator organizations (e.g., AASHTO) and distribute guidance on best practices.

Conclusion: Radar and backup:

- Weather radar systems need to be able to discriminate between precipitation phases, and their mixtures.
- Radar systems need to be able to account for beam blockage in algorithms from terrain, structures or atmospheric refraction.
- Radar algorithms need to be able to account for loss of returned signal due to beam attenuation (either through hydrometeorological targets or accretion on the radar dome).
- Adequate backup radar should be available in the event that the main weather radar system is taken out of service and to compensate for lack of coverage, especially close to ground surface.
- The operational practice of volume coverage patterns in weather radars should give adequate emphasis to near-ground coverage, including technologies to reduce clutter effects near to ground surface, and anomalous propagation.

4.6 Recommendation: The Road Weather Management Program should lead surface transportation interests in becoming significant partners in the Doppler weather radar program, including the incorporation of alternative (e.g., air traffic management) radars. This should be done via the OFCM and expand the existing consortium of the NWS, DOD and FAA based on their applications interests that are no greater than those of surface transportation. Participation should include significant funding from the surface transportation community. The objects of the funding should be research on improved radar technologies and algorithms, and the location of radars to fill gaps that are important to the surface transportation applications. Operationally, the surface transportation community should be active in setting such policies as volume coverage patterns and exploiting the forthcoming open system architecture for applications that serve the surface transportation community.

Conclusion: Satellite remote sensing capabilities and backup:

- Satellite sounding capabilities need to be refined to be able to report near-ground conditions (such as precipitation, temperature and winds) regardless of cloud cover.
- Snow accumulation/depth survey data from satellites would be a good tool for initializing NWP models and for distributing surface resources.

4.7 Recommendation: The Road Weather Management Program should take leadership in applying the NASA/RSPA program for applications of remote sensing to transportation to road-condition observation, and for coordinating that program with OFCM JAG-WIST and CIOS activities. The NASA/RSPA program represents significant funding under USDOT control. The NASA/RSPA program may also be the best way to gain a surface-transportation voice in the multi-agency satellite programs, similar to that recommended for radar. However, it is recognized that the technical limitations on resolution and coverage to ground surface limit the payoffs relative to radar and it is questionable that comparable funding to the observing platforms should be committed. A recommendation for investigating use of currently-classified sensing for surface-thermal applications was made above.

Conclusion: Density of Surface Stations:

- The number of maintained and calibrated ESS units should be increased to properly cover the microclimates associated with roadways throughout each maintenance district.
- Each ESS should be equipped with all meteorological equipment necessary to observe conditions in its local climate.
- Each ESS observation should be properly formatted and transmitted so that it can be included in current observational collectives and be made available for model updates.

4.8 Recommendation: The FY 00 research on ESS deployment should be concluded as part of defining appropriate roles for ESS in the overall environmental sensing strategy. This should be used to produce guidance to deployers on appropriate levels and siting for ESS deployment. This will also contribute to the NHS surveillance requirements policy. The cost effectiveness, accuracy and open-system dissemination of observations are addressed in previous recommendations.

Conclusion: Ability to Collect and Process Data from Proprietary Networks:

- Some transportation agencies have proprietary ESS networks where data are not available to other agencies.
- Some private organizations maintain networks of ESS's (e.g., around power stations). These data sets should be made available for use in analysis and forecasting.

4.9 Recommendation: The issue of proprietary ESS data has been addressed. The incorporation of all available observations into meso nets should be part of a strategy for regional environmental information. Since the meso nets have wide application, the Road Weather Management Program should seek interested allies in this issue through the OFCM.

Conclusion: Need capabilities to archive and retrieve storm histories, including retrieval quickly (within 24 hours of the past events/forecasts):

- Archive current weather conditions, model forecasts and status of the road maintenance district (personnel, resources, budget).
- Quickly retrieve archived weather conditions, model forecasts and status of the road maintenance district.
- Quickly retrieve archived meteorological case studies of significant weather events that affected the district to compare with a forecast event.

4.10 Recommendation: This area falls under the ADUS user service. The ADUS requirements should be reviewed by the National ITS Architecture Team to ensure consistency with the requirements above. On the surface transportation side, the requirements should be implemented by guidance on the importance of archived data, especially to the learning/evaluation process in the development of improved information systems. More specific guidelines, and an archival strategy should be developed for the data relevant to decision support involving weather threats (e.g., road surface LOS data as well as traffic LOS). On the meteorological side, archive requirements are levied primarily on the National Climatic Data Center (NCDC). There are issues of appropriate archiving relative to road conditions and the products made available to DSS. The ADUS requirements activity should be expanded to address these inter-agency issues, generally under the ITS program.

Conclusion: Both the NWS and the ITS are developing advanced information architectures. These should be better integrated and the NWS should better exploit high capacity and open-system communications channels for the dissemination of information to the public.

4.11 Recommendation: The NWS information architecture should be integrated with the National ITS Architecture to take advantage of developing information dissemination capabilities to mobile and stationary users. Specific implementations, like The All Hazards Warning System should be jointly developed. The NWS should increasingly disseminate graphical products to the public, as generated by AWIPS and other processes, through the Internet and other open system channels to the ITS.

6.5 ITS/ESS Data Elements

Conclusion: The National ITS Architecture needs completion of an O&M user service to represent the winter road maintenance functions that are the current focus of the OCD and PIR. This is proceeding, but it is unknown how this will represent the OCD functional requirements at the architecture level. The architecture representation should promote WIST-DSS deployment guidance.
5.1 Recommendation: The Road Weather Management Program should continue to monitor and review the O&M user service narrative. The Program should also participate closely in the requirements analysis that results.

Conclusion: Environmental information permeates the National ITS Architecture, and is not focused in particular applications, physical subsystems or logical processes. This makes it difficult for the National ITS Architecture to represent a coherent and consolidated picture of environmental information, and limits its effectiveness in supporting guidance in this area. A single user service for environmental information may not be an adequate approach.
5.2 Recommendation: The National ITS Architecture Team should refer to this PIR (Section 5 especially) and consider possible modifications to the architecture, or support of an “overlay” representation that consolidates environmental information and applications. The Road Weather Management Program should confer with the Architecture Team to determine the degree of control desired over the latter, as a guidance product, and within the proposed regulations regarding use of the architecture. The Road Weather Management Program should support and work with the ITS America Weather Information Applications Task Force (WIATF), that currently is reviewing the National ITS Architecture with respect to road weather information. A separate weather or environmental information user service should not be pursued since the user services should focus on applications that produce improved transportation performance (e.g., DSS), and not just the production and dissemination of contextual information. Requirements for information quality should be levied on data flows and processes according to which, across all possible applications, is binding. A review of the National ITS Architecture should determine what data flows and processes, if any should be allocated requirements at a more detailed level within the general architecture, or within standards activities.

Conclusion: There are many ITS standards that affect, or are affected by, the WIST-DSS information requirements. The ESS data objects are directly applicable, and so are other center-to-center and traveler-information message sets and data dictionaries. The Road Weather Management Program has not had the resources to be involved closely in the standards development. There has been involvement by the parties to the Foretell test.

5.3 Recommendation: The Road Weather Management Program should be aware of emerging de facto standards as well as relevant ITS standards developments. The Program should contribute to standards developments by sponsoring application developments that test the standards, as in the Foretell case. The Program should specify use of the ITS standards, even in draft form, in further development with the proviso that projects produce critiques of the standards. The Program should request the ITS standards program to perform a review of all ITS standards activities to identify environmental information issues.

7. Glossary

AASHTO	American Association of State Highway and Transportation Officials
ADUS	Archive Data User Service (of the ITS)
APWA	American Public Works Association
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
CIOS	Committee on Integrated Observing Systems
CPU	Central Processing Unit
DGPS	Differential Geolocation Positioning System
DID	Data Item Description
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)
IDEF	Integrated Computer Aided Manufacturing DEFinition

IRRIS	Integrated Road and Rail Information System
ISP	Information Service Provider or Internet Service Provider
ITS	Intelligent Transportation System
ITS-JPO	ITS Joint Program Office
IVHS	Intelligent Vehicle/Highway System
JAG-WIST	Joint Action Group, Weather Information for Surface Transportation
LAPS	Local Analysis and Prediction System
LDAD	Local Data Acquisition and Dissemination
LOS	Level of Service
MUTCD	Manual of Uniform Traffic Control Devices
NACO	National Association of Counties
NASA	National Aeronautics and Space Administration
NCDC	National Climatic Data Center
NCEP	National Centers for Environmental Prediction
NESDIS	National Environmental Satellite Data and Information Service
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
O&M	Operations and Maintenance
OCD	Operational Concept Description
OFCM	Office of the Federal Coordinator for Meteorology

PC	Personal Computer
PDA	Personal Digital Assistant
PIR	Preliminary Interface Requirements
RFC	River Forecast Center
RMA	Reliability, Maintainability, Availability
RPU	Remote Processing Unit
RSPA	Research and Special Programs Administration
RWIS	Road Weather Information System
RWML	Road Weather Markup Language
SHRP	Strategic Highway Research Program
SOA	State of the Art
SOP	Standard Operating Procedure, State of the Practice
STWDSR	Surface Transportation Weather Decision Support Requirements
TMC	Traffic Management Center
TOP	Traffic Operations Personnel
USDOT	United States Department of Transportation
VAMS	Value Added Meteorological Services
VMT	Vehicle Miles Traveled
WFO	Weather Forecast Office
WIST-DSS	Weather Information for Surface Transportation Decision Support System
XML	Extended Markup Language

Appendix

A1. WIST-DSS Interfaces Taxonomy (V2.0)

WIST-DSS Information Resource Interfaces Taxonomy

- 1 Warning scale information (elements not specified here)
- 2 Operational scale information
  - 2.1 Operational scale information to Update Context
    - 2.1.1 Weather
      - 2.1.1.1 Winds
        - 2.1.1.1.1 Wind direction
        - 2.1.1.1.2 Wind speed
        - 2.1.1.1.3 Wind situation
        - 2.1.1.1.4 Maximum wind gust speed
        - 2.1.1.1.5 Maximum wind gust direction
        - 2.1.1.1.6 Stability
      - 2.1.1.2 Temperature
        - 2.1.1.2.1 Air temperature
        - 2.1.1.2.2 Wet-bulb temperature
        - 2.1.1.2.3 Dew-point temperature
        - 2.1.1.2.4 Maximum temperature
        - 2.1.1.2.5 Minimum temperature
        - 2.1.1.2.6 Time and air-temperature integrals
          - 2.1.1.2.6.1 Degree days
          - 2.1.1.2.6.2 Other
        - 2.1.1.2.7 Air temperature change rate
      - 2.1.1.3 Relative humidity
      - 2.1.1.4 Hydrometeors
        - 2.1.1.4.1 Precipitation indicator (binary)
        - 2.1.1.4.2 Rainfall or water equivalent of snow rate
        - 2.1.1.4.3 Snowfall accumulation rate
        - 2.1.1.4.4 Precipitation situation (augment with hail)
        - 2.1.1.4.5 Ice deposit thickness
        - 2.1.1.4.6 Precipitation start time
        - 2.1.1.4.7 Precipitation end time
        - 2.1.1.4.8 Precipitation accumulation
          - 2.1.1.4.8.1 past one hour
          - 2.1.1.4.8.2 past three hours
          - 2.1.1.4.8.3 past six hours
          - 2.1.1.4.8.4 past twelve hours
          - 2.1.1.4.8.5 past twenty-four hours

        - 2.1.1.4.8.6 other
    - 2.1.1.5 Radiation Objects
      - 2.1.1.5.1 Total sun
      - 2.1.1.5.2 Solar activity
      - 2.1.1.5.3 Cloud cover situation (augmented)
    - 2.1.1.6 Visibility
      - 2.1.1.6.1 Visibility parameter (distance)
      - 2.1.1.6.2 Visibility situation
    - 2.1.1.7 Lightning
    - 2.1.1.8 Severe storms (advisory, watch, warning under each type)
      - 2.1.1.8.1 Thunderstorm
      - 2.1.1.8.2 Heavy/severe thunderstorm
      - 2.1.1.8.3 Tornado
      - 2.1.1.8.4 Waterspout
      - 2.1.1.8.5 Squall
      - 2.1.1.8.6 Other heavy precipitation/winds events
      - 2.1.1.8.7 Storm cell tracks
        - 2.1.1.8.7.1 Direction
        - 2.1.1.8.7.2 Speed
    - 2.1.1.9 Weather indices
      - 2.1.1.9.1 Wind chill
      - 2.1.1.9.2 Heat/humidity
      - 2.1.1.9.3 Other
    - 2.1.1.10 Weather prediction model parameters
  - 2.1.2 Terrestrial/hydrologic conditions
    - 2.1.2.1 Flooding (depth)
    - 2.1.2.2 Debris flow (type and appropriate metric)
    - 2.1.2.3 Water course flow volumes
    - 2.1.2.4 Water body depths
    - 2.1.2.5 Snow cover
    - 2.1.2.6 Avalanche danger
    - 2.1.2.7 Seismic activity
    - 2.1.2.8 Volcanism
    - 2.1.2.9 Soil moisture
    - 2.1.2.10 Soil temperature
    - 2.1.2.11 Fire
    - 2.1.2.12 Other
  - 2.1.3 Road condition*s*
    - 2.1.3.1 Road temperature
      - 2.1.3.1.1 Pavement surface temperature
      - 2.1.3.1.2 Pavement temperature (2-10 cm below surface)
    - 2.1.3.2 Road surface condition
      - 2.1.3.2.1 Water depth

2.1.3.2.2 Flowing water velocity
2.1.3.2.3 Adjacent snow depth (incl. plowed berms)
2.1.3.2.4 Roadway snow depth
2.1.3.2.5 Roadway snow pack depth
2.1.3.2.6 Surface status
2.1.3.2.7 Surface water depth
2.1.3.2.8 Surface salinity
2.1.3.2.9 Surface conductivity
2.1.3.2.10 Pavement freezing point
2.1.3.2.11 Surface black ice signal
2.1.3.2.12 Pavement ice
2.1.3.2.13 Ice bonding of snow
2.1.3.2.14 Mobile friction
2.1.3.2.15 Mobile observation for the state of the ground
2.1.3.2.16 Mobile state of the pavement
2.1.3.3 Road surface condition indices
2.1.3.3.1 Level of service
2.1.3.3.2 Tractability
2.1.3.3.3 Maneuverability
2.1.3.3.4 Other road condition index
2.1.3.4 Road subsurface condition
2.1.3.4.1 Sub-surface type
2.1.3.4.2 Sub-surface sensor depth
2.1.3.4.3 Sub-surface temperature
2.1.3.4.4 Sub-surface moisture
2.1.3.5 Driving visibility
2.1.3.5.1 Visibility parameter (distance)
2.1.3.5.2 Visibility situation
2.1.4 Resources status
2.1.4.1 Financial
2.1.4.1.1 Financial account types
2.1.4.2 Staff
2.1.4.2.1 Availability
2.1.4.2.2 Work time since last off
2.1.4.2.3 Work schedule
2.1.4.2.4 Assignment
2.1.4.3 Mobile treatment (crews)
2.1.4.3.1 Status
2.1.4.3.2 Equipment assigned
2.1.4.3.3 Beat completed
2.1.4.3.4 Dispatched beat (cf. ESS Pavement treatment objects)
2.1.4.3.4.1 Treatment product type
2.1.4.3.4.2 Treatment product form

      - 2.1.4.3.4.3 Percentage of treatment type in mix
      - 2.1.4.3.4.4 Treatment amount
      - 2.1.4.3.4.5 Treatment width
  - 2.1.4.4 Fixed treatment
    - 2.1.4.4.1 Treatment completed
    - 2.1.4.4.2 Treatment setting
  - 2.1.4.5 Treatment stocks
    - 2.1.4.5.1 Amounts on hand
      - 2.1.4.5.1.1 Type (including mixes)
  - 2.1.4.6 Other stocks
    - 2.1.4.6.1 Fuel on hand
    - 2.1.4.6.2 Spares on hand
    - 2.1.4.6.3 Other
  - 2.1.4.7 Equipment status
    - 2.1.4.7.1 Type
      - 2.1.4.7.1.1 Availability
      - 2.1.4.7.1.2 Readiness
      - 2.1.4.7.1.3 How dressed
      - 2.1.4.7.1.4 How equipped
- 2.1.5 Surface transportation network status
  - 2.1.5.1 Road network
    - 2.1.5.1.1 Segment characteristics
      - 2.1.5.1.1.1 Traffic density
      - 2.1.5.1.1.2 Traffic speed
      - 2.1.5.1.1.3 Safe speed
      - 2.1.5.1.1.4 Open/closed
      - 2.1.5.1.1.5 Structure condition
      - 2.1.5.1.1.6 Pavement condition (heaves, fissures, potholes, etc.)
      - 2.1.5.1.1.7 Facility condition
      - 2.1.5.1.1.8 Pavement type
      - 2.1.5.1.1.9 Emissivity
      - 2.1.5.1.1.10 Albedo
    - 2.1.5.1.2 Node characteristics
      - 2.1.5.1.2.1 Signals
    - 2.1.5.1.3 Origin-destination characteristics
      - 2.1.5.1.3.1 Travel times
      - 2.1.5.1.3.2 Throughput
  - 2.1.5.2 Rail
  - 2.1.5.3 Inland waterway
  - 2.1.5.4 Transit service
- 2.1.6 Other transportation network status
- 2.1.7 Communications contact addresses
  - 2.1.7.1 Maintenance staff

    - 2.1.7.2 Other agencies
  - 2.1.8 Communication, power and control system status
    - 2.1.8.1 Links
      - 2.1.8.1.1 Connectivity
      - 2.1.8.1.2 Capacity
      - 2.1.8.1.3 Transmission quality
    - 2.1.8.2 Nodes
      - 2.1.8.2.1 Operating status, including power
  - 2.1.9 Environmental impacts
    - 2.1.9.1 Air quality
    - 2.1.9.2 Water quality
    - 2.1.9.3 Other environmental impacts
- 2.2 Operational scale information to Update Clock
  - 2.2.1 Time synchronization
    - 2.2.1.1 Time
    - 2.2.1.2 Date
    - 2.2.1.3 Day of week
- 2.3 Operational scale information unique to learning mode
  - 2.3.1 System states
  - 2.3.2 System outputs
- 2.4 Operational scale information unique to collaboration mode
  - 2.4.1 Other system states
  - 2.4.2 Other system outputs (decisions)
  - 2.4.3 Resource shadow prices
- 2.5 Operational scale information unique to human interface
  - 2.5.1 Display
    - 2.5.1.1 GUI
    - 2.5.1.2 Other
  - 2.5.2 User input
    - 2.5.2.1 GUI
    - 2.5.2.2 Keyboard
    - 2.5.2.3 Other

3 Planning scale information

- 3.1 Planning scale information to Select Context used in operational decisions for winter road maintenance.
  - 3.1.1 Jurisdictional limits
  - 3.1.2 Resources
    - 3.1.2.1 Budget
      - 3.1.2.1.1 Accounting categories
    - 3.1.2.2 Organization
      - 3.1.2.2.1 Own organization
      - 3.1.2.2.2 Coordinating organizations
    - 3.1.2.3 Staffing

    - 3.1.2.3.1 Work rules
    - 3.1.2.3.2 Work schedules (baseline)
    - 3.1.2.3.3 Staff
      - 3.1.2.3.3.1 Job/skill levels (own agency)
      - 3.1.2.3.3.2 Other personnel data
      - 3.1.2.3.3.3 Job/skill levels (coordinating agency)
  - 3.1.2.4 Treatment stocks
    - 3.1.2.4.1 Available from supplier/depot
    - 3.1.2.4.2 Performance data on chemicals
  - 3.1.2.5 Other stocks
    - 3.1.2.5.1 Available from supplier/depot
  - 3.1.2.6 Equipment
    - 3.1.2.6.1 Type inventory
    - 3.1.2.6.2 Type capability
    - 3.1.2.6.3 Item history
      - 3.1.2.6.3.1 Purchase
      - 3.1.2.6.3.2 Use
      - 3.1.2.6.3.3 Maintenance
      - 3.1.2.6.3.4 Safety
      - 3.1.2.6.3.5 Other
  - 3.1.2.7 Facilities
    - 3.1.2.7.1 Type inventory
    - 3.1.2.7.2 Item history
      - 3.1.2.7.2.1 Purchase/construction
      - 3.1.2.7.2.2 Maintenance
      - 3.1.2.7.2.3 Utilities
      - 3.1.2.7.2.4 Other
- 3.1.3 Procedures
  - 3.1.3.1 Treatment strategies
    - 3.1.3.1.1 Indicated conditions
  - 3.1.3.2 Coordination procedures
- 3.1.4 Surface transportation network
  - 3.1.4.1 Road network
    - 3.1.4.1.1 Segment characteristics
      - 3.1.4.1.1.1 Functional
      - 3.1.4.1.1.2 Surface
      - 3.1.4.1.1.3 Subsurface
    - 3.1.4.1.2 Bulk dumping locations
  - 3.1.4.2 Other surface transportation
    - 3.1.4.2.1 Rail
    - 3.1.4.2.2 Inland waterway
    - 3.1.4.2.3 Transit services
- 3.1.5 Other transportation network

- 3.1.6 Road surface climate
  - 3.1.6.1 Temperature
  - 3.1.6.2 Surface condition
  - 3.1.6.3 Visibility
- 3.1.7 Atmospheric climate
  - 3.1.7.1 Temperature
  - 3.1.7.2 Winds
  - 3.1.7.3 Precipitation
    - 3.1.7.3.1 Type
  - 3.1.7.4 Lightning
- 3.1.8 Surface characteristics and physiography
  - 3.1.8.1 Topography (orography)
  - 3.1.8.2 Heat-radiation characteristics
  - 3.1.8.3 Watersheds
  - 3.1.8.4 Flora
  - 3.1.8.5 Fauna
  - 3.1.8.6 Soils
  - 3.1.8.7 Seismicity
  - 3.1.8.8 Volcanism
  - 3.1.8.9 Other environmental sensitivity
  - 3.1.8.10 Other
- 3.1.9 Communication, power and control systems
  - 3.1.9.1 Links
    - 3.1.9.1.1 Physical media
    - 3.1.9.1.2 Reliability, maintainability, availability
    - 3.1.9.1.3 Capacity
  - 3.1.9.2 Nodes
    - 3.1.9.2.1 Physical characteristics
    - 3.1.9.2.2 Reliability, maintainability, availability
    - 3.1.9.2.3 Capacity
- 3.1.10 Social factors
  - 3.1.10.1 Political sensitivities to treatment practices
  - 3.1.10.2 Other
- 3.1.11 Other

3.2 Information embedded in the WIST-DSS as parameter settings, etc., that adapt the system to its operational environment, and that are set in evaluation mode.

- 3.2.1 Graphical user interface (GUI) settings
- 3.2.2 Meta data on information sources
- 3.2.3 Program objects and parameters
- 3.2.4 Hardware objects and parameters
- 3.2.5 Communications network addresses
- 3.2.6 Other

A2. Sample of the Needs-Information Traceability Matrix

The table below is a portion of the matrix that defines the information required by each decision and then maps that to the information taxonomy of the interfaces. Under each operational-scale decision (2.n) is the information needed. The column on the right lists the corresponding taxonomy types. Only two decisions are included here and the full 53 decisions appear in full in a separate document. It should be used to check that the interfaces do meet the needs.

				Decision	
DM#		**#**	**ID**	**Information Needed**	**Information Taxonomy Type**
1.0	Infrastructure Operators				
1.1	Highway maintainer (winter)				
		9	2.1	become aware of weather threat	
				precipitation type	Precipitation indicator (2.1.1.4.1)
					Rainfall or water equivalent of snow rate (2.1.1.4.2)
					Precipitation situation (2.1.1.4.4)
				precipitation accumulation	Precipitation indicator (2.1.1.4.1)
					Rainfall or water equivalent of snow rate (2.1.1.4.2)
					Snowfall accumulation rate (2.1.4.4.3)
					Precipitation situation (2.1.1.4.4)
					Ice deposit thickness (2.1.1.4.5)
					Precipitation start time (2.1.1.4.6)
					Precipitation end time (2.1.1.4.7)
					Precipitation accumulation (2.1.1.4.8)
					Flooding (2.1.2.1)
					Water course flow volumes (2.1.2.3)
					Water body depths (2.1.2.4)
					Snow cover (2.1.2.5)
					Water depth (2.1.3.2.1)
					Roadway snow depth (2.1.3.2.4)
					Roadway snow pack depth (2.1.3.2.5)
					Surface water depth (2.1.3.2.7)
					Pavement ice (2.1.3.2.12)
					Ice bonding of snow (2.1.3.2.13)
				precipitation rate	Rainfall or water equivalent of snow rate (2.1.1.4.2)
					Snowfall accumulation rate (2.1.1.4.3)
					Precipitation accumulation (2.1.1.4.8)
				precipitation onset and ceasation	Precipitation start time (2.1.1.4.6)
					Precipitation end time (2.1.1.4.7)
				temperature trends	Air temperature (2.1.1.2.1)
					Temperature (2.1.1.2.2)
					Dew-point (2.1.1.2.3)
					Maximum temperature (2.1.1.2.4)
					Minimum temperature (2.1.1.2.5)
					Time and air-temperature integrals (2.1.1.2.6)
					Air temperature change rate (2.1.1.2.7)
				dew point	Dew-point (2.1.1.2.3)
				wind speed	Wind speed (2.1.1.1.2)

				Wind situation (2.1.1.1.3) Maximum wind gust speed (2.1.1.1.4) Stability (2.1.1.1.6)
			wind direction	Wind direction (2.1.1.1.1)
			expected visibility	Visibility parameter (2.1.1.6.1) Visibility situation (2.1.1.6.2)
			current chemical stockpiles	Amounts on hand (2.1.4.5.1) Type and mixes (2.1.4.5.1.1)
			trained personnel schedules	Availablity (2.1.4.2.1) Work time since last off (2.1.4.2.2)
			trained personnel availability	Availablity (2.1.4.2.1) Work time since last off (2.1.4.2.2)
			local environmental sensitivities	Other social factors (3.1.10.2)
			local political sensitivities	Political sensitivities to treatment practices (3.1.10.1)
			available personnel budget	Budget (3.1.2.1)
			available chemicals budget	Budget (3.1.2.1)
	10	2.2	monitor weather threat	
			precipitation type	Precipitation indicator (2.1.1.4.1) Rainfall or water equivalent of snow rate (2.1.1.4.2) Precipitation situation (2.1.1.4.4)
			precipitation accumulation	Precipitation indicator (2.1.1.4.1) Rainfall or water equivalent of snow rate (2.1.1.4.2) Snowfall accumulation rate (2.1.4.4.3) Precipitation situation (2.1.1.4.4) Ice deposit thickness (2.1.1.4.5) Precipitation start time (2.1.1.4.6) Precipitation end time (2.1.1.4.7) Precipitation accumulation (2.1.1.4.8) Flooding (2.1.2.1) Water course flow volumes (2.1.2.3) Water body depths (2.1.2.4) Snow cover (2.1.2.5) Water depth (2.1.3.2.1) Roadway snow depth (2.1.3.2.4) Roadway snow pack depth (2.1.3.2.5) Surface water depth (2.1.3.2.7) Pavement ice (2.1.3.2.12) Ice bonding of snow (2.1.3.2.13)
			precipitation rate	Precipitation indicator (2.1.1.4.1) Rainfall or water equivalent of snow rate (2.1.1.4.2) Precipitation situation (2.1.1.4.4)
			precipitation onset and cesation	Precipitation start time (2.1.1.4.6) Precipitation end time (2.1.1.4.7)
			temperature trends	Air temperature (2.1.1.2.1) Temperature (2.1.1.2.2) Dew-point (2.1.1.2.3) Maximum temperature (2.1.1.2.4) Minimum temperature (2.1.1.2.5) Time and air-temperature integrals (2.1.1.2.6)
			dew point	Dew-point (2.1.1.2.3)
			wind speed	Wind speed (2.1.1.1.2)

	Wind situation (2.1.1.1.3)
	Maximum wind gust speed (2.1.1.1.4)
	Stability (2.1.1.1.6)
wind direction	Wind direction (2.1.1.1.1)
expected visability	Visibility parameter (2.1.1.6.1)
	Visibility situation (2.1.1.6.2)
alternate forecasts (NWS, VAMS, etc)	Wind direction (2.1.1.1.1)
	Wind speed (2.1.1.1.2)
	Wind situation (2.1.1.1.3)
	Maximum wind gust speed (2.1.1.1.4)
	Maximum wind gust direction (2.1.1.1.5)
	Stability (2.1.1.1.6)
	Temperature (2.1.1.2)
	Air temperature (2.1.1.2.1)
	Wet-bulb temperature (2.1.1.2.2)
	Dew-point temperature (2.1.1.2.3)
	Maximum temperature (2.1.1.2.4)
	Minimum temperature (2.1.1.2.5)
	Time and air-temperature integrals (2.1.1.2.6)
	Air temperature change rate (2.1.1.2.7)
	Relative humidity (2.1.1.3)
	Precipitation indicator (binary) (2.1.1.4.1)
	Rainfall or water equivalent of snow rate (2.1.1.4.2)
	Snowfall accumulation rate (2.1.1.4.3)
	Precipitation situation (augment with hail) 21144
	Ice deposit thickness (2.1.1.4.5)
	Precipitation start time (2.1.1.4.6)
	Precipitation end time (2.1.1.4.7)
	Precipitation accumulation (2.1.1.4.8)
	Total sun (2.1.1.5.1)
	Solar activity (2.1.1.5.2)
	Cloud cover situation (augmented) (2.1.1.5.3)
	Visibility parameter (distance) (2.1.1.6.1)
	Visibility situation (2.1.1.6.2)
	Lightning (2.1.1.7)
	Severe storms (advisory, watch, warning) 2.1.1.8
current traffic conditions	Road condition (2.1.3)
	Maneuverability (2.1.3.3.3)
	Other road condition index (2.1.3.3.4)
	Driving visibility (2.1.3.5)
	Visibility parameter (distance) (2.1.3.5.1)
	Visibility situation (2.1.3.5.2)
	Traffic density (2.1.5.1.1.1)
	Traffic speed (2.1.5.1.1.2)
	Safe speed (2.1.5.1.1.3)
	Origin-destination characteristics (2.1.5.1.3)
	Travel times (2.1.5.1.3.1)
	Throughput (2.1.5.1.3.2)
current surface conditions	Flooding (depth) (2.1.2.1)
	Debris flow (type and appropriate metric) (2.1.2.2)
	Water course flow volumes (2.1.2.3)
	Water body depths (2.1.2.4)

	Snow cover (2.1.2.5)	
	Avalanche danger (2.1.2.6)	
	Seismic activity (2.1.2.7)	
	Volcanism (2.1.2.8)	
	Soil moisture (2.1.2.9)	
	Soil temperature (2.1.2.10)	
	Fire (2.1.2.11)	
	Other (2.1.2.12)	
	Road condition (2.1.3)	
	Road temperature (2.1.3.1)	
	Pavement surface temperature (2.1.3.1.1)	
	Pavement temperature (2-10 cm below surface) (2.1.3.1.2)	2
	Road surface condition (2.1.3.2)	
	Water depth (2.1.3.2.1)	
	Flowing water velocity (2.1.3.2.2)	
	Adjacent snow depth (incl. plowed berms) (2.1.3.2.3)	
	Roadway snow depth (2.1.3.2.4)	
	Roadway snow pack depth (2.1.3.2.5)	
	Surface status (2.1.3.2.6)	
	Surface water depth (2.1.3.2.7)	
	Surface salinity (2.1.3.2.8)	
	Surface conductivity (2.3.1.2.9)	
	Pavement freezing point (2.1.3.2.10)	
	Surface black ice signal (2.1.3.2.11)	
	Pavement ice (2.1.3.2.12)	
	Ice bonding of snow (2.1.3.2.13)	
	Mobile friction (2.1.3.2.14)	
current subsoil conditions	Road subsurface condition (2.1.3.4)	
	Sub-surface type (2.1.3.4.1)	
	Sub-surface sensor depth (2.1.3.4.2)	
	Sub-surface temperature (2.1.3.4.3)	
	Sub-surface moisture (2.1.3.4.4)	
previous day's weather	Precipitation indicator (2.1.1.4.1)	
	Rainfall or water equivalent of snow rate (2.1.1.4.2)	
	Snowfall accumulation rate (2.1.4.4.3)	
	Precipitation situation (2.1.1.4.4)	
	Ice deposit thickness (2.1.1.4.5)	
	Precipitation start time (2.1.1.4.6)	
	Precipitation end time (2.1.1.4.7)	
	Precipitation accumulation (2.1.1.4.8)	
	Flooding (2.1.2.1)	
	Water course flow volumes (2.1.2.3)	
	Water body depths (2.1.2.4)	
	Snow cover (2.1.2.5)	
	Water depth (2.1.3.2.1)	
	Roadway snow depth (2.1.3.2.4)	
	Roadway snow pack depth (2.1.3.2.5)	
	Surface water depth (2.1.3.2.7)	
	Pavement ice (2.1.3.2.12)	
	Ice bonding of snow (2.1.3.2.13)	

				Wind direction (2.1.1.1.1)
				Wind speed (2.1.1.1.2)
				Wind situation (2.1.1.1.3)
				Maximum wind gust speed (2.1.1.1.4)
				Maximum wind gust direction (2.1.1.1.5)
				Stability (2.1.1.1.6)
				Temperature (2.1.1.2)
				Air temperature (2.1.1.2.1)
				Wet-bulb temperature (2.1.1.2.2)
			previous precipitation impacts	Precipitation indicator (2.1.1.4.1)
				Rainfall or water equivalent of snow rate (2.1.1.4.2)
				Precipitation situation (2.1.1.4.4)
				Ice deposit thickness (2.1.1.4.5)
				Precipitation start time (2.1.1.4.6)
				Precipitation end time (2.1.1.4.7)
				Precipitation accumulation (2.1.1.4.8)
				Flooding (2.1.2.1)
				Water course flow volumes (2.1.2.3)
				Water body depths (2.1.2.4)
				Snow cover (2.1.2.5)
				Water depth (2.1.3.2.1)
				Roadway snow depth (2.1.3.2.4)
				Roadway snow pack depth (2.1.3.2.5)
				Surface water depth (2.1.3.2.7)
				Pavement ice (2.1.3.2.12)
				Ice bonding of snow (2.1.3.2.13)
				Wind situation (2.1.1.1.3)
				Temperature (2.1.1.2)
				Air temperature (2.1.1.2.1)
				Maximum temperature (2.1.1.2.4)
				Minimum temperature (2.1.1.2.5)
				Time and air-temperature integrals (2.1.1.2.6)
				Relative humidity (2.1.1.3)
				Precipitation indicator (binary) (2.1.1.4.1)
				Rainfall or water equivalent of snow rate (2.1.1.4.2)
				Precipitation situation (augment with hail) 21144
				Ice deposit thickness (2.1.1.4.5)
				Total sun (2.1.1.5.1)
				Solar activity (2.1.1.5.2)
				Cloud cover situation (augmented) (2.1.1.5.3)
				Visibility situation (2.1.1.6.2)
				Severe storms (advisory, watch, warning) (2.1.1.8)
				Thunderstorm (2.1.1.8.1)
				Heavy/severe thunderstorm (2.1.1.F78.2)
				Tornado (2.1.1.8.3)
				Other heavy precipitation/winds events (2.1.1.8.6)
				Weather prediction model parameters (2.1.1.10)
				Flooding (depth) (2.1.2.1)
				Debris flow (type and appropriate metric) (2.1.2.2)
				Water course flow volumes (2.1.2.3)
				Water body depths (2.1.2.4)
				Snow cover (2.1.2.5)

				Avalanche danger (2.1.2.6)
				Seismic activity (2.1.2.7)
				Volcanism (2.1.2.8)
				Fire (2.1.2.11)
			political sensitivities	Political sensitivities to treatment practices (3.1.10.1)
			local government coordination	Operational scale information unique to collaboration mode (2.4)
				Other system states (2.4.1)
				Other system outputs (decisions) (2.4.2)

A3. NOAA’s Environmental Technology Laboratory (ETL) Technology Components

In the STWDSR project, the participating national labs were asked to propose WIST-DSS technology components based on their prototyping and system development experience. The components were variously allocated to the WIST-DSS and its information resources. The following sections describe the various ETL systems (instrumentation and products) that are applicable primarily as part of the information resources for the WIST-DSS. The figure references are in the ETL website locations.

A3.1 Millimeter Cloud Radar

(MMCR) http://www4.etl.noaa.gov/cloudradar/
Figure 1

Description:
35 GHz (Ka band) radar designed to provide detailed, long-term observations of non-precipitating and weakly precipitation clouds. Other features include excellent sensitivity and vertical resolution to detect weak and multiple thin layers of ice and liquid water clouds with long unattended operation in remote locales. The cloud radar design emphasizes commercial off the shelf (COTS) subsystems, including its primary signal-processing engine.

Products:
Melting Layer, Precipitation type, Snow fall rate, Cloud type/height/ thickness/ radiative properties, Particle size/ concentration/ ice and liquid water content, Vertical velocities, Fractional coverage

Work in progress:
Develop automated processing to objectively determine the number of cloud layers, the heights, and the thickness of the layers as a function of time. We are also working on automating the microphysics retrievals, such as estimating ice mass content as a function of height and time. These things are not ready to purchase off the shelf, but they are close to being ready for operational use. The only operational, continuous, products from the cloud radar are the color images.

Existing Systems or Networks:
Currently there 3 working MMCRs operating around the world, but only one in the continental United States, Lamont, OK, as part of the Cloud and Radiation Testbed (CARTs). Data from these sites can be found in near real-time on the internet. The primary purpose of these sites is to study the effects of clouds on global climate change. Three primary locations -- Southern Great Plains, Tropical Western Pacific, and North Slope of Alaska -- were identified as representing the range of climate conditions that should be studied. Each CART site has been heavily instrumented to gather massive amounts of climate data. Using these data, scientists hope to better understand the effects and interactions of sunlight, radiant energy, and clouds on

temperatures, weather, and climate. There are other cloud monitoring type radars with similar capabilities.

References:

Gossard et al., 1997: The potential of 8-mm Radars for Remotely Sensing Cloud Drop Size Distributions, J. Atmos. Oceanic Tech., 14, 77-87.

Matrosov et al., 1996: Estimation of Ice Hydormeteor Types and shapes from Radar Polarization Measurements. J. Atmos. Oceanic Tech., 13, 85-96.

Moran et al. 1998, An unattended Cloud-Profiling radar for use in climate research. Bull. Amer. Meteor. Soc., 79, 443-455.

Orr and Kropfli, 1999: A method for Estimating Particle Fall Velocities from Vertically Pointing Doppler Radar, J. Atmos. Oceanic Tech., 16, 31-37.

A3.2 Radar Wind Profiler/Radio Acoustic Sounding System

(RWP/RASS)
Figure 2

Description:
Radar wind profilers have been around for over 15 years and commercially available for over 10 years. These are Doppler radars designed for measuring wind profiles in all weather conditions. RASS combines acoustic sources with RWP to measure the profile of virtual temperature. They differ from what is classified as a scanning weather radar in that they point vertically cycling through 3 to 5 antenna beam positions by way of electronic-beam steering. Currently there are 2 major types of profilers: Boundary Layer Profiler (BLP) and higher powered systems such as used in the NOAA Profiler Network (NPN). The first type of RWP is primarily used, as its name applies, for study the lower atmosphere (4-6 km) with several operational networks designed to aid in the monitoring of air pollution. The second type of RWP is a more powerful system developed by the which is capable of probing much higher into the atmosphere (15-20 km and higher).

Though the primary products produced by these systems are wind and temperature profiles, studies have shown their potential in many other areas. Some of these include detecting precipitation, mixing layer depths, atmospheric turbulence, cloud parameters, and even migratory birds. The System Demonstration and Integration Division (SDID) within ETL has developed new algorithms to help extract this information with improved quality control. Private industry and NOAA have a cooperative research and development agreement (CRADA) in place to allow for easy transfer of new technology from ETL and the private sector. Figures 3 and 4 are examples of old and new RWP product displays. Figure 3 shows how new signal processing (bottom) can improve the product passed on the models, forecasters, and WIST-DSS. Figure 4 is an example of what would be considered a near real time display that can be made available at any level in the decision making process. We suggest that some of these color displays be made available to the DOT USERS for initial evaluation. It is understood that not all USERS will have the infrastructure or even want such information. These data would most likely be useful on the micro-scale.

Products:
Freezing Level, Precipitation type, Wind profiles, Temperature Profiles, Mixing layer depth, Humidity profiles, Vertical velocities, Cn2 profiles, Rain fall rate

Existing Systems or Networks:
Two major networks of RWPs currently exist across the US. The NOAA Profiler Network (NPN, http://www-dd.fsl.noaa.gov/profiler.html) consists of 33 sites (Fig. 5) with the data from these systems being using in National Weather Service (NWS) models. The so called second network is really a grouping of many BLP RWPs (Fig. 6) operating around the country. Through the efforts of FSL, systems with communication links have their data assimilated into NWS models in the same fashion as the NPN (http://oak.fsl.noaa.gov/blp/displays/blpus.html). Many of these systems are owned and operated by local, state or private agencies.

References:

Chadwick et al., 1988: The Wind Profiler Demonstration Network. Extended Abstracts, Symp. On Lower Tropospheric Profiling Needs and technologies, Boulder, CO. Amer. Meteor. Soc., 109-110.

Ecklund et al., 1990: Field tests of a lower tropospheric wind profiler. Radio Sci., 25, 899-906.

Gossard et al., 1992: Cloud layers, particle identification, and rain-rate profiles fron ZRVf measurements by clear-air Doppler radars. J. Atmos. Oceanic Tech., 9, 208-119.

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Ralph, 1995: Using Radar-Measured radial vertical velocities to distinguish precipitation scattering from clear-air scattering. J. Atmos. Oceanic Tech., 12, 257-267

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Wolfe et al., 1997: 449 MHz Profiler/RASS: Meteorological support for the California Air Resources Board 1995 Mojave desert ozone experiment. NOAA Technical Memo. ERL ETL-273, pp 96.

A3.3 Radiometers (Microwave and Infrared)

http://www6.etl.noaa.gov/instruments/#radiometers
http://www1.etl.noaa.gov/radiom/irradiom.htm
Figure 7

Description:
Atmospheric radiometers measure the emissions of the atmosphere itself. For example, a microwave antenna pointed into the air receives an abundance of thermal radio emissions from the atmosphere's various constituents. Each constituent possesses a unique emission spectrum that corresponds exactly to its absorption spectrum. Radiometers "listen" at frequencies selected to best sort the constituents out.

NOAA Two-Channel Microwave Radiometer - This instrument is a two-frequency system which simultaneously measures liquid water in clouds and precipitable water vapor in the atmosphere. The system is completely passive, detecting the natural emission of microwave energy by liquid water and water vapor. Measured quantities are total liquid water and water vapor integrated along the path observed by the instrument, normally in the zenith direction. In addition, profiles of water vapor density may be measured when the instrument's antenna is directed vertically. The system contains two independent microwave radiometers: the is sensitive primarily to water vapor and the second is sensitive primarily to liquid water at any temperature. The radiometers are coupled into an antenna system that is steerable in elevation for calibration using "tipping curves".

NOAA Steerable Three-Channel Microwave Radiometer - This instrument operates on the same principles as the two-channel radiometer. It contains three independent microwave radiometers: the first is sensitive primarily to water vapor; the second is sensitive primarily to liquid water at any temperature, and the third operates is sensitive to both vapor and liquid. The third frequency is approximately six times more sensitive to liquid water than the second thus, the third frequency increases the sensitivity of the instrument to small amounts of cloud liquid. These radiometers are coupled into an antenna system that is steerable in both azimuth and elevation. Therefore, the system may be used to study both spatial and temporal variability of liquid water in clouds and atmospheric water vapor.

All objects at temperatures above absolute zero radiate energy because of molecular and atomic motion. The brightness of such "blackbody radiation" depends on temperature and electromagnetic wavelength. As temperature increases, blackbody radiation moves to shorter wavelengths. Therefore, an infrared radiometer operating at wavelengths near 10 µm is good for measuring the "brightness temperature" of typical terrestrial objects. The brightness temperature is equal to the physical temperature for a perfect blackbody (an object with 100% absorption), but is less than the physical temperature for an object with lower absorption.

Infrared Spectro-Radiometry - This instrument is a multi-frequency spectro-radiometer for measuring spectra of atmospheric emission. This instrument is based on a commercial Fourier

Transform InfraRed (FTIR) spectrometer. We are using these emission spectra to improve radiative transfer models, to quantify the effect of water vapor on climate, and to investigate the radiative properties of clouds.

Single-Band Infrared Radiometry - This instrument is a commercial radiometer that measures the radiance integrated over a particular spectral band. Such radiometers are useful for measuring the brightness temperature of the atmosphere, of clouds, or of the ocean surface. We are experimenting with using these radiometers to measure the polarization of emissions from a rough ocean surface, which might be useful for measuring sea-surface roughness or for determining wind speed and direction.

Products:
Total precipitable water vapor, Total Liquid water, Liquid water profiles, Water vapor profiles, Cloud radiative properties

Existing Systems or Networks:
The NOAA radiometers described above are research instrumentation, but there are several private companies that make similar commercially available systems. The only operating network of radiometers that we know of is part of the Cloud and Radiation Testbed (CARTs) at the Southern Great Plains site.
(http://www.arm.gov/docs/sites/sgp/sgp.html).

References:

Westwater et al. Ground_based microwave radiometric observations of atmospheric attenuation at 20.6, 31.65, and 90 GHz: A comparison of measurement and theory. IEEE Trans. Antennas Propagat. 38, 1569-1580.

Westwater et al., 1998: Remote sensing of the total precipitable water vapor by microwave radiometers and GPS during the 1997 Water Vapor Intensive Operating Period. Proc. IGARSS "98 Conf., Seattle, WA. IEEE, 2158-2162.

A3.4 LIDAR
http://www2.etl.noaa.gov/
Figure 8

Description:
Light is scattered and attenuated by molecules, aerosols (dust), and cloud (water or ice) particles in the atmosphere. The sky can be clear and blue or hazy and white. Red sunsets are a beautiful manifestation of the scattering and attenuation of sunlight. Clouds can appear white, grey, or dark depending on conditions. The rainbow and ice-particle displays like sundogs and light pillars are less frequent. Light scattering and attenuation can be used to investigate the

atmosphere using a remote-sensing instrument called a lidar. A lidar system uses laser pulses to measure atmospheric constituents such as aerosol particles, ice crystals, water vapor, or trace gases (e.g. ozone). Profiles of these atmospheric components as a function of altitude or location are necessary for weather forecasting, climate modeling, and environmental monitoring.

A lidar transmits short pulses of laser light into the atmosphere. The laser beam loses light to scattering as it travels. At each range, some of the light is backscattered into a detector. [Fig. 1a] Because the light takes longer to return from the more distant ranges, the time delay of the return pulses can be converted to the corresponding distance between the atmospheric scatterer and the lidar. The end result is a profile of atmospheric scattering versus distance. [Fig. 1b] Analysis of this signal can yield information about the distribution of aerosols in the atmosphere. The amount of backscatter indicates the density of the scatters. This can be used to measure cloud base height or track plumes of pollution.

Other properties of the atmosphere can also be deduced from the lidar return signals. A frequency shift in the light because of the Doppler effect permits measurement of wind speeds. By detecting the amount of depolarization, one can discriminate between liquid droplets and nonspherical ice particles. Differential Absorption Lidar (DIAL) uses absorption, as evidenced by reduced backscatter from greater distances, to measure the concentration of atmospheric gases. A Raman lidar detects particular atmospheric components (such as water vapor) by measuring the wavelength-shifted return from selected molecules.

Products:
Water vapor profiles, Could height and thickness, Fractional coverage, Cloud drop size and phase, Vertical velocities, Radiative properties, Wind profiles

Existing Systems or Networks:
There are no known networks of Lidar systems, but Lidars are commercially available as eye-safe, solid-state, Doppler laser radar system for measuring 3-dimensional, wind information at airports, harbors, aboard ships, and at research sites. NOAA has a sweet of research Lidar systems: (http://www2.etl.noaa.gov/instruments.html).

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Grund, C.J., R.M. Hardesty, and B.J. Rye. Feasibility of tropospheric water vapor profiling using infrared heterodyne differential absorption lidar. Proceedings from the Fifth, Atmospheric Radiation Measurement (ARM) Science Team Meeting, CONF-9503140, UC-402, U.S. Department of Commerce, NTIS, Springfield, VA 22161, p 129-132.

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Wulfmeyer, V. Ground-based differential absorption lidar for water-vapor and temperature profiling: Requirements, development, and specifications of a high-performance laser transmitter. Applied Optics, 37, 3804-3824 (1998).

A3.5 Global Postioning System Integrated Preicipitable Water Vapor

(GPSIPW) http://www4.etl.noaa.gov/gps/
Figure 7

Description:
The concept of monitoring atmospheric water vapor using GPS is one of newest and most exciting using remote sensing. This system allows you to monitor the total precipitable water vapor (TPW) above a GPS site inexpensively and continuously. Total precipitable water vapor in the past was obtained from NWS balloon soundings 2 twice a day. With GPS you get this same information every 30 minutes. Water vapor is one of the most significant constituents of the atmosphere since it is the means by which moisture and latent heat are transported to cause "weather". Water vapor is also a greenhouse gas that plays a critical role in the global climate system. This role is not restricted to absorbing and radiating energy from the sun, but includes the effect it has on the formation of clouds and aerosols and the chemistry of the lower atmosphere. Despite its importance to atmospheric processes over a wide range of spatial and temporal scales, water vapor is one of the least understood and poorly described components of the Earth's atmosphere.

This technique is based on the principle that GPS satellite radio signals are slowed as they pass through layers of Earth's atmosphere; the ionosphere and the neutral atmosphere. This slowing delays the arrival time of the transmitted signal from that expected if there were no intervening media. It is possible to correct for the ionospheric delay. The delays due to the neutral atmosphere are depend on the constituents of the atmosphere which are a mixture of dry gasses and water vapor (~97% and 3%). In a ground-based measurement system, the signal delays from several (typically 6 or more) satellites in view are simultaneously measured. These delays are mathematically adjusted (scaled) such that all satellites are seemingly directly overhead (at zenith) simultaneously using the function 1/sin (elevation angle of the satellite). The averaged vertically scaled signal delay introduced by the atmospheric constituents is called the Zenith

Total (or Tropospheric) Delay (ZTD). ZTD can be separated into two terms called the zenith hydrostatic delay (ZHD) and the zenith wet delay (ZWD). The ZHD is calculated by measuring the surface pressure and applying a mapping function. The ZHD is then subtracted from the ZTD to give the ZWD. The IPW directly above a GPS antenna is then proportional to ZWD through a factor that is proportional to the mean temperature of the atmosphere.

It is true that satellites also produce TWP, but are limited to clear sky conditions and are not as accurate over land. Data from GPS is just now being assimilated into atmospheric models for testing with very promising results. At the same time as this testing, more and more navigational and geodetic GPS sites are being upgraded to full blown GPS water vapor sites by the simple addition of a surface temperature and pressure sensor.

Products:
Total precipitable water vapor, Navigational information (positioning)

Existing Systems of Networks:
GPS is nearing the end of its demonstration period and very shortly should be considered an operational system. NOAA/FSL has taken the lead on this by developing a GPS integrated precipitable water vapor (GPSIPW) network (Fig. 9). Initially this network was started as part of the NPN, but since has expanded to encompass many US Coast Guard Differential GPS sites (USCG-DGPS) and the Continuously Operating Reference Station (CORS) network managed by NOAA's National Geodetic Survey. There are many more GPS networks used for geodetic and navigational purposes that could potentially be converted to GPS-IPW with the installation of surface temperature and pressure sensors.

References:

Businger et al., 1996: The Promise of GPS in Atmospheric Monitoring. Bull. Amer. Meteor. Soc., 77, 5-18

Wolfe and Gutman, 2000: Developing an Operational Surface-based, GPS, water Vapor Observing System for NOAA: Network Design and Results. J. Atmos. Oceanic Tech., 17, 426-440.

A3.6 Optical Wind Sensors

Description:
This type of sensor is a line-of-sight optical method for measuring atmospheric winds. It observes the scintillation patterns induced in an optical beam by atmospheric turbulence and monitors the advection of the patterns across the beam. It provides a line-averaged estimate of the winds transverse to the beam. This technology has already been passed on to the private sector and is currently in use with a visibility sensor for the monitoring and prediction of drifting snow.

Products:
Cross-beam line averaged wind speed

Existing Systems or Networks:
At the time of this report we did not find any information readily available (ie INTERNET). We did hear via personal communication that this technique is in use in New York and possibly other states.

References:

Clifford et al., 1975: Optical wind sensing by observing the scintillations of a random scene. Appl. Optics, 14, 2844-2850.

Lawerence et al., 1972: Use of scintillations to measure average winds across a light beam. Appl. Optics, 15, 403-408.

A3.7 Multi-sensor Retrieval of Atmospheric Properties

(MRAP) http://www4.etl.noaa.gov/combined/#multi
Figure 10

Description:
The Multi-Sensor Retrieval of Atmospheric Properties (MRAP) is a method developed in ETL (Stankov 1998) which improves the accuracy and resolution of humidity and temperature measurements throughout the troposphere by combining:

1) High-resolution measurements of the lower atmosphere using ground-based remote sensing systems
2) In situ observations from commercial airliners covering the middle atmosphere
3) Accurate upper atmospheric measurements and global coverage by satellite-based systems

MRAP humidity retrievals, although of lower vertical resolution than lidar retrievals, and MRAP temperature retrievals have the potential to provide global coverage with sufficient vertical resolution for most applications in Numerical Weather Prediction (NWP) and climate modeling. The major advantage of the MRAP method is that it incorporates data from many existing, diverse, individual remote sensors in a physically consistent manner and leads to insights that individual instruments cannot provide. Thus, MRAP is well suited for easy incorporation of additional information from new remote sensors as new technologies develop.

Products:
The products from this data integration method can include any of the products produced by the individual sensors, although in its present form it is designed to produce combined temperature and moisture profiles for input to NPW models.

References:

Gossard, E.E., D.E. Wolfe, K.P. Moran, R.A. Paulus, K.D. Anderson, and L.T. Rogers, 1997: Measurement of clear-air gradients and turbulence properties with radar wind profilers. J. Atmos. Ocen. Technol., 15, 321-248.

Stankov, B.B., 1998: Multisensor Retrieval of Atmospheric Properties. Bull. Amer. Meteor. Soc., 79, 1835-1854.

A3.8 Mobile Profiler System

(MPS) http://www4.etl.noaa.gov/mps/
Figure 11

Description:
MPS includes:
(a) A RWP with RASS for measuring wind and temperature throughout the lower troposphere
(b) A meteorological tower for measuring wind, temperature, and humidity just above the surface
(c) A four-channel radiometer for temperature and a two channel radiometer for moisture;
(d) A satellite-receiving system with global positioning system (GPS) for processing satellite radiometer data and obtaining TPW
(e) A balloon sounding system for validation.

Products:
This is a transportable system with integrated multiple remote sensors. This integration allows for easy access to the data from multiple sensors and then with the use of software such as MRAP, any number of products can be provided. In theory such a system could be made-up with any instrumentation you wanted and the data processing tailored to fit the instrumentation as well as the needs of the user.

Existing Systems or Networks:
The original MPS system, designed and built by NOAA/ETL, is now operated by the Army at the White Sands Missile Range. The Army is in the process of contracting to have similar systems manufactured for field use. The National Center for Atmospheric Research (NCAR) also has developed several integrated sounding systems (ISS).

References:
Moran and Weber, 1993: The Mobile Profiler System: A Transportable integrated sounding system for measuring atmospheric parameters. Preprint 26th Int. Conf. On Radar Meteor. Norman, OK, Amer. Meteor. Soc., 637-639.

Parsons et al., 1994: The Integrated Sounding System; Description and preliminary observations from TOGA COARE. Bull. Amer. Meteor. Soc., 75, 553-567.

Weber, 1995: Proposal to Develop a Mobile profiler network for fire weather support

Wolfe et al., 1995: An Overview of the Mobile Profiling System: Preliminary results from field tests during the Los Angeles Free-Radical Study. Bull. Amer. Meteor. Soc., 76, 523-534.