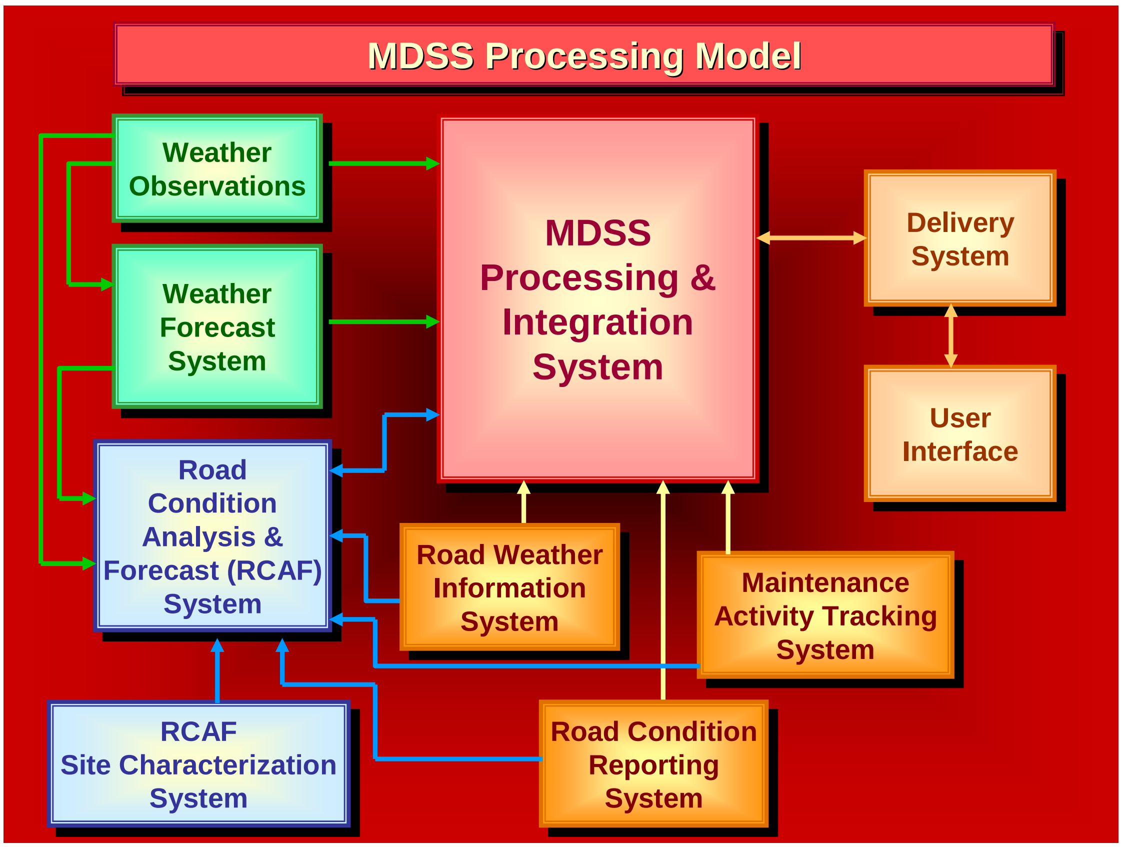
South Dakota
Department of Transportation
Office of Research

SD2002-18-I
TPF-5(054)



Development of a Maintenance Decision Support System: Phase 1

Study SD2002-18
Interim Report

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December 2003

DISCLAIMER

ACKNOWLEDGEMENTS

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The work was performed as transportation pooled fund study TPF-5(054) sponsored by the Indiana Department of Transportation, the Iowa Department of Transportation, the Minnesota Department of Transportation, the North Dakota Department of Transportation, and the South Dakota Department of Transportation, in cooperation with the United States Department of Transportation Federal Highway Administration.

STANDARD REPORT TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
SD2002-18-I		
4. Title and Subtitle Development of a Maintenance Decisions Support System—Phase 1		5. Report Date December 16, 2003 6. Performing Organization Code
7. Author(s) Robert Hart , Leon F. Osborne		8. Performing Organization Report No.
9. Performing Organization Name and Address Meridian Environmental Technology, Inc. P.O. Box 14178 Grand Forks, ND 58208-4178		10. Work Unit No. 11. Contract or Grant No. 310814
12. Sponsoring Agency Name and Address South Dakota Department of Transportation Office of Research 700 East Broadway Avenue Pierre, SD 57501-2586		13. Type of Report and Period Covered Interim Report; November 2002 to December 2003 14. Sponsoring Agency Code HRZ218(01) 187N TPF-5(054)
15. Supplementary Notes		

16. Abstract

This report is a summary of the work done during the first year of a multi-year pooled fund study of the Departments of Transportation in South Dakota, North Dakota, Minnesota, Indiana, and Iowa. The South Dakota DOT was the lead agency. The intent of the complete project is to develop and deploy a maintenance decision support system (MDSS) for transportation department personnel who deal with winter maintenance.

This report addresses Phase 1 of the project, which:

- defined the scope of the project and established a work plan;
- evaluated a prototype MDSS project done by the FHWA;
- clarified user requirements through an interview process;
- assessed existing road condition reporting and communications capabilities in each state;
- evaluated the receptivity of DOT personnel to technological solutions to support maintenance decisions;
- proposed an architecture for the development of an operational MDSS.

17. Keywords	18. Distribution Statement		
winter maintenance; decision support;	No restrictions. This document is available to the public from the sponsoring agency.		
19. Security Classification (of this report) Unclassified	20. Security Classification (of this page) Unclassified	21. No. of Pages 148	22. Price

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FOREWORD

A Maintenance Decision Support System (MDSS) is an automated tool for providing decision support to winter road maintenance managers. Used effectively, MDSS could reduce the effects of adverse weather conditions, which annually cause 6,600 people to die, 470,000 people to be injured and 544 million hours of time to be lost. Customer surveys have also indicated that the primary safety concern of travelers in the "snow belt" states is winter driving conditions. In order to provide safe roadways, state transportation agencies must apply effective highway maintenance treatments appropriate to a wide range of winter and year-round conditions.

Several factors have complicated the ability of state agencies to meet the motorists' expectations for clear and safe roadways:

- Increasing need to travel at all times of the day, every day of the year
- Fixed levels of agency funding and staff
- Difficulty in obtaining reliable and timely road condition reports
- Difficulty in forecasting certain weather-related conditions
- Complex interactions of snow, ice, water, chemicals and traffic atop pavements
- Effect and effectiveness of innovative maintenance treatments not fully understood
- Experienced maintenance staff retiring

In 1999, the Federal Highway Administration's Office of Transportation Operations began the development of a Functional Prototype winter MDSS as part of their Surface Transportation Weather Decision Support Requirements initiative. A proof of concept prototype commenced in 2000 and testing is anticipated through the winter of 2003 - 2004. However, the efforts of the national research centers are limited to exploring and developing prototypical modules that may be later used to construct operationally deployed systems. The responsibility for implementing these prototype modules as an operational deployed MDSS is expected to be that of the individual states and/or the public sector.

The goal of the MDSS is to integrate accurate weather forecasts, road condition and resource information so proactive decisions can be made before and during adverse weather events. The benefits include a higher level of service and reduced operational costs, resulting in safer highway operations.

The present MDSS would be technically practical and sound, and user friendly to maintenance forces. Its basic functions are:

- Ingest and evaluate current road and weather condition data from all sources
- Integrate accurate, timely, site-specific weather forecasts

- Utilize decision logic to recommend different maintenance response scenarios based upon forecast weather and a range of maintenance strategies, and give an indication of the expected effectiveness and economics of each
- Notify state agencies of approaching adverse conditions and suggest optimal maintenance treatments utilizing available resources
- Learn from operational results and continually improve the system

To this end, the state Departments of Transportation from Indiana, Iowa, Minnesota, North Dakota and South Dakota, in partnership with Meridian Environmental Technology, Inc., and through the vehicle of a Pooled Fund Study, have begun the task of constructing an operational MDSS that not only satisfies the needs of these states, but also meets or exceeds the present national expectations for a deployed MDSS.

Four initial objectives have been identified to help reach the MDSS goal:

1. Assess the need, potential benefit, and receptivity in participating state transportation departments for state and regional MDSS
2. Define functional and user requirements for an operational MDSS that can assess current road and weather conditions, forecast weather that will affect transportation routes, predict how road conditions will change in response to candidate maintenance treatments, suggest optimal maintenance strategies to maintenance personnel, and evaluate the effectiveness of maintenance treatments that are applied
3. Build and evaluate an operational MDSS that will meet the defined functional requirements in the participating state transportation departments
4. Improve the ability to forecast road conditions in response to changing weather and applied maintenance treatments

The Phase I contract work that work meets the first two objectives is outlined in this report. The following primary tasks were completed:

1. In consort with the project's Technical Panel, defined the project scope and work plan;
2. Critically evaluated the results of the FHWA's Functional Prototype project to develop a prototype operational MDSS;
3. Interviewed front-line and mid-level maintenance supervisors from each of the participating states to identify and prioritize needs for maintenance support functionality;
4. Assessed the participating states' current and near-term capability to report current roadway conditions and track maintenance activities on specific highway routes;
5. Assessed institutional receptivity to maintenance management decision support in the participating states and recommend actions to overcome potential barriers;

6. Based upon results of previous tasks, proposed in a technical memorandum to the project's Technical Panel the high-level functional and user requirements for an operational MDSS and proposed an architectural framework for the system; separately identified those requirements that can be immediately satisfied and those that will require fundamental research;
7. Identified and prioritized fundamental research needs supporting MDSS.

It is anticipated that the next phases of this project will result in the deployment of a functional MDSS, thus accomplishing the third objective. The success of the deployment of a functional MDSS will constitute the accomplishment of the fourth objective.

Most of the challenges that the MDSS faces relate less to creating new basic technology than to the need to change and update existing institutions. The MDSS Pooled Fund Study maintains a solid grasp on practical reality, particularly constraints on time, human resources and money. However, its overall vision is bold and reasonable, ready to help state agencies undertake the significant 21st century challenges of providing a safe, reliable and secure transportation system to their customers.

EXECUTIVE SUMMARY

This project report represents the concerted efforts of the Maintenance Decision Support System (MDSS) Pooled Fund Study (PFS), which is a partnership between the states of Indiana, Iowa, Minnesota, North Dakota and South Dakota, and Meridian Environmental Technology Inc. (Meridian), during Phase I work accomplished between November 2002, and October 2003.

The project evolved from several efforts initiated to enhance the decision support resources of highway maintenance operations. The consolidation of these efforts occurred in 1999 when the Federal Highway Administration (FHWA) Office of Transportation Operations (OTO) began the development of a MDSS Functional Prototype (FP) winter decision support system as part of its Surface Transportation Weather Decision Support Requirements (STWDSR) initiative. This proof of concept prototype commenced in 2000 and testing is anticipated through the winter of 2003 - 2004. The STWDSR initiative stipulated that the six National Oceanographic and Atmospheric Administration (NOAA) National Labs would develop the prototype under the direction of the FHWA and then relinquish responsibility to the private sector to implement and market operational Maintenance Decision Support Systems. The states involved in this project realized that the implementation of an operational MDSS required close coordination between the states and a private sector agent interested in deploying a MDSS. The Pooled Fund Study project grew out of the mutual interests of the member states and Meridian.

The State of South Dakota became the lead state in the Pooled Fund Study project. The member states organized an oversight panel comprised of representatives from each of the participating states and both the federal and regional offices of the FHWA. This panel, designated the Technical Panel, met with Meridian and jointly composed a tentative multi-year research plan and a more complete Detailed Phase 1 Research Plan to define the project's first year efforts. The multi-year plan outlined fourteen primary tasks; the Phase 1 Research Plan addressed the entire assessment of work in six of these tasks and the initial work in two others. The Phase I report documents what was completed under this research plan.

Task 1: Define Project Scope and Research Plan

After determining that the state Departments of Transportation from Indiana, Iowa, Minnesota, North Dakota and South Dakota were interested in developing the MDSS, Meridian met with the newly formed Technical Panel to refine the project scope and work plan. The Detailed Phase I Research Plan emerged from this meeting along with an agreement that Meridian provide periodic progress reports (including critical milestones reached) and that the Technical Panel communicate on a periodic basis through face-to-face meetings and conference calls.

As an initial step, the panel defined the objective of the study and specified what personnel or groups would serve as resources. These two resources provided a clear idea of what information was required and who would serve as the primary source of that information. Each state identified Technical Panel members, champions and test area field personnel, and the appropriate modes of communicating with, and levels of participation by, each group.

The objectives of the project included:

1. Document the MDSS background
2. Describe the MDSS architecture
3. Establish a baseline of existing MDSS components
4. Define the maintenance needs that drive decision support requirements
5. Gain an understanding of maintenance user's receptivity to technology
6. Agree upon an MDSS implementation program
7. Initiate the development of MDSS and establish an evaluation procedure

The collection of background information was a critical component of Phase I. Three of the tasks were dedicated to collection of detailed support information for the project. The individual information collection requirements included:

- an expanded understanding of maintenance operations and DOT needs
- the infrastructure and operational specifications for communications, data transfer, and IT facilities
- user receptivity to technology.

The panel developed a strategy to collect each of these information resources. Since the study populations were different for each of the different tasks the solutions required a variety of collection methods, ranging from direct face-to-face interviews to surveys.

In order for the Technical Panel to coordinate its efforts, an email reflector address was set up for the exchange of documents, schedules of meetings and teleconferences, and report drafts. In addition, Meridian set up a web site to serve as a repository for information pertaining to MDSS. The web site is divided into a public component and a password protected resource for PFS members only.

Task 2: Evaluate the FHWA Functional Prototype

The predecessor to the MDSS Pooled Fund Study was the FHWA Functional Prototype. The software for this prototype was tested in Minnesota during the winter of 2001 – 2002 and the software was released for evaluation in late September 2002. The Technical Panel felt that a full evaluation of the FP would be beneficial to determine the assets and debits of the federal program. The MDSS designs of both the FP and the PFS incorporated five basic components:

- the weather system
- the pavement forecast system
- the DOT operations and control system
- the MDSS decision logic system
- the delivery and display system

Since Meridian had already developed and refined the weather system, pavement forecast system and a related delivery and display system components, it had the necessary background and experience to evaluate the MDSS FP. Meridian was able to acquire the initial release of the MDSS FP software (v1.0) for review from the National Center for Atmospheric Research (NCAR) in December, 2002. NCAR delivered an undocumented interim release (v1.5) in late July, 2003; however, Meridian did not have sufficient time to evaluate the interim version for this report.

Working with the MDSS FP v1.0 software and the National Oceanic and Atmospheric Administration (NOAA) National Labs, Meridian experienced considerable difficulty installing and initiating successful execution of the software. It is important to note that without sophisticated computing resources and knowledgeable software engineers and meteorologists, most private sector entities would have major challenges completing this task properly.

The software was evaluated and documented. Three components were recommended for possible inclusion into the MDSS PFS project. These included elements of the Graphical User Interface (GUI), the chemical concentration algorithms, and the road condition and treatment module framework. A detailed description of the GUI design procedures and standards is presented in Appendix C.

Task 3: Interview maintenance personnel to improve understanding of maintenance needs

The first of the three critical information collection tasks was to encapsulate the knowledge base of experienced maintenance personnel. The PFS has placed significant emphasis on refining the MDSS to address the needs and priorities of the front-line and mid-level maintenance supervisors. Further, the graphical user interface must be properly designed in order to ensure ease in use, yet effectiveness in handling complex weather and maintenance information. The Technical Panel felt it important to document as many facets of the maintenance decision process as possible in order to lay a firm foundation for the development of the PFS MDSS.

The PFS panel felt it imperative to use previous work as a starting point. The first step was to review the extensive needs assessment work the FHWA had performed as part of its Surface Transportation Weather Decision Support Requirements (STWDSR) project. The information was compiled and distilled into a needs assessment summary. This synopsis provided an excellent framework for the initial understanding of the unique needs of the maintenance community. The FHWA needs assessment summary also provided the fundamental guide to the development of the interview question set discussed later in this task discussion.

The Meridian investigators obtained maintenance manuals and additional manuals of practice/guidance from the Departments of Transportation in each of the Pooled Fund Study states. The investigators thoroughly reviewed the documents in order to produce a summary of maintenance practices. This information was important in the subsequent development of interview questions and becomes an instrumental resource for the development of the decision logic component of the MDSS.

Meridian chose to view the DOT needs as a response to the needs of its constituents or customer base—i.e., those individuals who use the state's highways for commerce, business, or personal travel. In order to ensure flexibility within the MDSS design, the needs of the travelers were summarized into seven categories:

- Mobility
- Safety
- Access to personal services
- Convenience
- Aesthetics
- Limited environmental impact
- Infrastructure

The charge of the maintenance division of all DOTs is to take the appropriate actions to assure that the DOT meets the expectations of its users. As an example of the relationship between travelers' needs and DOT action, consider one of the primary needs under the mobility and safety categories—the removal of snow and ice to return the road surface to an appropriate state that permits the traveler to move efficiently and safely from origin to destination. Travelers need the DOT to take the appropriate action to permit the traveler to use the highway in as normal a manner as possible. Therefore, each DOT action is tied to some traveler need.

Although it is these traveler needs that dictate the resulting maintenance actions, the actions themselves become the dominant consideration in the specification of a maintenance program. The state maintenance manuals reviewed by the investigators focused on the DOT responsibilities (the set of actions necessary to address winter conditions). Thus actions become the focal point of maintenance directives.

The investigators evaluated these routine maintenance actions and determined that each action was a decision outcome that was based upon a review of a set of information resources. For example, the action to plow roads requires information about equipment availability and status, the availability and scheduling of personnel, the route plan, the recent weather conditions, the existing weather conditions, the existing road conditions, the forecasted weather conditions, traffic volumes, potential for congestion, etc. These are the information needs necessary to appropriately execute the action. It is these needs that the MDSS must address and model effectively in order to provide the optimal response options.

After this thorough development of a list of maintenance needs, Meridian distilled the list into these seven primary categories:

- Level of service
- Materials
- Equipment

- Road reporting
- Scheduling
- Weather
- Winter weather scenarios

It is imperative that these DOT user needs are modeled properly in the MDSS in order to recommend the best response options.

Meridian utilized the review of the FHWA FP, the state maintenance practices documentation, and the needs evaluation just discussed to formulate a series of questions designed to extract the user requirements of DOT personnel within the PFS member states. The questions were formulated to interactively discuss operational needs with supervisors and field foremen at various locations within each of the five states. After several iterations and reviews, the technical panel approved the final data acquisition plan. A series of ten interview sessions were held in the five states, each lasting three to four hours in length. The interviews were structured around the interview questions; however, they were held in a free discussion format and participants were allowed to discuss a topic of interest for some duration before the investigators returned the discussion to a structured format. This approach allowed the investigators to determine what topics were important to the participants.

During the interviews the Meridian investigators recognized several recurring key factors that became dominant threads throughout the interview process. They were:

- The maintenance decision process is extremely complex and adaptive.
- The operational approaches vary considerably both across the member states and within each state.
- Policies and procedures control decisions to some extent and these local rules must be an integral part of the MDSS design.
- Maintenance resources (personnel, equipment, and materials) have a tremendous impact on the decision process.
- Short-term tactical decisions represent a greater requirement than mid-term strategic decisions.
- The MDSS design must start as a simple solution and work in phases toward a more complex solution.
- The initial design must understand the ultimate goal and have the appropriate architecture to permit the integration of more and more complex options.

The primary findings in each of the DOT needs categories are summarized in Table X-1.

Needs Category	Primary Findings
Level of Service	Each state has a defined LOS specification for all routes
	Traveler expectations may modify the expected LOS from the published LOS
	Maintenance personnel take pride in meeting or exceeding the LOS requirements
Materials	The selection of materials is in transition Sand/salt to salt only Solids to brine Salt to alternative chemicals in special situations Straight salt to salt with corrosion inhibitors and "sticking agents"
	The selection of materials and application rates vary based upon weather conditions. Most agencies use some form of guide for determination of the nominal application rate for the existing weather conditions
	Most of the decisions on the materials and rates are tactical in nature and adjustments are made on the fly as road conditions dictate
	Wind and temperature changes towards the end of an event create the most difficult decisions on the use or lack of use of chemical to restore LOS and still limit refreeze conditions
Equipment	Plowing performance is dependent upon a number of variables including blade type, shoe settings, down pressure, the plow angle, the plowing speed, and the character of the plowed surface with plowing speed deemed most important
	Participants discussed plow configurations, underbody plows, wings, snow blowers, and related snow removal equipment; these options need further documentation
	All application equipment is prone to clog or fail during operations which requires close monitoring
	The combination of application type and distribution pattern of materials creates a wide diversity of results on highway surfaces and different options may be used for specific situations
Reporting	Drivers stay in contact with other drivers and the central facility via radio
	All states have some form of logging material usage for inventory control
	Maintenance participates in the road reporting function in MN, ND, and SD; in the other states the reporting is done by the highway patrol
	Automated logging is in the research stage and is not operationally integrated in any of the states yet
	Scheduling
Scheduling	Schedule adjustments are necessary throughout the winter to handle extended events
	Each state has a different set of guidelines for adjusting schedules
	Scheduling decision times vary between states
Weather	Accurate weather forecasts are very high priority wish of all maintenance personnel
	Radar has become the dominant decision support tool outside of the forecasts
	Pavement temperature forecasts are seen as essential to the decision process
	Weather forecasts are only part of the decision equation; decisions under the same weather situation may vary based upon other factors impacting the decision process
Winter Scenarios	The three winter situations affecting the decision process the most are blowing snow, freezing rain, and refreeze
	The dominant concern varies within states as well between states and the concern may change over short distance

Table X-1: Primary Interview Findings

The other factor that came out of the interview sessions was the critical decision timeframe. Most of the concerns dealt with tactical, or short-term, decisions that had a lead time of 2 to 3 hours. Strategic decisions representing lead times of 3 to 12 hours were important for modifying schedules for extended events but were not the primary concern of the participants in the interviews.

Task 4: Evaluate State Communications, Networking, and Data Processing Environments

The second critical information resource was an assessment of the resources to collect maintenance specific information from the field and integrate it into the proposed MDSS program. Meridian reviewed the existing road reporting activity in each of the states and summarized the current programs and development efforts in progress. All states have a road reporting service of some nature. Road reporting in Indiana, Iowa, and Minnesota is a continuous process whereas North Dakota and South Dakota provide updates during specified time periods. The transfer of the information from the collection mechanism also varied from continuous updates to periodic transfer for public consumption and a lack of standardized data exchange protocol limits the exchange of road reporting data between states or to a centralized collection and display facility.

Meridian also reviewed the existing and planned maintenance activity tracking capabilities in the PFS states. Current programs use manual procedures to log and transfer maintenance actions and are primarily limited to the use of materials to support inventory control. Initial efforts have begun or are in planning to implement or expand experimental programs using Automated Vehicle Location (AVL) monitoring and reporting capabilities but none of the programs enjoys widespread participation yet. Meridian summarized the status of the maintenance tracking programs and indicated the gap that exists between maintenance data requirements and the data acquisition capabilities of operational capabilities.

Task 5: Assess Institutional Receptivity

The implementation of MDSS will constitute a significant paradigm shift in maintenance management practices and how information is conveyed across a state's information infrastructure. Technology has become more pervasive both in maintenance operations and in the tools provided to support decision processes. The members of the PFS team felt it was important to assess the receptivity of technology and technological innovations within their maintenance staffs. Meridian, working with the Technical Panel, determined that the assessment needed to encompass a broad spectrum of DOT personnel and a formal survey was the best instrument. The team determined the design of the survey and the questions within it should not show bias or in any way attempt to direct or coax specific answers. After several iterations the team agreed upon the survey composition and it was distributed to 1162 DOT employees in the five states.

The survey was designed to assess the user's current operational environment and receptivity to technology. The questions sought the user's views of operational resources, technology changes, the user's access to PCs and the Internet, and familiarity with MDSS. Sixty percent of the surveys were completed and returned. The answers from each survey were transferred to a state summary sheet and the counts for each response were kept. This transfer process permitted Meridian to evaluate the distribution of answers for all respondents in the state. This also permitted an evaluation of the entire set of responses. The survey had captured information on job classification, location, years of experience, and age; however, because of the way the data was transcribed to the spreadsheet Meridian was unable to look at the distributions within demographic classes. The surveys have been transferred again to permit this evaluation but the results were not completed for this report.

The results indicate that technology is viewed as an asset and is accepted by most DOT personnel. In fact, the survey results infer that users would like to have access to and use computer resources more than they do now. Many are limited in the use of the Internet and the some of the processing capabilities because of institutional limitations. Roughly 25% of the respondents have no access or limited access to computer resources at their location. This fact impacted a number of questions on the survey because users could not relate to some of the other questions that really required previous Internet experience. For those who do have access to an Internet interface and who use the Internet, they see value in technological resources and programs similar to MDSS in their decision making processes. However, even the more experienced users indicated that operational resources (availability of personnel, equipment, and materials) were more important factors in their decision process than were technological tools such as RWIS and MDSS. The conclusion from the survey was that technology advances are an accepted tool amongst maintenance personnel and users will integrate them into their daily operations if the tool proves its merit.

Task 6: Propose Architecture for the MDSS

The creation of a comprehensive and fully functional MDSS is a substantial, multi-year project. However, the development process is modular and must follow a high-level system design (i.e. architecture) that incorporates relative functional and user requirements.

The basic functional infrastructure of the MDSS is described in the body of the Phase I report. The fundamental architecture of the FHWA MDSS Functional Prototype is very similar to that of the MDSS Pooled Fund Study except in two areas. The design of the Weather component the MDSS FP uses a completely automated forecasting technique, whereas the MDSS PFS design incorporates a forecasting technique that integrates computer based processing and the expertise of professional meteorologists. The second major departure is in the design of the Process and Integration component the MDSS FP. The Functional Prototype uses the FHWA Rules of Practice (based upon "normal" maintenance experience) to generate appropriate response scenarios, where the MDSS PFS views each weather induced situation as unique and the appropriate response is based upon the physics and chemistry of the processes occurring on the pavement surface.

One of the primary design requirements of the Pooled Fund Study was that it meet the standards of the National ITS Architecture (NITSA) and be developed in a modular infrastructure that permits interoperability and interchangeability with modular components subsequently developed by other vendors. To meet this Technical Panel requirement, Meridian evaluated the design within the framework of NITSA. Within v4.0 of the National ITS Architecture, MDSS falls into the Maintenance and Construction Management subsystem. MDSS data flows have been identified and correlated to the NITSA, where it is important to note that both weather and non-weather elements are central to the decision making process. Meridian will work with each participating DOT to ensure that the MDSS complies with their respective state or regional ITS architectures. Non-meteorological decisions modules will also be included.

Task 10: Identify Research Requirements to Support MDSS

Meridian assessed the additional research needs that were deemed important to the development of an effective MDSS but which do not currently exist as an operational algorithm, module, or program. Most of these research needs represented research efforts that have not been addressed and are research efforts that will require a substantial time to develop. Meridian's evaluation was converted to a research wish list and priorities were placed on the research efforts. The list contains topics such as:

- computation of chemical concentrations for all anti-freeze agents
- blowing snow

- a traction index
- migration of chemical in slush with and without the influence of traffic
- frost characteristics
- bonding of ice to pavement surfaces
- latent heat effects associated with chemical applications
- traffic simulation and its effects on pavement surface conditions

Many of these topics are pure research efforts best suited for exploration in academia or research facilities. As part of Phase II Meridian will provide greater detail on the research requirements and make a recommendation on where the research might be done. Once the pure research is completed and the logic is converted to code, Meridian will integrate the enhanced processing capabilities into the architecture of the MDSS.

CHAPTER 1: INTRODUCTION

1.1 Background

Approximately 6,600 fatal crashes and an additional 470,000 injury crashes result from adverse weather each year within the United States. In addition to the costs of these accidents in both lives and repairs, over $2 billion are spent annually in providing winter road maintenance across the United States. Coping with the weather and the effects it has on both visibility and pavement conditions is an important dynamic that affects maintenance, traffic flow, and emergency response. To improve the response to these factors within winter maintenance programs, personnel who manage maintenance operations must seek innovative new techniques and decision making methods that complement the sophisticated system of road condition and weather data collection, analysis, and forecasting that continues to evolve and expand within the United States.

From its inception in the early 1970's the present Road Weather Information System (RWIS) program in the United States has offered the prospect of improving the effectiveness and efficiency of winter maintenance operations and improving safety on the nation's highways. RWIS monitoring devices (both weather instruments and in-pavement sensors, known as Environmental Sensing Systems) supply weather and pavement information along highway corridors, providing informative insight into existing conditions and recent trends. However, these systems fail to project pavement conditions forward into the decision time frame of roadway maintainers. This prediction limitation was first addressed in 1985 with the introduction of pavement temperature and surface condition forecasts provided by public and private weather forecast services. The combination of Road Weather Information System networks and pavement-specific weather forecasts has long promised to provide substantial reductions in operational maintenance costs. Research conducted in the early 1990's, as part of the Strategic Highway Research Program (SHRP), suggested potential reductions of up to 20% of the $2 billion cost of winter maintenance. While several states have documented savings of 1% to 6% associated with their RWIS programs, none have approached the magnitude projected by the SHRP research. The rapid expansion of state RWIS programs since the early 1990's has left many RWIS program managers questioning why they are not able to get the savings and cost-to-benefit ratio they anticipate.

In 2000, the Federal Highway Administration (FHWA) identified a significant need within the maintenance community for site-specific, road network-wide analyses and predictions of pavement conditions that included the latest technologies emerging from the weather forecasting research community supported by advancements in maintenance treatment strategies and procedures. To promote solutions for improved weather-based support for the maintenance community, the FHWA funded the development of the Maintenance Decision Support System (MDSS) Functional Prototype to identify possible methods that could be incorporated into an operational MDSS. The principal goal of the MDSS is for state departments of transportation to obtain the analysis and forecasting support necessary to meet their specific winter maintenance management needs. The Functional Prototype has been developed as a proof of concept for the FHWA by several U.S. National Oceanographic and Atmospheric Administration (NOAA) National Laboratories, and is being made available to state departments of transportation and the private sector to customize and meet local demands.

1.2 Creation of a Pooled Fund Study

The present project is a Pooled Fund Study that brings together participants from the public and private sectors. The Federal Highway Administration (FHWA) sponsors this activity as part of their Transportation Pooled Fund Program. This provides a means for interested states, the FHWA, and other organizations to partner when significant or widespread interest is shown in solving transportation-related problems. Within these programs partners may pool funds and other resources to solve problems through research, planning, and technology transfer activities.

In order for this Pooled Fund Study to exist, the states of South Dakota (lead state), North Dakota, Minnesota, Indiana, and Iowa determined that the development of a Maintenance Decision Support System was sufficiently important to their future winter maintenance programs to commit funds to conduct research, planning and technology transfer to support the MDSS development activity. Since the FHWA anticipates that MDSS implementation for state and regional applications will require special customizations beyond the Functional Prototype, the Pooled Fund Study provides the opportunity for research efforts that respond to these state and regional variations within MDSS. To conduct the research for the Pooled Fund Study, the participating states contracted with Meridian Environmental Technology, Inc., based on Meridian's demonstrated expertise in the topic, its familiarity with the maintenance operations of the participating states, and its current support of road and weather information technology in each state.

1.3 Problem Statement

The concerns raised about the lack of realization of promised benefits of Road Weather Information Systems (RWIS) being deployed in many states have prompted a broad discussion within the winter maintenance community. In addition, both the commercial and public driving communities have expressed a significant desire for improving winter driving conditions for increased mobility and safety. Thus the improvement of road conditions and provision of a safer driving surface through next generation maintenance efforts has both a significant financial and psychological impact on road users and state transportation agencies alike.

Numerous forums dedicated to winter maintenance issues have debated the challenges of effective RWIS and winter maintenance applications. Forums such as the American Association of State Highway and Transportation Officials (AASHTO) Winter Maintenance Committee, the AASHTO Snow and Ice Cooperative Program, the Aurora consortium, National Association of County Engineers (NACE) conferences, the Multi-state RWIS meetings, and Federal Highway Administration (FHWA) sponsored conferences have all spent considerable time discussing the present limitations. All have found the data and information available of considerable value, but with the following limitations and challenges:

- The volume of information is overwhelming and more than most decision makers have time to assimilate prior to making an operational decision;
- The readings from the RWIS pavement sensors are inconsistent and unreliable in too many situations, especially relating to chemical concentrations;
- Effective use of the RWIS data and weather forecasts require a meteorological background that maintainers do not have nor desire to obtain;
- Weather forecasts are seen as being critically important in making maintenance decisions; but the accuracy of existing forecast services is generally viewed as insufficient to meet user expectations.
- The expectations of the traveling public and commercial carriers are rising because of increasing need to travel during all hours of the day;
- Agencies are constrained to relatively fixed levels of funding and staffing;
- Reliable and timely reports of conditions for specific areas can be difficult to obtain;
- Certain weather-related conditions, such as blowing and drifting snow, are difficult to forecast;
- The interactions of snow, ice, water, and chemical atop pavement are very complex, and few maintenance personnel comprehend the true effects of specific maintenance actions on this layer;
- Innovative maintenance treatments, such as anti-icing technology, are becoming available, but their effect and effectiveness over the full range of possible conditions are not well understood;
- Less experienced workers are replacing retiring maintenance staff.

Unfortunately, many of the weather-related winter maintenance issues that exist today are found at spatial and temporal scales that make their observation and prediction problematic within the existing meteorological observation and forecasting framework. Thus, maintenance personnel must decide what treatments to apply, and when to apply them, based upon imperfect knowledge of current pavement conditions, current and forecast weather conditions, and available maintenance techniques and resources. In large part, these decisions are guided by the prior experience of maintenance personnel and supervisors. To overcome these deficiencies and improve the overall effectiveness of winter maintenance, new solutions must be developed that take better advantage of all data available and that apply sophisticated scientific methods to improve the analysis and forecasting of weather and pavement conditions as well as the application of those improvements in the decision making framework. The challenge is to identify these new methods of problem solving associated with winter maintenance and to develop, test and implement these methods for improved operational capabilities. Hence, the challenge of developing a Maintenance Decision Support System is to provide a more effective and efficient maintenance effort by:

- Assessing site-specific current road and weather conditions using all available observations and reasonable inferences based upon those observations and physical laws;
- Providing highly time- and location-specific weather forecasts along all transportation routes;
- Predicting how road conditions will change due to the combined effects of the forecast weather and the application of candidate road maintenance treatments;
- Notifying state agencies of approaching adverse conditions and suggesting optimal maintenance treatments that can be achieved with resources available to the transportation agencies; and
- Evaluating the reliability of predictions and the effectiveness of applied maintenance treatments for specific road and weather conditions so that the decision support logic can be improved.

In addition, one of the biggest challenges of deploying a Maintenance Decision Support System is to overcome the inertia of existing maintenance programs. Prior experience of maintenance personnel creates practices that are the most successful approaches discovered by maintainers using the knowledge and data available. However, research indicates that there may often be more effective approaches to winter maintenance available at substantially reduced resource costs. Many of these approaches seem counter-intuitive to today's maintainers because of a general lack of understanding of the complex interactions that occur atop the road. Appropriate combinations of human experience, scientific understanding, and high-performance computing must be used to produce various scenarios that, when made available to maintenance supervisors in an effective decision support framework, will improve decision-making.

1.4 Research Objectives

The primary goal of this Pooled Fund Study is to provide integrated weather, road condition, treatment and resource information to the appropriate maintenance personnel so they can make proactive decisions to better manage the transportation system before, during, and after adverse weather conditions. The anticipated benefits of this project include reduced operating expenses and a higher level of service, which will result in safer and smoother highway operations and traffic flow. This effort will also make more efficient use of chemicals, which reduces impacts on the environment.

The objective of this Pooled Fund Study is not to replace the human element of the decision process, but rather to demonstrate the benefits that can be achieved by utilizing the decision support program as a decision aid. Given this challenge it is not an absolute that all state departments of transportation are prepared to embrace the advanced methods associated with an MDSS. The reasons for this may lie in a lack of perceived (or real) need for an MDSS, insufficient benefits for the state Department of Transportation (DOT) relative to the program's costs, or a resistance to changing existing paradigms of operation within the state DOT. Primary to this effort will be improvement in the understanding of the complexities of interactions between the current road conditions, the weather, traffic, and the mitigating effects of residual and applied maintenance treatments.

The ultimate goal of this Pooled Fund Study is to construct an operational Maintenance Decision Support System for the states of South Dakota, North Dakota, Minnesota, Indiana, and Iowa that not only satisfies the needs of these states, but also meets or exceeds the national expectations for a deployed MDSS. The objectives of this Pooled Fund Study are:

1. To assess the need, potential benefit, and receptivity in participating state transportation departments for state and regional Maintenance Decision Support Systems.
2. To define functional and user requirements for an operational Maintenance Decision Support System that can assess current road and weather conditions, forecast weather that will affect transportation routes, predict how road conditions will change in response to candidate maintenance treatments, suggest optimal maintenance strategies to maintenance personnel, and evaluate the effectiveness of maintenance treatments that are applied.
3. To build and evaluate an operational Maintenance Decision Support System that will meet the defined functional requirements in the participating state transportation departments.
4. To improve the ability to forecast road conditions in response to changing weather and applied maintenance treatments.

1.5 Research Tasks

To accomplish the objectives and goals set forth for this Pooled Fund Study, it required the preparation of a research plan that addresses fourteen specific research tasks. These tasks are

1. Meet with the project's technical panel to refine the project scope and work plan.
2. Critically evaluate the results of the Federal Highway Administration's project to develop a prototype operational Maintenance Decision Support System.
3. Interview front-line and mid-level maintenance supervisors from each of the participating states to identify and prioritize needs for maintenance support functionality.
4. Assess the participating states' current and near-term capability to report current roadway conditions and track maintenance activities on specific highway routes.
5. Assess institutional receptivity to maintenance management decision support in the participating states and recommend actions to overcome potential barriers.
6. Based on results of previous tasks, propose in a technical memorandum to the project's technical panel the high-level functional and user requirements for an operational Maintenance Decision Support System and propose an architectural framework for the system. Separately identify those requirements that can be immediately satisfied and those that will require fundamental research.
7. Upon approval of the panel, construct a basic prototype MDSS incorporating those requirements that can be immediately satisfied.

8. Prepare, for approval of the project's technical panel, a plan for pilot deployment and evaluation of the basic prototype MDSS in a multi-state test region spanning portions of North Dakota, South Dakota, and Minnesota and separate areas in Iowa and Indiana.
9. Upon approval of the technical panel, deploy the basic prototype MDSS in state agency offices in the multi-state test region and evaluate its performance in actual winter conditions.
10. Develop and test new system components that satisfy those requirements requiring fundamental research, incorporating ongoing and emerging technology improvements associated with weather forecasting and maintenance practices.
11. Based on the results of the evaluation and development of new system components, recommend needed improvements and design modifications and identify operational limitations requiring additional research and development.
12. Upon approval of the technical panel, make system improvements, deploy an improved prototype MDSS in state agency offices in the multi-state test region, and evaluate its performance in actual winter conditions.
13. Prepare a final report summarizing methodology, findings in performance, conclusions and recommendations.
14. Make an executive presentation to the project's technical panel and provide electronic copies of the presentation material to participating states.

The relationship between the listed tasks and the project objectives are summarized in Table 1-1. Task 13 and Task 14 are summary tasks and are not reflected in Table 1-1. As proposed at the outset of this project, the Pooled Fund Study will span a period of three years with this report summarizing the efforts of the first year. Thus, of the fourteen tasks listed above, only Tasks 1-6 and a small portion of Task 10 were addressed during the first year of the project. Upon review and approval of the Pooled Fund Study Technical Panel subsequent activity on the remaining task will be conducted.

Objective	Task											
	1	2	3	4	5	6	7	8	9	10	11	12
1	●		●	●	●							
2		●				●						
3							●	●	●	●	●	●
4										●	●	●

Table 1-1 Relationship Between the Pooled Fund Study Objectives and Tasks

The following chapters describe the research efforts, accomplishments and recommendations associated with the tasks listed above. The final chapter provides a summary of the first year of the Pooled Fund Study.

CHAPTER 2: DEVELOP THE PROJECT SCOPE AND WORK PLAN

Task 1 - Meet with the project's technical panel to refine the project scope and work plan.

2.1 The Pooled Fund Study Team

The Maintenance Decision Support System (MDSS) Pooled Fund Study (PFS) team is comprised of the Technical Panel, additional support personnel from each of the states, and a private contractor enlisted to perform the investigation. Management and direction of the PFS is the responsibility of the Technical Panel. The study's technical panel comprises those individuals within the five member states participating in this pooled fund study who have the responsibility to monitor and guide all phases of the development of the MDSS, both in its general evolution and its involvement within their state. The State of South Dakota is the lead state and is responsible for oversight on the project. In addition to the state members, membership on the panel also includes individuals within the FHWA who have been involved with RWIS and 511 programs at the national and regional levels. The current membership is listed below in Table 2.1.

Panel Member	Affiliation
Jon Becker	SDDOT Research
Dennis Belter	INDOT Program Support
Dennis Burkheimer	IADOT
John Forman	SDDOT Operations Support
Jerry Horner	NDDOT Maintenance
David Huft	SDDOT Research
Bruce Hunt	FHWA
Larry Kirschenman	SDDOT Yankton Area
Mike Kisse	NDDOT Maintenance
Tony McClellan	INDOT Operations Support
Curt Pape	Mn/DOT Maintenance
Paul Pisano	FHWA
Rudy Persaud	FHWA

Table 2.1: MDSS Project Technical Panel

The state members of the Technical Panel serve as coordinators for PFS activities within their respective states, and act as liaisons with a number of additional support personnel with specific areas of expertise critical to the success of the PFS. The PFS team defined the support areas and indicated their function in the support of the program (see Table 2.2). The PFS coordinators subsequently enlisted the services of the appropriate individuals within their state and submitted the names of these individuals for the resource list.

Meridian Environmental Technology, Inc. was the contractor selected to perform the research for the states involved in the pooled fund study. Its responsibility was to design and develop an operational maintenance decision support system with the approval of the Technical Panel. This report was prepared by Meridian as the final deliverable for Phase I of the longer term MDSS PFS project.

Category	Type of Responsibility/Special Interest
Research Support Personnel	Communications, data processing, DOT network administration, and ITS programs.
Field Supervisors in Test Areas	Oversee and monitor all aspects of the MDSS PFS field tests.
Field Representatives Interested in MDSS	Other individuals with an interest in the MDSS program but who are not directly involved in the field tests. These individuals may provide guidance on maintenance conditions within the state but outside the test areas that have different maintenance requirements not prevalent in the test areas.
Contract Administrators	Contractual concerns within the member states; Dave Huft serves as the primary liaison for all contract administration issues.
RWIS Service Administrators	Coordination of the RWIS program, management of the RWIS data processing capabilities, and service of the RWIS field components

Table 2-1 MDSS Project Resource Categories

2.2 Objectives of Phase I of the MDSS PFS

One of the initial steps in the research program was to define the objectives of the program during Phase I of the study. From the outset of the PFS, the Technical Panel desired to clearly understand and define the requirements of the MDSS effort. Their fundamental approach was to document previous MDSS efforts, assess how each DOT's people might respond to the MDSS program, understand the architecture of the MDSS processing scheme, and start a logical, phased development to build and test an operational MDSS. Meridian and the members of the Technical Panel agreed upon the following seven objectives to guide the progress of the Phase I research efforts.

1. ***Document the background that lead to the requirement for a Maintenance Decision Support System approach to augmenting the operational response to maintenance obligations.***

The purpose of documenting the background efforts was to provide an understanding of the needs that generated predecessor products and services (e.g., RWIS) and to document the limitations of the information resources provided by these predecessor services. The panel knew MDSS was not an innovation but an evolution in an evolving technological approach to maintenance. It was important to place MDSS in the broader maintenance perspective and assess whether current and proposed development approaches truly address the evolving maintenance vision.

2. ***Fully describe the MDSS architecture, alternative approaches to the architecture, and provide justification for the infrastructure chosen for this development effort.***

The team felt it was essential that a maintenance decision support system satisfy the requirements of its name. The system had to be designed to serve the decision support function for maintenance. Although the primary emphasis of the current MDSS development effort was for winter maintenance, it was important that the design also be amenable to the broader set of maintenance requirements. The group agreed that maintenance decisions were not to be limited to, nor totally driven by, response scenarios to meteorological conditions. The architecture had to revolve around the decision support function and the design needed to integrate input from meteorological, logistical, and resource subsystems. The architecture also had to support interactions with ancillary programs such as inventory control, equipment management, human resource management, homeland security, traveler advisory services, and communications services.

3. ***Establish a baseline of current operational procedures that are key components of the MDSS architecture or are fundamental processes in the maintenance decision process.***

The baseline was needed to help understand what components of the MDSS required the most development effort. The proposed architecture required some enhanced capabilities that exceeded existing capabilities. The PFS team felt it necessary to establish where we were at the beginning of the project in order to get a better understanding on the development direction and level of effort needed to reach certain milestones. This documentation process was seen as a necessary requirement to justify the fiscal support of the program.

4. ***Define the maintenance needs that serve as fundamental requirements for the development of an MDSS and which must be partially or fully satisfied in order to create a successful MDSS design.***

This objective defined the fundamental approach to this pooled fund study. The team felt it was imperative that the PFS fully document the operational needs of maintenance to clearly define the direction of the project and determine features in the architecture needed to wholly or partially satisfy specific DOT needs. Designing solutions without understanding the needs that must be fulfilled was seen as an inappropriate plan.

5. ***Gain an understanding of the perception of MDSS within the states at various levels within the agencies and determine potential approaches to overcome sources of resistance.***

The team realized that technological changes only occur with associated changes in attitudes. For MDSS to be successful, it was deemed essential that it be accepted among field personnel as an effective tool that does not threaten their job security. The Technical Panel felt it imperative to understand what potential barriers might exist and use this understanding to create an effective implementation program that minimized the sociological concerns.

6. ***Agree upon the MDSS design, a phased development and implementation program to build the MDSS infrastructure, and a test program to evaluate the performance of the evolving MDSS program.***

The eventual MDSS design needed to be a successful integration of the information gained by accomplishing the tasks associated with Objectives 1 through 5. Once these tasks were completed, the team felt it would be able to finalize the architecture and test program design.

7. ***Enhance, further develop, and integrate the initial modules of the MDSS to provide a framework for evaluation of the MDSS concept and subsequent guidance on the direction of the development effort.***

Growth and progress come from a cyclical process that includes new development, evaluation, feedback, reassessment, design modification, and an agreement on a refined work plan. The objective was to evolve the MDSS design into an effective maintenance support tool.

2.3 MDSS Information Resources

The foundation of the MDSS PFS research program was a thorough understanding of the needs and environment that argued the need to develop the MDSS. The following information resources were considered key components in the foundation and development of an operational decision support system. This outline was used to collect materials to support both research requirements and essential data tables in the MDSS decision logic component of the MDSS processing system:

- History of RWIS Program
  - Evolution of the program
  - Pavement specific forecasting
  - User acceptance
  - Ancillary uses (bridge spray systems, meteorological support, etc.)
- Deficiencies of RWIS Program
  - Sensor performance
  - Pavement condition accuracy
  - Siting issues
  - Service concerns
- Maintenance Needs – Fundamental Requirements for Operation
  - STWDSR documentation
  - Maintenance policies and practices manuals
- Maintenance Needs – Information Resources to Support Operations
  - Pavement conditions
  - Weather data
  - Status of resources (staffing, materials, and equipment)
  - Methods of data communication
- Maintenance Needs – Decision Tools to Support Operations
  - Policies and procedures
  - Manual of practice
  - Rules, general and local
  - Rules, physical and chemical
    - Decision logic
- Characterization of FHWA MDSS Functional Prototype (FP) program
  - Documentation
  - Experience with software
  - Results and reviews of field tests
- Analysis of DOT's information technology infrastructure
  - Network configuration and performance
  - Communications resources and performance
  - Computing facilities
  - Security considerations
- User's receptivity to MDSS
  - Acceptance of technology
  - Willingness to change methods
- MDSS architecture
  - Organization of primary functional components
  - Processing techniques
  - Data structures
  - Data exchange protocols
  - Communication protocols

- Required research

2.4 Modes of Investigation

The objectives in section 1.1 contained several requirements to transfer a substantial body of information from maintenance personnel into the PFS knowledge base. The three primary information acquisition tasks defined in the MDSS PFS Research Plan were:

- Identify and Prioritize the Needs for Maintenance Support Functionality (Task 3)
- Assess Capabilities for Road Condition Reporting and Tracking Maintenance Activities (Task 4)
- Assess Institutional Receptivity to MDSS (Task 5)

A significant portion of this information covered maintenance needs, perceptions, and practices. Some of this information was formally documented but much remained as experience and perceptions amongst members of the field staff of the five state Departments of Transportation. The transfer was also necessary to provide the Meridian research and development team a detailed comprehension of maintenance equipment, materials, practices, and operational approaches in order to lay the appropriate framework for the design of the MDSS PFS data tables and decision logic system.

The objectives stipulated the collection of a broad spectrum of information and the PFS team quickly realized that the various requirements would dictate different collection techniques. Meridian listed potential modes of investigation and provided the strengths and weaknesses of each approach as it related to the collection of information needed to support the development of the Maintenance Decision Support System. Meridian and members of the Technical Panel reviewed the options and agreed upon the most appropriate methods to collect different types of information. Table 2.3 lists the potential approaches selected with a brief description of each.

As the information requirements became clear in Tasks 3, 4, and 5 within the PFS Phase I Research Plan (see chapters 4, 5, and 6 of this report), the Technical Panel and Meridian agreed upon the appropriate mode of investigation for each of the tasks. The methods selected for each task were:

- Development of a detailed question set and the use of this question set as the basis for the ***face-to-face interviews*** (Task 3 and part of Task 4 of the Detailed Phase 1 Research Plan)
- A combination of phone interviews and unstructured discussions (Primary mode of Task 4 of the Detailed Phase 1 Research Plan)
- Use of a survey ***questionnaire*** to assess the receptivity of the MDSS in a DOT-wide distribution of the survey (Task 5 of the Detailed Phase 1 Research Plan)

Investigation Mode	Description
Face-to-Face Interviews	Dialog between principal investigators and field personnel structured around a set of questions with joint approval of the Technical Panel and Meridian
Phone Interviews	Conference calls or direct one-on-one discussions following the same format as face-to-face interviews
Survey Questionnaire	A series of "yes/no" or multiple choice questions limited to a couple of pages. Takes no more than 5 – 10 minutes to complete. The survey should be mailed to designated participants and collection techniques should retain respondent's anonymity.
Detailed Questionnaire	A series of questions designed to extract complete, complex responses from respondent. Questionnaire may be done using a formal document or through interaction on a web site.
Time-Study Analyses	A third party evaluator monitors and documents routine maintenance operations for an external viewpoint. Technique is envisioned to allow Meridian investigators to better comprehend DOT operations and practices, not to evaluate DOT performance.
Feedback on Interface Prototypes	A combination of the techniques presented above to evaluate the user's perception of potential MDSS PFS graphical user interfaces.
Unstructured Discussions	Informal discussions concerning specific issues within the MDSS development effort. Discussions may occur during any phase of the study and may be spur of the moment digressions that provide essential input to the research team.

Table 2.3: Potential Modes of Investigation

2.5 Modes of Participation

Although discussions concerning the involvement of DOT personnel in the MDSS program started with the initial talks about a pooled fund study, formal consideration began in March 2003 with the request for the Points of Contact list in Task 1.1 of the research plan. Indiana, Minnesota, and South Dakota indicated they desired widespread participation of their personnel and Iowa and North Dakota preferred to concentrate their involvement among smaller groups, primarily team members in the designated test areas. Once it was decided in mid February of 2003 that the Task 5 user receptivity analysis would be done as a general survey distributed evenly throughout each of the states, Indiana decided to focus its MDSS field participation within two sub-districts in Indiana. When the face-to-face interview mode was confirmed as the appropriate mode of investigation in Task 3, the state coordinators were tasked to specify DOT participants in the interview process. Indiana submitted its contact list on March 31. The remaining states defined the groups that would participate in the interviews during May and June and provided the contact lists during June of 2003.

Iowa had to delay its decision due to their involvement in the FHWA MDSS Functional Prototype test. Iowa had been advised late in the winter that the FHWA might want to continue the FP test for a second winter. Due to the additional workload, the Iowa DOT did not feel that the individuals involved in the FHWA test would be willing to participate in the pooled fund effort as well. The FHWA informed Iowa of its decision to continue the MDSS Functional Prototype program on June

17. Because of this FHWA decision, Iowa opted to move the MDSS test area to District 3 encompassing the northwest corner of the state and submitted its list of participants in July.

2.6 Coordination Procedures

To facilitate the exchange of communications between the members of the Technical Panel and the principal investigators at Meridian, Meridian established an email reflector on January 10, 2003. The email address (mdss-project@meridian-enviro.com) was used to facilitate a uniform exchange of information to all MDSS project participants. Present membership on this reflector is provided in Table 2.4, including the individuals' names and their affiliations.

Contact	Affiliation	Contact	Affiliation
Jon Becker	South Dakota DOT	Henry Lieu	Federal Highway Administration
Dennis Belter	Indiana DOT	Tony McClellen	Indiana DOT
Dennis Burkheimer	Iowa DOT	John Mewes	Meridian
John Forman	South Dakota DOT	Kathy Osborne	Meridian
Bob Hart	Meridian	Leon Osborne	Meridian
Jerry Horner	North Dakota DOT	Curt Pape	Minnesota DOT
David Huft	South Dakota DOT	Paul Pisano	Federal Highway Administration
Bruce Hunt	Federal Highway Administration	Rudy Persaud	Federal Highway Administration
Larry Kirschenman	South Dakota DOT	Ed Rodgers	South Dakota DOT
Mike Kisse	North Dakota DOT	Ed Ryen	North Dakota DOT

Table 2.4: MDSS Pooled Fund E-mail Reflector Membership

The primary use of this reflector site was for material exchange, scheduling meetings and teleconferences, and distribution of report materials.

In addition to the use of the reflector site for exchange of information via e-mail, it was anticipated that further communication tools were necessary to provide access to, view, and distribute larger files and documents (for example, graphical user interface and software-related products). A project web site was developed to provide this functionality. The web site contains both public and project-only sectors. The public component contains general information regarding the MDSS PFS project and documents released by the Technical Panel for public distribution. The project-only component contains ongoing research documentation and internal administrative materials, including project personnel contact information. The web site has been completed and is ready for activation pending approval of the Technical Panel.

CHAPTER 3: EVALUATE THE FHWA'S FUNCTIONAL PROTOTYPE

Task 2 -Critically evaluate the results of the Federal Highway Administration's (FHWA) project to develop a prototype operational Maintenance Decision Support System.

3.1 Installation and Testing of the Maintenance Decision Support System Functional Prototype

The Federal Highway Administration established in 2001 a program to develop a prototype operational Maintenance Decision Support System referred to in this document as the Functional Prototype. Selected to perform this development were the six national laboratories listed in Table 3-1. To monitor the development and utilize elements appropriate for the pooled fund study, Meridian attended meetings and held discussions with representatives of the national laboratories in addition to acquiring, installing and evaluating public domain modules of the Functional Prototype software.

Laboratory
National Center for Atmospheric Research
USCOE Cold Regions Research and Engineering Laboratory
NOAA Forecast Systems Laboratory
NOAA National Severe Storms Laboratory
NOAA Environmental Technology Laboratory
Massachusetts Institute of Technology - Lincoln Laboratory

Table 3-1 National Laboratories Involved in the Development of the Operational Functional Prototype for MDSS

The Functional Prototype version 1.0 software and documentation was released in late September 2002 with a subsequent interim release, version 1.5, released in mid-summer 2003. Beginning in December 2002 with the version 1.0 release, Meridian reviewed the software and documentation of selected elements of the Functional Prototype (Table 3-2). Only the open-source version of the release was obtained as Meridian did not believe acquiring the proprietary binary release of the Road Weather Forecasting System would provide meaningful information in the evaluation of the code composition and functionality. Furthermore, the code that was anticipated from the NOAA Forecast Systems Laboratory was not included in the version 1.0 release and subsequently was not reviewed. The version 1.0 software source code was installed on Meridian computer systems and copies of the software documentation were distributed to an internal evaluation team.

Module	Source Code Obtained?	Binary Code Obtained	Source Code Language	Successfully Tested?
Road Weather Forecasting System (RWFS)	No	No	Not available	N/A
Road Temperature Module (SNTHERM)	Yes	Yes	FORTRAN	Yes [1,3,5]
Road Condition and Treatment Module (RCTM)	Yes	Yes	C++ & FORTRAN	Yes [1,3,5]
Precipitation Algorithms	Yes	Not Available	*C++*	Yes [1,4,5]
Rules of Practice	Yes	Yes	*C++*	Yes [1,5]
Chemical Concentration Algorithm	Yes	Yes	*C++*	Yes [1,5]
Display data formatter	Yes	Yes	*C++*	Yes [1]
MDSS GUI	Yes	Yes	*Java*	Yes [1,5]
Assorted NCAR library routines	Yes	No	*C++*	Yes [2]

Table 3-2 Functional Prototype Modules Evaluated and Status of Evaluation

Table 3-2 summarizes the FP code acquired for the evaluation and the status of the testing. The testing of each module was completed following a consistent set of steps. The initial system used for the installation and testing was an Intel-based workstation running FreeBSD UNIX and GNU C, C++ and g77 FORTRAN compilers. After problems were encountered with the use of g77 FORTRAN (see comment 3 below), the FORTRAN-based software was moved to a SUN UltraSPARC 60 running SUN OS version 5.8 with SUN C, C++ and FORTRAN 77/90 compilers.

The Functional Prototype software was installed following the installation instructions found in Appendix G of the MDSS FP documentation. The compiling of the software resulted in difficulties as noted by the superscripted flags in the testing column in the table above. The value of the superscripted flags relate to the following difficulties:

1. The software distribution Makefiles found in all source directories referenced an environment variable (*RAP_MAK_INC_DIR*) that was on a #include that pointed to a non-existent directory in the release expecting to contain two dependency files for the Makefile (*rap_make_macros* and *rap_make_targets*) to resolve against. There were additional undocumented environment variables set for RAP_INC_DIR and RAP_LIB_DIR, which pointed to the expected locations of include and library files for support packages of netCDF and the assorted NCAR library routines included with the distribution. The latter two environment variables, along with the environment variables for the compiler and link loader flags, were quickly discovered and changed without much delay. However, a significant effort and considerable time was involved in replacing the two dependency files. Eventually, these files were reconstructed manually and the compiling of the code could commence.
2. The construction of the NCAR libraries in the distribution required manual execution of the C++ compiler and formation of the necessary library archives. No documentation was provided to indicate where the libraries were to be located after their formation. Fortunately, there were no hidden dependencies, and experience in installing libraries in the past permitted the installation to proceed without significant difficulties.
3. Difficulties developed when compiling and constructing executables involving the FORTRAN routines associated with SNTHERM and the RCTM. The FreeBSD workstation in use only supported a GNU version of FORTRAN (g77). Various routines in the distribution for the RCTM required FORTRAN 90 and a number of routines in the

SNTHERM distribution, which was all FORTRAN 77, would not compile immediately with g77. The solution to this was approached in two ways. The first and most expedient solution was to move SNTHERM and the RCTM to a Sun OS machine that supported both FORTRAN 77 and FORTRAN 90. With this move, no additional compiler difficulties were encountered other than having to once again modify the required Makefile process. The second solution that was approached, over time, was to make appropriate modifications to the source code to permit compiling on the FreeBSD machine. The FORTRAN 90 code solution was accomplished by recasting the code in C++. This was simple to do as the routines were small and did not involve any intrinsic FORTRAN capabilities. The conversion of the SNTHERM code to a version supporting g77 took significantly longer, particularly the process of verifying that no damage was done to the precision and computations inherent in the original code.

4. Working with the National Severe Storms Lab (NSSL) precipitation algorithms were significantly different than other routines since it had no connection with the code distributed in the strictly public release, i.e., the precipitation algorithms are used in the Functional Prototype only with the RWFS. Hence, to test the code required developing driver routines that not only provided data to the precipitation algorithms, but also extracted the data for inspection. Further, since no meaningful documentation existed for this code, it required time to 'read' the source code to determine the data constructs expected on input and output. However, after some time the appropriate driver code was developed.

5. The most time consuming effort to test the routines involved providing observed and forecasted weather information. Prior to acquiring weather data, it was necessary to ensure that appropriate data handling software required by the Functional Prototype software was in place. The required software is listed below in Table 3-3.

Software	Version	Web Source
GNU gcc	2.9.5	http://gnu.org/
NcFTP	3.1.4	http://ncftp.com/
Java	1.3	http://java.sun.com/
Perl	5.0	http://www.cpan.org/
Python	2.0	http://python.org/
Unidata LDM	5.1.4	http://www.unidata.ucar.edu/packages/ldm/
Unidata netCDF	3.4	http://www.unidata.ucar.edu/packages/netcdf/
Unidata netCDF-perl	1.2.1	http://www.unidata.ucar.edu/packages/netcdf-perl/
Unidata UDUNITS	1.11.7	http://www.unidata.ucar.edu/packages/udunits/

Table 3-3 Required Software for Data Handling

The data standard used for exchange between FP modules is the Unidata netCDF (network common data format) standard that is in widespread use within the meteorology community. The data standard employs a self-describing data method encapsulated in a definition file known as the common data language or CDL. With the CDL, it is possible to describe the spatial and temporal nature of the data, the data units, the data limits, etc. While the standard does not promote compression and can become unwieldy for large binary files, the standard is acceptable for the transfer of most, if not all, of the data exchanged within an MDSS.

The version 1 Functional Prototype software is built around the Unidata Local Data Manager (LDM) for information acquisition and exchange. The data flow at Meridian is based upon a dramatically different data acquisition scheme than LDM. Although both can utilize NOAAPort data as input, the LDM system is built upon a flat-file system whereas the Meridian data base system is designed around a MySQL data base manager, resulting in greater efficiency in the Meridian system. However, for the purpose of testing the Functional Prototype in its native form, it was necessary to have a LDM data feed. Fortunately, the University of North Dakota was able to provide this data feed as they support the LDM as an active member of UNIDATA. After resolving issues of LDM configuration of data sets, the data flows were completed and testing of the Functional Prototype was able to be completed.

The testing of the graphical user interface (GUI), beyond the difficulties encountered in completing a fresh compilation of the java code, proceeded without much difficulty. Using the Java archive files in the distribution, it was possible to run the software immediately after copying the files to the testing workstation and setting the proper CLASSPATH values. While the distributed Java was developed using JDK 1.3.1 and the workstation had JDK 1.4.1 installed, no problems were encountered in running the software.

The installation and initial execution of the Functional Prototype software is not simple and requires knowledgeable staff to perform the configuration of data sources and software. The most significant concern about the software is not from the existing module structure, but concerns the potential difficulties that might be encountered where future changes are to be made by other entities than the developers at the national laboratories. The documentation provides only limited technical descriptions of the algorithms contained in the software release, and in particular the documentation of the Java software associated with the graphical user interface needs to be expanded greatly. While the software is a step forward in providing important building blocks to construct MDSS applications, it must be recognized that the software was the first release and has the typical discrepancies found with early software releases. It is anticipated that future versions of the software will be dramatically improved as more testing and development of the early software modules can be completed.

3.2 Evaluate Software Performance and Make Notes About Functionality

The National Laboratories' Functional Prototype software was designed to be a predominantly server driven system. This is to say that all data is processed off-site from the state DOT client and then distributed to the client at prescribed times. Numerous processes interact to build the information that will be provided in the graphical user interface. Unfortunately, the version 1.0 release of the software demonstrated considerable problems with interprocess communications that were based upon file transfers. This method resulted in unnecessary delays in the data processing, analysis and forecasting efforts. However, significant modifications were made to this interprocess communications prior to the 2003 winter field tests of the Functional Prototype and are reflected in the version 1.5 interim release.

Other difficulties encountered during testing of the software were associated with the use of the Unidata LDM as the backbone for weather information for the system. Although the data provided via UND for this test came to the University of North Dakota over an Internet 2 connection, the lack of reliability of the data flow from the upstream LDM site made the use of an Internet-based LDM questionable. Meridian is aware that LDM has been configured to ingest directly from a NOAAPort satellite downlink and believe that if LDM is used in this manner a significant reduction in problems will result. However, issues were not only with the reliability of the data flows into LDM, but with the stability of the LDM software. Frequent difficulties of the LDM software had a tremendous impact on the operational effectiveness of the Functional Prototype software execution. While several LDM patches and upgrades were made to the software during this time, the lack of reliability of the software and the lack of specific software maintenance personnel rectify software irregularities makes the use of this public domain solution less than optimum for operational use. Therefore, it is recommended that an alternative to the LDM backbone of the Functional Prototype software be made available. Since this data provision is external to the client-side application of the MDSS, this recommendation is not anticipated to impact the client-side software components of the MDSS while providing a more reliable source of data.

Since no sustained operational tests were conducted by Meridian with the Functional Prototype modules, there can be no statistical basis for assigning value to these modules. However, from the review of the software construction and physical content of the code, it is believed that three components of the Functional Prototype software bear closer consideration for use within the pooled fund study efforts. These three components are 1) elements of the graphical user interface, 2) the chemical concentration algorithm and 3) the road condition treatment module framework.

The development of a final graphical user interface for the client-side application will take considerable time to design. Using the Functional Prototype GUI framework as a starting point permits considerable code reuse and provides support for utilization and acceptance testing with maintenance personnel. It is anticipated that the final GUI will evolve as continued interaction with winter maintenance personnel provides more direction as to how to achieve the greatest levels of user effectiveness.

The Functional Prototype chemical concentration module was established from sound principles albeit for a limited variety of chemicals. As with the GUI, it is recommended that the Functional Prototype code be considered for adoption in the early stage of the pooled fund study. However, it is not recommended to continue with the rules of practice algorithm in the Functional Prototype. This decision was not based on the quality of the code, but rather on the concept of best practices and the inherent ambiguities associated with this concept. Pooled fund study interviews with maintenance personnel have indicated that this algorithm must be far more dynamic and flexible to be effective and representative of existing practices.

The final recommendation of code adoption is the framework that comprises the RCTM. Although, for reasons just cited, it is not recommended to adopt the Rules of Practice algorithm, it is believed that the code framework constituting the RCTM is worthy of consideration for code reuse in the pooled fund study. While the incorporation of the code saves valuable development time, the module must be expanded to provide for a more dynamic interaction with road condition and maintenance databases.

3.3 Read Through the Detailed Documentation and Evaluate the Design and Expected Performance

The Functional Prototype developed by the National Laboratories is structurally an analog approach to decision support. The term analog refers to a method that relates the current situation to similar situations that occurred in the past. Input to the decision support logic of the Functional Prototype is almost exclusively limited to forecasted weather information. Output from the decision support system is based upon typical responses derived from years of experience; thus the decision made today is based upon experience and practices carried out over the last several years – an analog process.

More than half of the document discusses the Road Weather Forecast System (RWFS) and its automated support components. The RWFS is a data fusion system used to generate ensemble forecasts for sites having verifiable data. The ensemble forecast routine is limited to those meteorological parameters available in the model output statistics (MOS) system. This does not encompass all of the parameters needed for the Road Condition Forecast System. Best approximations for these non-verifiable parameters are used (e.g., radiation flux or the alternative, cloud cover percentages). The majority of the code comprising RWFS was developed over the past several years, much of it as a dedicated project for a special concern.

The Road Condition and Treatment Subsystem (RCTS) utilizes an energy/mass balance model that takes its input from the RWFS and transforms this point specific weather forecast data into the most probable pavement temperature and pavement conditions for the given weather input. RCTS uses SNTHERM as its energy/mass balance model. The SNTHERM model was developed at CRREL in the 1970’s and 1980’s to emulate snow accumulation characteristics over open terrain. The research objective had been a high-resolution physical representation of the snow layer(s) above bare or vegetation-covered ground surfaces. Since subsurface conditions and the earth/atmosphere or earth/contaminant interfaces were not the focus of the research, the author made several gross assumptions that did not affect the modeling of the snowfield characterization above ground. However, these assumptions do impact the energy and mass flux relationships for a paved surface and its concomitant physical infrastructure. From research and evaluation of the model, it is known that the model:

- does not permit an impermeable layer such as pavement
- fails to emulate the true flow of moisture in the subsurface

- is not designed to handle the hydrological balance of the water-ice components on the surface of the pavement.

Further, the FORTRAN code was developed for a single run research analysis and was not configured to work in a redundant, operational environment.

The treatment component is not designed to model the physical state of the contaminant layer on the surface of the pavement. This layer is the mixture of snow, ice, water, various chemicals and mixtures of chemicals, grit, and other extraneous materials added to applied materials. RCTS does not directly deal with the state changes and the associated mass balance of the liquid phase and the combined ice/water combination (slush) induced when chemicals are present in the mix. Rather, the approach taken in the RCTS is to assume a no treatment scenario and monitor for precipitation events that exceed some pre-specified criteria (freezing rain, snow depth > *x* inches, etc.). Once one of these criteria is met, the model employs a treatment response derived from the Manual of Practice, then uses the SNTHERM model and integrated chemical analysis module to project the pavement surface conditions based upon the interaction of the treatment with the forecasted snow/ice/water in the forecast.

There was no indication in the documentation of proposed maintenance responses to potential frost conditions, the development of black ice, potential icing conditions tied to blowing snow, potential refreeze conditions, and refreeze conditions associated with the ice cream freezer[1] effect induced by applying chemical to slush.

The Road Condition and Treatment Subsystem does not directly address the physics and chemistry of highway maintenance practices. Winter maintenance is the practice of keeping the winter weather induced contaminants atop the pavement in a workable consistency sufficient to permit plowing action in order to remove the contaminants from the pavement surface without the development of a bond between the ice and the pavement. One of the primary values of an MDSS is to project the most efficient use of materials to permit physical removal of the contaminants in subsequent passes during the storm. Towards the end of a storm, an MDSS must project the proper use of chemicals – or the lack of use of chemicals – to permit effective removal of residual materials from the pavement surface through melting and runoff, evaporation/sublimation, or removal by the effects of traffic. The RCTS cannot address these issues because it does not assess the ongoing road condition and/or state of the contaminant layer and compute the optimal treatment to achieve the best maintenance outcome.

The user interface offers several excellent ideas. The main screen contains five components:

- alert status screen
- geographic locator or state map screen

[1] Ice cream freezer effect – the introduction of salt into a bath of water and ice causes the ice in the bath to change from ice to water; the latent heat necessary to cause this change from ice to water is taken from the ice/water bath reducing the temperature of the bath by several degrees below the standard 0° Celsius temperature of a pure water/ice mixture

- weather or treatment category selector box
- time and animation controls
- treatment information

Each of these components is critical in the operation and display components of the graphical user interface. Display options such as point specific or route specific information may be selected by simple use of the mouse to select the desired location. The time and animation controls permit excellent control of the displays.

Users can easily navigate from the main view to the route view to view local guidance. From the local or route view users may view weather forecast information, route condition forecasts, and treatment options. For each treatment plan the display can present such parameters as the pavement temperature, snow depth, mobility index, and chemical concentration values in a time series display for a specific route. The time series illustrates the effect on each of the display parameters for no treatment, the current selected treatment, and the recommended treatment. The user may also define treatment options that then become a treatment option in the user interface selection set. Users may try what-if scenarios by selecting one or more of these alternative options and view the effect of that treatment on the various pavement condition parameters.

The graphical user interface contains a wealth of information and user options. The display is complex and for a new user is busy, if not overwhelming. With use, the tools available in the interface become more straightforward and navigation through the various windows and drop down menus becomes more logical. However, maintenance users have a wide spectrum of understanding and technical experience. For some, the GUI will provide an effective tool. For many the interface will be too complex. It may be necessary to provide the option to present key elements of the information in a much simpler display format. As mentioned in an earlier sub-task, the documentation for the java software was virtually non-existent and seriously handicaps the ability to modify the provided code. Further, the original V.1 application did not provide extensive user help nor rigorous end-user documentation or user guide. In February, 2003 the national labs released a tutorial prepared for the initiation of the Iowa field test. This tutorial was a PowerPoint presentation based upon Version 2.0.1 of the Functional Prototype software. The tutorial was available at http://www.rap.ucar.edu/projects/rdwx_mdss/iowa.html as either a PowerPoint file or a PDF file. The PowerPoint presentation provides an excellent overview of the features of the GUI and capabilities allowed the user. Although the PowerPoint presentation was developed for a training session, it is reasonably easy to follow as the presentation does builds on the screen. The PDF file is harder to use since it captures all the builds after they are complete.

The documentation contains one significant omission - a well-defined architecture description based upon standard programming requirements e.g., data flow diagrams, stipulated in federal and state guidelines. The modules constituting the client-side of the MDSS information could be described using data flow diagrams such that it would document the modularity, standards of interoperability, modular interchangeability, and defined interface protocols found within the Functional Prototype.

Finally, the early documentation of efforts of such programs as the Office of the Coordinator for Meteorology's Weather Information for Surface Transportation and the FHWA's Surface Transportation Weather Decision Support Requirements programs proposed that the federal government develop a prototype Functional Prototype and that the resulting software be delivered to the private sector for further development, customization, and implementation. From the evaluation performed of the version 1.x Functional Prototype, it is concluded that making substantive changes will be extremely difficult for most vendors without considerable assistance from the National Labs involved in the Functional Prototype development.

CHAPTER 4: ACQUISITION OF MAINTENANCE INFORMATION

Task 3 - Interview front-line and mid-level maintenance supervisors from each of the participating states to identify and prioritize needs for maintenance support functionality.

4.1 Information Acquisition Plan

The need to understand the maintenance decision thought process and to some extent mimic that thought process was a central focus of the Pooled Fund Study effort from the beginning. In order to capture the process it was necessary to understand the needs that drove maintenance responses and the extensive information resources (or lack thereof) with which maintenance personnel had to deal. This chapter addresses the development of a clear understanding of maintenance needs, the collection of detailed maintenance information to support the decision process, and an interface mechanism to permit users to interact with a decision support system.

4.2 Graphical User Interface

One of the five primary components of the MDSS architecture is the User Interface System. The PFS team felt it was important to address the development of a conceptual user interface early in the project. Meridian sought advice from computer science faculty members at the University of North Dakota who specialize in software engineering design practices and graphical user interfaces. These direct interactions were supplemented with a background review of published literature on graphical user interface design practices. In addition, Meridian held internal discussions among its software engineers who have considerable experience in the design and implementation of both server- and client-based software packages.

The complexities of graphical user interface design mandated that Meridian exercise caution in deploying such interfaces too soon in the development process. Based upon the assessment of GUI design practices and the recommendations of the university computer scientists consulted in this task, the decision was made to take a more pragmatic approach and develop an understanding of present computer literacy among DOT personnel before presenting sample GUIs. Further, the sequential research plan of Phase 1 required both an assessment of user needs and expected receptivity to MDSS as well as the completion of an approved MDSS architecture as predecessors in the design of the user interface. The net result was that Meridian was allowed the opportunity to perform the necessary design research, review accepted GUI design standards, and take advantage of the lessons learned from the MDSS Functional Prototype field test in Iowa.

4.3 Needs Assessment Review

The MDSS program evolved from a number of separate efforts in the mid-1990's to establish more effective tools to support the winter maintenance decision processes of DOT and public works personnel. The concepts emerged from two separate venues, the Road Weather Information Systems (RWIS) program and research efforts on advanced, high-resolution forecasting techniques. The formal program to develop a Weather Information for Surface Transportation Decision Support System (WIST-DSS) grew out of the rural ITS program of the ITS Joint Program Office (ITS-JPO).

The first formal program was the Surface Transportation Weather Decision Support Requirements (STWDSR) project.

According to FHWA's Office of Transportation Operations:

> "The STWDSR project originated in work of the FHWA Weather Team, created in January 1997. The Weather Team was founded with membership from various FHWA offices involved in weather programs and a state DOT representative from the AURORA pooled-fund research consortium of states concerned with weather information and winter road maintenance. The first major actions of the Weather Team were to draft its White Paper based on a stakeholder symposium in 1997, and initiate the Foretell™ operational test of advanced weather information for road maintenance and other users. The White Paper defined the FHWA weather information program focus and Foretell, which is undergoing a 3-year evaluation funded by the ITS-JPO, will be an important experience base for WIST-DSS development and requirements validation. The Advanced Transportation Weather Information System (ATWIS) operational test in the Dakotas is also an important basis for the WISTDSS along with other weather-related projects sponsored by the USDOT and the many commercial developments of the VAMS."[2]

Mitretek performed the background research for the FHWA and released the first STWDSR V1.0 report in December 1999. At the same time the Office of Federal Coordinator for Meteorological Services and Supporting Research held its first WIST symposium. The STWDSR program continued during 2000 with stakeholder meetings in February and May. A second report, STWDSR V2.0, was released in June, 2000. STWDSR V2.0 contains a compilation of the needs assessment information submitted as part of the two stakeholder meetings and follow-up dialog Mitretek had with the states participating in the STWDSR meetings.

[2] FHWA. 2000. Surface Transportation Weather Decision Support Requirements, Version 1.0. Office of Transportation Operations, Federal Highway Administration, page 11.

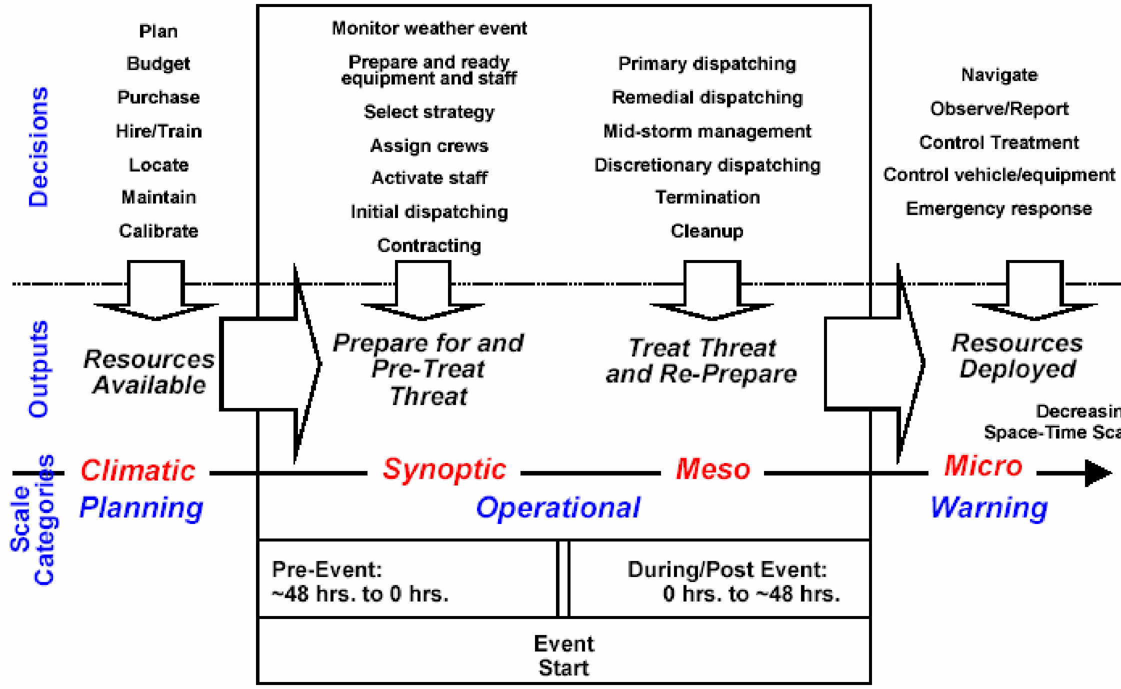

Figure 4-1 Scales of Decisions and Outputs Relative to Threat Event

Based upon input from the states, Mitretek developed a needs assessment summary for a decision support system. The compilation was fairly extensive and served as an excellent framework for the initial understanding of the unique needs of the maintenance community. The analysis broke the decision process into a composite time and space scale (see Figure 4-1). Decisions made 48 hours prior to the initiation of an event (threat in the STWDSR document) were associated with broad scale decisions. As the forecasted time to the initiation of the event got shorter, decisions addressed more localized issues. During the event, maintenance personnel tended to focus on very local issues, especially where small-scale differences in weather conditions impacted minute by minute adjustments in the maintenance response. As decisions became more focused on the local issues within the maintenance "warning" category, the requirement for weather information changed to a very high resolution forecast.

The analysis of the DOT-provided data suggested that decisions may be classified into decision clusters which are effective in different time intervals (Figure 4-2). Within each of these clusters there existed a number of time-dependent needs.

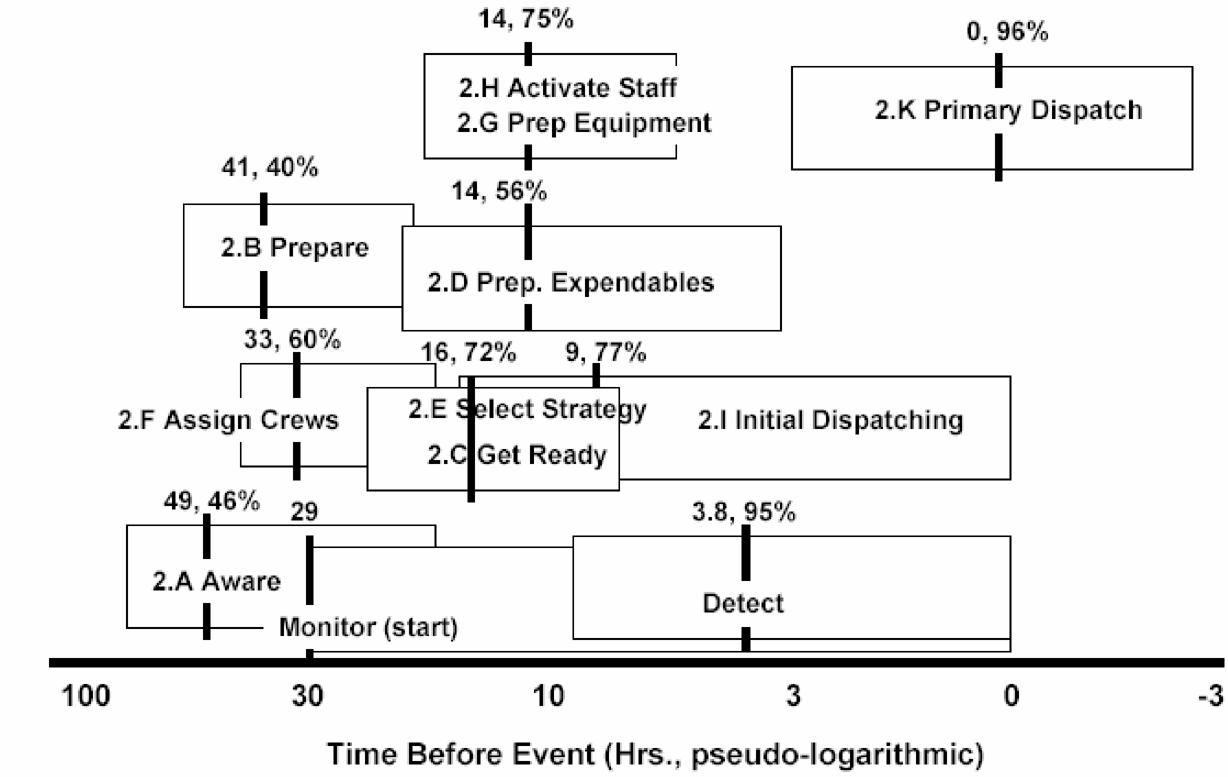

Figure 4-2 Decision Clusters, Time Lead, and Confidence

These two figures are a quick summary of the extensive work done for the STWDSR. These documents laid the framework for subsequent development efforts of the FP and became an essential baseline for the development of the "extended" needs assessment in this PFS report. The principal investigators found the STWDSR needs assessment document an invaluable resource.

4.4 Maintenance Documentation – DOT Manuals

Table 4-1 lists those materials provided by the states in response to a request for documentation of each state's Policies and Practices sent out on January 13, 2003.

Agency	Document	Content
INDOT	Total Storm Management Manual	Administrative management Environmental issues Personnel issues Equipment Snow & ice control materials Weather information systems Storm operations Special considerations
IADOT	Snow and Ice Control Instructional Memo 8.010	General guidelines
	Snow and Ice Control Instructional Memo 8.030	Preparations for winter
	Snow and Ice Control Instructional Memo 8.100	Snow and ice removal operations
	Snow and Ice Control Instructional Memo 8.400	Chemical and abrasives
MNDOT	Maintenance Manual	Snow and Ice Formula Winter Plan of Operation Equipment Materials Road Condition Reporting
	Maintenance Bulletin No. 99-1	Winter Rescue Law clarification
	Maintenance Bulletin No. 02-1	Non-Interstate Road Closure, Operations Manual
	Guidelines for Anti-icing (Electronic Copy)	Mn/DOT Anti-icing Guidelines References Chemicals
	Bare Lanes (PowerPoint presentation)	Pictorial of bare lane and non bare lane observed states
	Application Rates Guidelines (PowerPoint presentation	Series of guidelines for various chemicals and weather situations
	Maintenance Manual – Snow and Ice Control Guidelines	Operation guidelines for snow and ice control and clean-up operations
NDDOT	Maintenance Operations Manual – Snow and Ice Control	Service levels, operations rules, winter road reports, road closures, snow and ice strategies
	Route Guidelines and Personnel Listings	Maintenance routes and call lists
	Snow and Ice Control Plan	Goals and objectives, equipment, spreader tables, rules of operation
SDDOT	Policy Letter OM-1996-04	Reassignment of equipment during winter storms
	Policy Letter OM-2002-06	Winter Operations Priority One Routes
	Performance Standard 2501	Drift prevention
	Performance Standard 2524	Plowing Sanding
	Memorandum #10	RWIS utilization guidelines

Table 4-1 Documentation Received from Participating States

The materials received from the five states represented a broad spectrum of detail on maintenance practices. Table 4-2 summarizes the value of the materials received. The MATERIALS column indicates the type and volume of information within the documentation, while the COMMENTS column indicates how the information fit into the development of the PFS needs assessment document.

Agency	Materials	Comments
INDOT	Single maintenance summary document, 164 pages in length	Complete, well written, descriptive, well illustrated document; it was used extensively to establish a baseline for discussions in the interview sessions in Indiana and will be extremely helpful in the development of local parameterization of PFS model
IADOT	Four instructional memos, each 3 to 5 pages in length	Incomplete documentation of actual winter maintenance guidance used in Iowa; the interviews were used to attempt to augment the investigator's understanding of IADOT practices; more detailed questions are necessary to assess local policies and practices
MNDOT	Maintenance manual & update (~ 50 pages), bulletins on related policies, support presentations	Complete, well written, descriptive, well illustrated documents and PowerPoint series; material was used to prepare for interviews and will be merged with additional local information to support model parameterization
NDDOT	Snow and Ice Control Plan (~20 pages) and assorted operations guidelines	A relatively brief description of maintenance practices supported by detailed guidance on equipment settings and application rates
SDDOT	Two policy letters and two performance standard documents, each 1 to 3 pages in length	Incomplete description of actual winter maintenance guidance used in South Dakota; input from interviews filled part of the gaps but direct discussions with field personnel will be necessary to complete the documentation

Table 4-2 Value of Materials Received from Participating States

Although there was a wide spectrum in the amount of information provided by the five states, the content within the separate documents did cover a number of common topics. Typically, these topics included information that could be classified into the following categories:

- administrative issues
- safety considerations
- emergency response requirements
- traffic control responsibilities
- level of service obligations
- weather information resources
- chemicals—storage, characteristics, application rates, special guidelines
- equipment—type, use, maintenance, and operational regulations
- communications and reporting events from the field
- crew scheduling procedures and personnel issues
- response guidelines for specific weather situations

All of the documents served as resource materials both before and after the actual interview process discussed in section 4.6. The documents were used in preparation for the interviews and during the process of consolidating interview responses into a refined understanding of the DOT's operational requirements and practices. The documents will remain an important resource in the development of data tables to support the decision logic of the MDSS PFS software.

4.5 Needs Assessment Classification

During the Technical Panel conference call of March 31, 2003 Meridian presented a Needs Assessment document for maintenance personnel. The document laid the foundation for the approach Meridian had selected to extract information from the STWDSR research and the maintenance documentation provided by the participant states. Meridian chose to view the DOT needs as a response to the needs of its constituency or customer base - those individuals who use the state's highways for commerce, business, or personal travel. Interactions with DOT maintenance personnel involved in daily operations indicate that routine maintenance responses are often modified to address specific needs of the traveling public. To assure the MDSS design retains the flexibility to address these extraneous influences, Meridian felt it was important to address these factors from the beginning of the design.

Need of Users of DOT Maintenance Services

The needs of the travelers were summarized into seven categories:

- Mobility
- Safety
- Access to personal services
- Convenience
- Aesthetics
- Acceptable environmental impact
- Infrastructure

These seven categories were subdivided into 72 specific subclasses that represented specific needs or expectations that travelers had regarding the maintenance or upkeep of the highway system. The two dominant categories were mobility and safety. The 16 traveler needs for the mobility category are provided as a list of subclasses in Table 4-3. Each of the 72 designated user needs was then translated into maintenance actions necessary to satisfy or rectify the need or expectation of the traveler. As an example, one of the traveler expectations (needs) under the category mobility (subcategory 7) stated "Roads void of snow, ice, or slush". Possible actions that may be necessary to address this need included:

1. Pre-treat roadways
2. Prepare to plow or treat roadway
3. Plow or treat roadway
4. Post storm plowing or treatment to complete cleanup

See Table 4-4 for an example of the Mobility category, subclass 7 analysis. For each traveler need Meridian identified between 1 to 7 possible response actions with a total number of response actions just over 200.

Subclass	Mobility Category
1.	Road surface with sufficient roughness to permit traction but smooth otherwise.
2.	Road surface with minimal surface deterioration or with surface patched to provide a smooth ride.
3.	Road construction that does not have or create surface irregularities that are sufficient to slow traffic at or below safe driving speeds (which may be in excess of posted speed limit).
4.	Elimination of substructure irregularities that cause dips in the pavement or substantive changes in the height or position of one pavement slab relative to the next.
5.	Absence of any loose, solid materials on the surface that would impede traffic or cause other drivers to slow to avoid. This could include objects that fell from vehicles, dead animals, objects blown onto the road (e.g., tree limbs, power lines, signs), and fallen objects (rocks, etc.)
6.	Roads with no or minimal standing water or a layer of water sufficiently thin to permit coefficient of friction to remain high enough to retain traction at desired speeds. The source may be heavy rains, snow melt, melt from chemical application, etc.
7.	Roads void of snow, ice, or slush.
8.	Alternatively, snow- and/or ice-covered roads returned to normal driving conditions as quickly as possible. The return time to acceptable level of service varies with driver and covers a range that spans several hours. It would be helpful as an adjunct study to assess the traveler expectation of this parameter and what the key marker times are in the decision process. For example, does the traveler expect the roads to be returned to an acceptable LOS some time after the beginning of the storm or a time after the end of the storm or something in between. The DOTs typically define a time from the end of a storm.
9.	The absence of any frost, especially unexpected patches of frost on bridges or shaded areas.
10.	The absence of any local icy spots on roads with normal driving conditions elsewhere.
11.	The absence of vehicular obstructions on or near the traveled surface and/or occupied vehicles in distress on the shoulder of the road but not sufficiently removed from the shoulder to permit normal flow.
12.	Minimal use of lane closures and the expeditious return of any closed lanes to service.
13.	The use of signs to clearly mark transitions in traffic conditions (curves, speed limits, signals, entering and exiting traffic, services, and other items that may indicate changes in traffic flow.
14.	The control of meteorological conditions - where possible - that affect visibility such as blowing snow, blowing sand, blowing dust.
15.	The notification of meteorological conditions that may impact mobility due to reductions in visibility.
16.	Any mechanism to suppress the amount of road spray that affects visibility.

Table 4-3 Traveler Needs

Response Action	DOT Need
Pre-treat roadways	Liquid application equipment available
	Chemical available to prepare brine
	Brine prepared?
	Vehicle available to mount the equipment
	Equipment installed on truck and calibrated
	Brine loaded into tank and truck prepared for operation
	Route plan in place
	Personnel availability and their schedules
	Assessment of priority relative to other tasks
	Mid-term forecast to assess lead times for preparation of equipment, materials, and crew schedules
	24 hour forecast to more effectively time preparation of equipment, materials, and crews
	Forecast updates to refine decisions
	Current data and trends, especially radar data and reports of precipitation from adjacent areas
	Good estimate of precipitation start time
	Good indication of precipitation type (snow or freezing rain)
	Weather alerts or notification of precipitation start time
Prepare to plow and/or treat roadways	Equipment status
	Equipment availability for specific routes
	Route plan in place
	Personnel availability and their schedules
	48 hour forecast to assess lead times for preparation of equipment, materials, and crew schedules
	24 hour forecast to more effectively time preparation of equipment, materials, and crews
	Short-term weather forecast (<6 hours) and/or updates to refine decisions
	Current weather conditions and trends
	Good estimate of precipitation start time
	Good indication of precipitation type at start of precipitation (snow or freezing rain)
	Weather alerts or notification of start times
	List of current maintenance responsibilities
	Rank of responsibilities, listed by priority level
Plow and/or treat roadways	Equipment status
	Continued equipment availability on specific routes
	Route plan in place
	Personnel availability and their schedules
	24 hour forecast to assess adjustments in use of equipment, materials, and crews
	24 hour forecast to estimate end of snow and conditions after storm
	Short-term weather forecast (<6 hours) and/or updates to refine decisions
	Current weather conditions and trends
	List of current maintenance responsibilities
	Rank of responsibilities, listed by priority level
Post storm plow and treat roadways	Equipment status
	Continued equipment availability on specific routes
	Route plan in place
	Personnel availability and their schedules
	24 hour forecast to assess adjustments in use of equipment, materials, and crews
	Short-term weather forecast (<6 hours) and/or updates to determine wind conditions, pavement temperatures, air temperatures, and cloud cover
	Current weather conditions and trends, especially winds
	List of current maintenance responsibilities
	Rank of responsibilities, listed by priority level

Table 4-4 Example of Traveler Needs Under Mobility Category, Subclass 7 "Clear Roads"

Many of the actions were potential duplicates of actions required under other traveler need subcategories; however, Meridian opted to keep the actions separate because there were often subtle differences in the response or the needed information to execute the specific action for the specified traveler need. Meridian felt these subtle differences could be important in the subsequent system implementation and chose not to consolidate similar actions.

In the STWDSR analysis the evaluation of DOT needs commenced with the set of actions. These actions had been submitted by the DOT representatives in response to a request from the principal investigator on the STWDSR project asking "what do state maintenance providers have to do" to successfully fulfill their winter maintenance responsibilities. Meridian expanded the perspective, viewing maintenance responsibilities as a set of responses to meet the needs of the travelers on the state's highway infrastructure. The set of actions derived from converting "travelers' needs" to "actions" step as illustrated in Table 4.4 created a set of actions similar to the set of actions reported by the STWDSR project; however, Meridian found differences that will affect the MDSS design logic. For example, the level of service expectation of urban travelers is quite different than that of rural travelers. This difference in travelers needs causes a difference in the necessary response actions. This particular situation was documented in discussions with field personnel from the Seymour District in Indiana who had seen the level of service requirements change on rural state highways as urban travelers became more prevalent in their area of responsibility.

4.4.2 DOT Needs

In order to execute a specific maintenance action, maintenance personnel must evaluate a number of factors to determine the best response. These factors are defined as DOT decision support needs. For example, from item 3 in the action list in the previous section (4.4.1) in order "to plow and treat roadways" the DOT maintenance operator or supervisor needs to know information about:

- the availability of personnel resources,
- the status of available equipment,
- chemical resources,
- road conditions,
- recent and current weather conditions,
- weather forecasts (tactical and strategic),
- DOT policies,
- local DOT practices,
- route variability,
- social events and issues,
- and other miscellaneous factors.

Category	Why	Expected Use
Level of Service	▪ Determines maintenance outcome ▪ Determines extent of effort ▪ Specifies response by route ▪ Defines travelers' expectations	▪ Influences crew allocation ▪ Influences route return time ▪ Impacts type of material ▪ Influences application rates ▪ Impacts selection of equipment
Materials	▪ Chemicals reduce freeze point of ice ▪ Chemicals prevent ice bond to road ▪ Chemicals keep snow/ice workable ▪ Chemicals aid return to bare road ▪ Chemicals minimize frost potential ▪ Chemicals are a maintenance tool ▪ Inventory management is an important factor ▪ Grit aids traction ▪ Works with traffic to minimize effect of snow and ice	▪ Analysis of chemical concentration at any point in highway system ▪ Feedback to road condition processing module ▪ Determination of percent ice in slush to assess workability of slush ▪ Analysis of frost potential ▪ Analysis of traction index ▪ Evaluation of the effect of different chemical combinations ▪ Assessment of adverse treatment response ▪ Assessment of residual chemical
Equipment	▪ Essential for removal of snow & ice ▪ Essential for application of materials ▪ Number & type of vehicles, plows, & applicators determine response time to Level of Service requirements ▪ Serves as mobile communication hub	▪ Analysis of plowed conditions at any point in system ▪ Feedback to depth of layer as part of road condition processing ▪ Input into route cycle time ▪ Input into a routing module to assess optimal use of limited equipment ▪ Input into an equipment servicing module to assess return to service time for inoperable equipment
Road reporting	▪ Essential for ground truth of road condition ▪ Depth of snow/ice/slush layer essential for MDSS model	▪ Reset initial surface conditions for any point in road condition processing module ▪ Adjusted surface condition impacts chemical concentration, assessment of slush content, traction index, residual chemical ▪ Provides input into traveler advisory services
Scheduling	▪ Policies dictate potential use of crews ▪ Availability of individual crew members impacts all operations ▪ Scheduling and activating crews is major supervisory activity ▪ Performance levels dependent upon having experienced crew available at critical times	▪ Input to a crew scheduling module ▪ Scheduling module will integrate local policies and practices that affect labor ▪ Scheduling interacts with decision support timing which feeds back to road condition, equipment, & materials modules ▪ These feedback mechanisms create a looped feedback that, in turn, affects the scheduling module
Weather	▪ Weather is a forcing function that impacts nearly all modules in MDSS	▪ Primarily affects the road condition module which then impacts the forecast component of nearly every other module in the MDSS design
Winter scenarios	▪ Scenarios permit integration of all the above components into a cohesive plan of action ▪ Scenarios point out which impacts and response activities are most important ▪ Scenarios draw out the exceptional situations that require special treatment rather than the routine situations	▪ Scenarios are a synthesis process that affect differing modules throughout the MDSS ▪ Scenarios will permit the investigators to gain a better understanding of how the modules/components of MDSS must work together as a cohesive package ▪ Scenarios will highlight critical local events that need particular attention in the design and development of particular modules

Table 4-5 Categories of DOT Needs

Meridian prepared a similar information needs list for each of the actions. The list becomes the foundation for the decision logic process. Entries will be refined as further detail is integrated into the study and factored for local variability.

The DOT needs assessment list also served as the baseline for the development of a question set for the interviews discussed in section 4.6. Using this needs assessment evaluation and the summaries of the state maintenance documentation, Meridian separated the DOT needs requirements into seven separate categories:

- Level of service
- Materials
- Equipment
- Road reporting
- Scheduling
- Weather
- Winter weather scenarios

The categories are listed in Table 4.5 with explanations of why each was important to the question set and how the need would impact user decisions.

4.6 Information Transfer Approach

As indicated in section 2.3, the work in Task 3 of the Detailed Phase 1 Research Plan was to "identify and prioritize the needs for maintenance support functionality". This was one of three information transfer requirements. To validate its initial assumptions, Meridian sought professional input in the selection of the appropriate investigative techniques. Kathy Osborne was lead on this program and did the background research on the potential methodologies. The primary resource in assistance with the survey design was Brenda Badman, Marketing Consultant for the Center of Innovation in Grand Forks, North Dakota. Ms. Badman reviewed the intent of Tasks 3, 4, and 5 and recommended the interview technique as the most appropriate for Task 3 and stressed that the focus of the interview questions must be pertinent to the audience (the persons being interviewed). Ms. Badman's response substantiated Meridian's choice of technique and subsequent efforts centered on developing the tools to perform direct face-to-face interviews with DOT field personnel in each of the five states.

There was one concern with the interview process; interviews make it difficult to ascribe a good measurement technique to user responses. Following discussions, it was decided that the primary intent was to permit flexibility in the discussions and allow DOT personnel to highlight issues that were important to them. This focused the intent of the interview process on more general topics with the latitude to allow the interviewees to direct the emphasis of the talks. The selection of this investigative process put considerable pressure on the interviewer or the interview team to capture the content of the discussion. Metrics were more subjective in this format and placed more emphasis on capturing the recurring issues raised by the DOT personnel. Interviewers had to not only capture the issues, but also be cognizant of the individual raising the issue and what position in the organization this individual filled. Meridian recorded all of the interviews and then reviewed the tapes later to confirm and elaborate notes taken during the interviews.

Question Set for Interviews

Meridian evaluated the DOT needs categories presented in section 4.4.2 and prepared a series of questions in each of the categories. The question set also contained a set of "introduction" questions designed to determine the background and experience of the individuals involved in the interview. The series of questions is presented in Table 4.6**.**

The questions were worded to address the interests of the audience and allow the interviewer to extract as much detail from the interviewees as possible. It was also hoped that the questions that were chosen would entice DOT participants to take the lead in the discussions and relate their experiences. The questions were more of a road map for anticipated discussion topics than a series of specific queries that needed specific answers. Unlike the survey format used for Task 5 in the Research Plan (see Chapter 6 of this report), the question set was more open-ended. The questions sought concepts and specific procedural approaches rather than specific yes-no or fill in the blank type responses.

Category	Questions
Introductions	What is your current position with the DOT?
	What are your responsibilities in that position?
	How many years have you been with the DOT?
	What different experiences have you had with the DOT?
	Did you have any additional training/education prior to joining the DOT?
	Have you had specific training as a DOT employee that you use in making routine winter maintenance decisions?
	What do you consider the important lessons learned during your DOT experience?
Level of Service	What are the level of service guidelines you follow?
	How does LOS vary over different road classes?
	How does LOS vary based upon public expectations?
Materials	What materials do you use during winter maintenance operations?
	What are the DOT guidelines on the use of these materials?
	Do you adjust the guidelines to fit specific needs within your local jurisdiction?
	Do you use liquid chemical applications in your operations?
	Do you pre-wet solids as part of your maintenance program?
	If so, what chemicals do you use?
	What's your normal application rate?
	What changes do you make to application rates based upon specific weather conditions, such as temperature ranges, precipitation rates, and drifting snow?
	If you use grit what are the guidelines for the grit sizing?
	Does the type of grit used change as the weather conditions change?
	What are your application rate guidelines?
	Do you have a requirement for cleanup at the end of the season? At other intervals during the winter?
Equipment	What type of vehicles do you use for winter maintenance?
	What type of equipment do you use for application of chemicals? Grit?
	Do you have the ability to adjust the application rates?
	Can these adjustments be done from the cab?
	What is the range of adjustment?
	Can you monitor the application rates from the cab?
	What type of other monitoring devices do you have in the cab?
	Do the operating features of your spreaders cause variability in the spreading rates and spread patterns during normal operation?
	What types of problems do you experience with your spreading equipment?
	What type of plows do you normally use for snow and ice removal?
	What type of plow configurations do you use?
	Do you use different plows or plow configurations for different winter maintenance situation?
	When do you configure your equipment for winter maintenance?
	Do you change the equipment configurations during normal operations?
	Are there particular issues you have with specific types of plows and/or plow configurations?
Road Reporting	What mechanism do you have in place to officially report road conditions?
	What measures do you take in maintenance operations to report road conditions?
	How does the existing knowledge of road conditions affect your response along specific routes?
	Does existing knowledge of road conditions along one route alter your operational response plans within the entire crew? If so, how?
	Do you record the amount of material that is applied to a specific route?
	How do you report or record what snow/ice removal actions that have taken place?
Scheduling	What are the policies that impact the use of personnel within your operations?
	When there is the potential for a major winter storm lasting more than 24 hours, how do you adjust your scheduling of personnel to fight the storm continually?
	Please describe your planning process from the first indication of a winter storm through the mop up action at the end of the storm. Are there distinct phases in your decision making process?
Weather	What weather elements are most critical in your decision process?
	Do the important weather elements change with different situations?
	Is the weather information available to you adequate to support your decision process?
	Do you use the information from the Road Weather Information System sensors? In what way?
	What other sources do you use to get weather information other than NWS, RWIS, and other data available over the Internet?
Winter Scenarios	Explain your decision process during a major winter storm.
	Explain your decision process during a period of snow squalls and variable snows of an inch or less.
	Explain your decision process during blowing snow situations.
	Explain your decision process during freezing rain situations.
	Explain your decision process during frost situations.
	Explain your decision process during refreeze situations.
Summary	Are there issues that affect your decision process that we have not addressed in this discussion?

Table 4-6 Questions for MDSS Interview Sessions

Interview Scheduling

The set of questions for the interview was completed and approved in May, 2003 and Meridian projected that the interviews could be completed in June and early July. Meridian worked with the coordinators in each state to establish the number of interview sessions in each state, their locations and dates. Because the individual states each had differing philosophies on their mode of participation (section 2.4) the number of interviews and the logistics of getting all personnel to the interview site varied from state to state.

4.7 The Interview Process

The first interview session was done in Grand Forks, North Dakota on June 12, 2003. Meridian met with the supervisors and lead foremen from the Grand Forks and Fargo districts of North Dakota, whom shall be lead participants in the PFS MDSS field test.

In Indiana, the first interview was done in the Monticello sub-district office on June 24 and involved 12 Indiana DOT (INDOT) staff members primarily from the Monticello sub-district or the LaPorte district office. The majority of the participants were operations engineers or unit foremen. The second Indiana interview was held in the Columbus sub-district office on June 25, with 5 INDOT staff, who were primarily the foremen for the sub-district unit garages.

The South Dakota interviews were done in two sessions, the first done in Pierre on August 13 and the second in Huron on August 14. The Pierre session included seven DOT representatives from Districts in the western half of the state. At Huron, there were 7 DOT representatives from the eastern half of South Dakota. Dave Huft, SDDOT Technical Panel member, was also present at both interviews.

The two Iowa DOT (IADOT) interview sessions were held in Storm Lake, one on the 18th and the second on the 20th of August. The interview group included the 8 supervisors from Maintenance District 3 (Northwest Iowa). These eight supervisors will be the lead participants in the PFS MDSS field test.

The first of three Minnesota DOT (MnDOT) interview sessions was held in Brainerd on September 25th. The group included 4 DOT supervisors from the north-central portion of Minnesota plus Curt Pape, MnDOT Technical Panel member. The second session occurred in Mankato on October 6 and included 3 supervisors, a research engineer, and Mr. Pape.

The interviews proved beneficial in providing an overview of the essential elements that concern DOT personnel and gave the investigators an opportunity to learn who the champions were among the field personnel. In many cases the states had already identified these individuals, but it was important for the Meridian team to meet these individuals firsthand and establish rapport for future interactions. The Meridian interviewers also determined that the research plan going forward will need to put greater emphasis on direct contact with a smaller number of champions and field representatives in order to capture the detail necessary to build an effective MDSS.

The other observation the Meridian team made was that the information resources exist in a hierarchical order. The base information (e.g., the maintenance manuals, local policies and practices, and published guidelines) are broad scale and relatively general in nature. As the discussion moves toward the interests of the individual the issues become more detailed and complex. The impact of this assessment is that the MDSS design will likewise need to evolve in a similar hierarchical mode from a simplistic, highly parameterized approach to a gradually more complex, highly modularized solution. Feedback from the interviewees from all states suggested this will be a delicate balance. Those DOT personnel who participated in the interviews indicated an enthusiasm to “try MDSS”. At the same time, these individuals were fairly adamant that they want MDSS to correctly address their critical local issues. The PFS challenge will be to create an effective first pass at a fairly simplistic design level, yet make sure the design is adequately well thought out to permit the addition of a number of sophisticated new components that address the user’s complex local issues.

4.8 Results from the Interviews

This synopsis is an overview of the primary topics discussed in the interview sessions in all five states. The format of the summary follows the set of questions that were developed under Task 3 of the research plan and discussed in section 4.5.1 of this report. The synopsis includes a lead section on Decision Time Spectrum, a topic that was not in the question set but which became a pervasive consideration through all of the interview sessions.

Meridian extends its thanks to the participants from each of the states who were willing to participate in the interviews. The investigators were very pleased with the cordial reception at each of the interviews and the willingness to be open and candid in answering the questions that were asked. The dialog proved extremely informative and touched on issues that were not only critical to the DOT participants but important to the MDSS project as well.

The Meridian investigators realized several key factors as the interview series evolved. These key factors form a thread that winds through many of the discussions below. They are:

- The maintenance decision process is extremely complex and adaptive.
- The operational approaches vary considerably, both across the member states and within each state.
- Policies and procedures control decisions to some extent and these local rules must be an integral part of the MDSS design.
- Maintenance resources (personnel, equipment, and materials) have a tremendous impact on the decision process.
- Short-term tactical decisions represent a greater requirement than mid-term strategic decisions.
- The MDSS design must start as a simple solution and work in phases toward a more complex solution.

- The initial design must understand the ultimate goal and have the appropriate architecture to permit the integration of more and more complex options.

These factors represented a recurring theme in the set of interviews and appear repeatedly in the topic-specific discussions that follow.

Decision Time Spectrum

In the analysis done for the FHWA STWDSR project (discussed in section 4.2), maintenance decisions were separated into three categories classified as Planning, Strategic, and Tactical. Planning included those decisions that were 48 hours or more before an event, Strategic dealt with decisions from 48 hours up until to about 3 hours prior to an event, and Tactical referenced decisions from about 3 hours prior to an event to those decisions being made within the storm.

Discussions in all of the interviews focused primarily on guidance information and decisions in the tactical time frame. A general consensus was that, although a strategic planning toll would be useful in certain situations, once maintenance personnel are into the tactical timeframe factors that were not planned for often arise and the original plan of action becomes void. The one key exception was modification of the shift schedules in conjunction with extended winter weather events which was a strategic decision support requirement. This emphasis on tactical decisions was a very important realization because it indicates that the MDSS design needs to put considerable emphasis on improving the short-term support capabilities and permit a user interface that addresses relatively quick adjustments to a continually updated forecast scenario. It also requires a review of the information exchange process between the forecaster and the end user. Time becomes a critical factor in this design and it becomes important that there is a mechanism to alert users that new decision support information is available.

Level of Service

The Departments of Transportation have well-defined guidelines for the specification of Level of Service (LOS). In Minnesota, the formula is published in their Maintenance documentation. In the other states, there are published maps that indicate the LOS for all DOT-maintained highways, which DOT personnel attempt to meet or exceed those LOS guidelines. Typically the DOT personnel can achieve this objective, but certain stretches or short segments become problematic due to localized weather effects that require considerably more effort to keep highways within the LOS guidelines. DOT personnel indicated concern over the driving habits of both commercial trucking and private vehicles during storms, but especially as LOS levels are returning to “normal”. Because of the variability in driving conditions on routes rated at a specified LOS, DOT maintainers may reach the required LOS for nearly all of a route. However, local situations may cause the road conditions to deteriorate at one or more localized spots more quickly than the DOT can return to these trouble spots. Once the specified LOS is achieved on the dominant portion of the route, drivers return to their normal driving speeds and become complacent about the local problem areas. These actions impact the traveler’s safety and the safety of others. DOT personnel realize this fact but do not have the resources in most situations to address the local problems in the necessary timeframe.

Although the LOS classifications are set by formulas that are mostly based upon traffic volumes, the expectations of drivers may effectively change the LOS requirements along specific routes. The expectation levels of drivers are often higher than published requirements and the verbal or written complaints of these travelers impact the response level performed by maintenance personnel responsible for those roadways. Interviewees cited a number of these situations around major metropolitan hubs where urban drivers or rural commuters have higher expectations than the typical inhabitants of the area.

1-1.1 Materials

The selection of materials to address the broad variety of weather conditions across the five-state region was diverse. Several of the states are migrating from sand/salt mixtures to a salt-only approach. Sand is still used in the colder and less traveled areas where the LOS requirements do not mandate a bare road policy or the prevalent chemicals are not effective during periods of extreme cold, i.e., pavement temperatures (<10 to 15° F). Salt is the preferred chemical because of its cost, but magnesium chloride is used in the western portion of the region. Calcium chloride is used to some extent in extremely cold conditions or as an anti-caking agent in chemical stockpiles. The chlorides are primarily applied as pre-wet solids. Salt brine has become the dominant pre-wetting agent in the salt states, but even in these states magnesium chloride is also used to some extent when weather conditions warrant. With the acceptance of anti-icing practices over the past decade, straight brine applications have become more prevalent. Brine applications are primarily used prior to potential frost situations or before a winter storm event starts; however, the use of brine has become more widespread in urban areas where LOS requirements stipulate bare roads in relatively short time frames. There were also some tests being done with chemicals mixed with corrosion inhibitors or “sticking agents”.

Application rates vary both between states and within states. Many of the interviewees have application rate guides in their vehicles. The guides were typically tables with specific precipitation types/rates on one axis and temperature ranges on the other axis. The values in the cells represented the recommended average treatment rate for those conditions. Whatever the guideline used, it served as a starting point, but most drivers adjusted the spread rates from the guideline rate to fit the existing weather conditions and/or address local problem areas. Drivers are given complete discretion to adjust the application rates based upon their experience and the specific conditions that exist. Typically routes are selected that permit trucks with a specified capacity to make a complete loop leaving only a minimal amount of material left in the bed.

The important considerations about materials were the wide diversity of materials and rates used and the fact that chemicals are used in conjunction with other materials or chemicals. The selection of the appropriate material or combination of material depends on inventories and the specific road condition or weather condition at hand. Policies and practices also influence the decision in consort with political pressure for bare pavements. The choice of materials for a particular run is a combination of experiential factors from the previous run and an assessment of the forecasted conditions over and beyond the period of the ensuing run. The material for a particular run is a tactical decision based upon conditions from a broader perspective (e.g., a time window 4 to 6 hours— start of previous run to end of next run) and the associated application rate derives from a combination of DOT guidelines, experience from the previous run, and point by point observation of existing conditions during the current run.

1-1.2 Equipment

During the interviews, discussion generally did not focus on the exact equipment used in plowing operations and the application of chemicals. This information needs to be gathered in detail and the specific characteristics of each piece of equipment recorded in follow-up conversations. DOT personnel who participated in the interviews did specify the type of equipment they use and some of the advantages and disadvantages.

There are a number of plowing configurations that may be used and a number of these were discussed during the interview process. Each configuration has unique characteristics along with pros and cons for specific situations. The performance of a given plow is dependent upon several variables such as the blade type, shoe settings, downward plow pressure, angle of plow blade, plow speed, and the character of the plowed surface. Performance seems to be particularly affected by plowing speed. Slower speeds reduce the bounce and provide a more uniform plowed surface. Participants estimated that the residual layer after plowing is typically around 0.15 - 0.25 inch under proper plowing scenarios, but the amount can vary considerably. Further information is needed for underbody plows, wings, snow blowers, and other snow removal equipment.

The equipment to apply materials was also quite diverse and the approaches using the same equipment also varied. The investigators need to gain a better understanding of the details of materials application and work with the individuals who participated in the interview process to compile a detailed understanding of application processes and the characteristics/performance of the various application devices. This information gathering process also needs to capture the various modes of controlling the application rates both externally and in the cab.

DOT participants discussed several different methods of applying materials and some of the pros and cons of each. The primary methods addressed included spreading using spinners, furrowing using chutes, liquid sprays, and liquid drip. The collection of detailed information needs to be continued for the variety of application techniques used by the five states. Participants in the interviews did not have a good feel for the amount of chemical that actually stays on the road in different application situations. They had a general sense of how much remained; the quantitative estimates are a function of several application, surface condition, weather condition, and traffic factors. The participants and investigators need to work together to better define the true application rate onto the paved surface.

1-1.3 Reporting

All states have a method in place to record the amount of material applied by a given vehicle/driver during a specified period of time. Most states log the information after each run and accumulate the information for one or more days before transferring the data to a central location, either in an electronic form or a hand written log. The information at this point is primarily for material inventory purposes or validation of operational practices. The logging system is not designed to provide immediate or end of run feedback to a monitoring system.

The maintenance divisions in Minnesota, North Dakota, and South Dakota participate in the road reporting process. The State Patrol provides this input in Indiana and Iowa. The program was seen as a benefit to the traveling public and not of much value for DOT operations.

Iowa, Minnesota, and North Dakota have, or will have, a deployment of vehicles fitted with Automated Vehicle Location (AVL) equipment during the winter of 2003 - 04. In addition to the vehicle location component the programs incorporate logging systems to monitor and telemeter a number of maintenance activities. Minnesota plans to place some of their test AVL units in the Pooled Fund MDSS field test area to minimize the amount of information that needs to be logged by maintenance personnel in the test area.

Real time reporting is not a high priority in the current operational scheme. As one of the five primary components of the MDSS design, access to the current operational status is an important factor in the performance of the decision support system. The investigators and DOT personnel involved in this program need to work closely in the design and development of an automated logging program that not only benefits the MDSS program but also provides dividends for road condition reporting requirements, inventory control, validation of operations, and archival of maintenance practices. The last category provides a database to permit assessment of the performance of different maintenance approaches.

1-1.4 Scheduling

Maintenance personnel indicated scheduling personnel and equipment is a critical factor in the effective performance of a maintenance unit. The availability of crew and equipment may also impact route schedules and may drastically change the operational plan for the day as resources are reallocated to address the lost resource. Maintenance decisions may require as much or more consideration regarding the effects of resource limitations than what the impact of weather conditions will cause.

One decision that is driven by weather is the response to a forecasted weather event that is projected to affect the local facility for an extended period (12 hours or more) or which is projected to start at certain critical times in the DOT's normal shift schedule. Weather events that impact rush hour or special events often require adjustments in the schedule to assure adequate resources are available to eliminate or minimize the impact of the storm. The rules for schedule modification are not consistent from facility to facility. It will be necessary to capture a number of different scheduling approaches and then develop a method to integrate the rules used for the wide spectrum of factors that determine how and when the schedule needs to be adjusted.

1-1.5 Weather

Accurate weather forecasts were almost universally the primary wish of all maintenance personnel involved in the interview process. Many of the participants have become somewhat callous to winter forecasting because the forecasts do not live up to their expectations or because they have been negatively impacted by forecasts that did not verify. Some participants have turned to other weather resources to assist in their decision process. Radar imagery is accepted as a good optional tool to a weather forecast, although DOT users admitted they have difficulty interpreting the radar imagery at times, especially during winter situations. Weather information from the relatively dense RWIS networks in a couple of states has assisted a few users in their decision process.

The value of the Meridian forecasts is the projection of the pavement temperatures during critical weather situations. Several users indicated they have come to rely on the RWIS data and the forecasted pavement temperatures to assist in their decision process. The Meridian investigators also work with the weather and pavement data plus the numerical guidance that supports the value added forecasts provided to the five member states. The investigators see merit in the combined use of observed data and value-added forecasts and suggest that a training program on how to integrate the value of both approaches may provide users greater value from the available resources.

Winter maintenance is driven by different weather factors in different weather conditions. Precipitation start and stop times are critical to effectively respond to typical winter storm events whether they are a major storm or a brief disturbance of an inch or less. However, once there is loose snow on the ground wind becomes the key concern. Rapidly falling air and pavement temperatures create a completely different concern that must be addressed properly or pavement conditions can become major maintenance issues. These are but a few of the different decision scenarios. The response may be quite different for each of these meteorological conditions and the decision support logic will need to address this fact. Further work is needed to classify weather situations, understand the appropriate maintenance response and the reason why this response is effective while others are not.

1-1.6 Winter Scenarios

Time did not permit detailed discussion of the decision process at various stages moving into and through each of the winter scenarios. Meridian still needs to extract this information to guide development of the decision logic pattern. However, participants were asked to rank the 6 scenarios listed on the interview question sheet indicating which situation caused them the most problem. Three categories seemed to garner about equivalent response levels:

- blowing snow
- freezing rain
- refreeze

Participants from the plains states indicated blowing snow was their most critical issue. Freezing rain when it did occur was also a big problem. In the more sheltered areas of all states where wind was not a problem, freezing rain was viewed as the worst scenario DOT participants had to deal with. Refreeze was selected at a scattered set of locations. Although some of the explanations of refreeze issues dealt with snow melt and subsequent refreeze, the majority of the respondents highlighting refreeze saw the combined effects of blowing snow, residual chemical, and traffic as their primary refreeze issue. Winter storms were considered a concern, but usually the respondents indicated they knew the storms were coming and just worked through the storm to bring the roads back to a safe driving state. Situations that surprised the maintenance personnel were seen as most problematic.

4.9 Recommendations

Meridian investigators collected a huge amount of input during the nine interview sessions and expanded their individual knowledge of maintenance practices considerably. However, it was obvious to each of the Meridian team involved in the interview process that the interviews were generally overview in nature. Because of the free format, discussions did get into specifics on one or two questions in each session. In general, the answers were informative but did not provide the specific detail necessary to complete the response definitions discussed in section 4.4.2. In particular, the interviews demonstrated the need for specific information on chemicals and the various mixtures used, types of equipment used to apply materials, types of plows and plowing techniques, level of service requirements, personnel scheduling guidelines, reporting procedures, communications, and local practices and procedures. All of these details need to be captured and integrated into the need knowledge base. Meridian recommends that the information acquisition program continue into Phase II with the stipulation that the data collection process become a series of detailed information collection efforts, each addressing specific components of the broader knowledge base. To accomplish the collection of the detailed data and minimize the time and effort, Meridian recommends that the collection process occur via two separate mechanisms: an interactive web site and direct phone conferences. The web site would act as an interactive questionnaire plus provide guidance on methods to submit detailed information. The direct teleconferencing would permit one or more participants to interactively discuss specific topics in detail.

CHAPTER 5: ASSESSMENT OF ROAD CONDITION REPORTING CAPABILITIES

Task 4 - Assess the participating states' current and near-term capability to report current roadway conditions and track maintenance activities on specific highway routes.

5.1 Importance of Information on Roadway Conditions and Maintenance Activities

The development of MDSS involves an integration of data and information that reflect the roadway environment and how it is changing. While it is clear that the influence of weather is a dominant element within a maintenance decision making process, the state of the roadway and methods used to maintain the roadway are no less critical in producing an effective and efficient maintenance program. Studies conducted in Iowa by the National Laboratories for the Functional Prototype during the 2003 winter, underscored the critical importance of obtaining quality, fine resolution (spatial and temporal) maintenance data for a successful MDSS. Developing programs to gather current roadway conditions and to track maintenance activity along specific highway routes will be crucial not only during Pooled Fund Study development but also during the transfer of this system into an operational deployment.

The work of the Pooled Fund Study (PFS) has included a preliminary assessment of the state of capability of current roadway condition reporting and maintenance tracking activities found within each of the PFS states. This information was collected from various sources found within each state including the Pooled Fund Study Technical Panel and through interviews with maintenance personnel within each participating state DOT. Limited information was also collected from information technology personnel within North Dakota and South Dakota. Information sought during the assessment included identification of existing road condition reporting systems in each PFS state, how the information is gathered and the frequency of the collection process. Of particular interest for the Pooled Fund Study is the availability of this information and the speed by which this information is made available for integration with the decision support process.

5.2 Road Condition Reporting

Table 5.1 summarizes the information gathered on existing PFS road condition reporting activities within the five participating states. While each state has a road condition reporting system, a significant variation exists between states as to the method of recording the information and providing the information that is collected. All five states collect road condition information through a radio link to a centralized location where an individual stores the information in the road condition reporting system. For Iowa and Minnesota who use the Condition Acquisition And Reporting System (CARS), a pooled fund project lead by the Iowa DOT, the system involves entering the road condition into a central database that provides immediate user updates of road condition information.

State	Existence of Reporting System	Method of Information Gathering	Method of Recording Information	Frequency of Information Collection	Method of Report Distribution	Frequency of Information Distribution
Indiana	Yes	Radio Receipt from DOT and State Patrol	Manual transcription of reports	Continuous as reported	Web (State Police), Media, Telephone	Every 4 hours except when more frequent updates needed
Iowa	Yes	Radio Receipt from DOT and State Patrol	CARS	Continuous as reported	Web, 511, Media	Near real-time
Minnesota	Yes	Radio Receipt from DOT and State Patrol	MnCARS	Continuous as reported	Web, 511, Media	Near real-time
North Dakota	Yes	Radio Receipt from DOT and State Patrol	Manual transcription of reports	As reported between 6 AM and 9 PM CST	Web, 511, Media	5 times daily between 6:30 AM CST and 9:00 PM CST with updates as warranted
South Dakota	Yes	Radio Receipt from DOT and State Patrol	Manual transcription of reports	During discrete periods of 5:30 AM-7:15 AM CST, 10:30-11:30 AM CST, and 3:30 PM-4:30 PM CST unless otherwise warranted	Web, 511, Media	3 times daily between 8:00 AM CST and 5:00 PM CST with updates as warranted

Table 5-1 Summary of Existing Road Condition Reporting Activity in the Pooled Fund Study States

The remaining Pooled Fund Study states collect information for publication at preset times during the day through a more time consuming and labor intensive process of transcribing radio reports into a text message format. Collection of the information involves the use of radio communications having distance limitations and potential coverage difficulties in more remote state locations. In all PFS states the method of report distribution includes the use of the World-Wide Web, the media and telephone. The road condition information for each state can be found at the following web addresses:

- Iowa: http://www.iowaroadconditions.org/
- Indiana: http://www.ai.org/isp/roadinfo/weather.html
- Minnesota: http://www.511mn.dot.state.mn.us:8080/MN_TRIP/index.jsp)
- North Dakota http://www.state.nd.us/dot/rrs_mapc.html
- South Dakota http://www.sddot.com/Operations/Road_Condition_Report/index.htm

For all of the states except Indiana the information is available on the state's 511 traveler information telephone system. The frequency of information distribution closely parallels the data collection frequency with Indiana, Iowa and Minnesota providing around-the-clock support while the information from North Dakota and South Dakota is limited to approximately the normal DOT business hours.

While each Pooled Fund Study state has an established road condition reporting system, the manually intensive systems in Indiana, North Dakota and South Dakota do not provide sufficient databases of information to be of significant use to the Pooled Fund Study due to the lack of high frequency update times and the difficulty in representing the data in a consistent manner that follows

ITS road condition reporting standards such as the Traffic Management Data Dictionary (TMDD) or the emerging Advanced Travel Information System (ATIS) standard. The states of South Dakota and North Dakota are working to implement road condition reporting database systems with the South Dakota system to be available during the 2003-04 winter and a system available in North Dakota by the 2004-05 winter. No plans exist at present to implement a road condition reporting database system in Indiana.

5.3 Maintenance Activity Tracking

The maintenance activity tracking capabilities found within each of the Pooled Fund Study states are predominately limited to manual reporting of treatment activities using a post-shift reporting method. No statewide maintenance activities database exists in any of the states. None of the states utilize a routine automated maintenance activity tracking capability although Iowa has demonstrated such a system in the past through their Advanced Snowplow Concept Vehicle. This vehicle can provide remote updates from the maintenance vehicle that is equipped with a global position system receiver, temperature sensors, and a friction meter; however, due to the cost constraints of data collection from these vehicles has been limited. The Minnesota DOT will be deploying a limited number of sensor-equipped maintenance vehicles with data transmission capabilities during the 2003-04 winter and the North Dakota DOT is exploring the use of automated vehicle location capabilities with sensor-equipped maintenance vehicles beginning during the 2004-05 winter. At present there are no indications that a database is being planned that would be available for housing the data collected and making this information available.

At a minimum, a successful MDSS must have access to information that temporally and spatially identifies the maintenance activities that are underway, that have been completed or that are planned. Ideally, this information would reside in a dedicated database with published standards and having appropriate query interfaces to permit maintenance activities to be integrated within the decision support environment. As presented above, the present methods to collect this information are slow and tedious in the limited areas where such information even exists and none of the information resides in a database available to the Pooled Fund Study. Just as road condition information is now becoming a major thrust in data collection and dissemination, so too must the collection of maintenance activities be performed. To do this will require careful consideration and planning, which takes into consideration the present DOT information technology capabilities, budget constraints and support within maintenance personnel staffing. The minimum information needed to support MDSS efforts will include the 1) location of maintenance vehicles along routes at specific time intervals, 2) treatments made, including type of material and the application rate, and 3) plowing operations that are occurring. This information must be provided in an update time interval sufficient to provide support to pavement condition models that depend upon the level of maintenance applied to the pavement and the frequency of these treatments.

5.4 Recommendations that close the gap between existing capabilities and MDSS requirements

Given the significant effort required to establish the necessary data communications and data collection protocols to create near real-time road condition reporting and maintenance activity databases, it is believed this activity is critically important to the Pooled Fund Study. The prospects for South Dakota and North Dakota implementing a road condition database system suggests that only the Indiana DOT will not likely have such a system available in the near future. A challenge still remains for those states having such systems, because the systems exist within differing databases which make it necessary to develop translators for each before the information can be utilized within the Pooled Fund Study. With respect to the maintenance activity tracking, the Pooled Fund Study states are much closer in capabilities. For the states of Iowa, Minnesota and North Dakota, who have either demonstrated or are planning to demonstrate a capability of automatically collecting maintenance vehicle activity information, it is strongly encouraged that efforts be coordinated between the state DOTs to produce database standards that support Pooled Fund Study efforts. It will then be incumbent upon the remaining states to determine a method that will permit them to adopt a similar maintenance activity tracking capability. A recommendation of the Phase I work is for the development of a maintenance activity database from information collected either manually or electronically from maintenance vehicles in each Pooled Fund Study state DOT.

CHAPTER 6: INSTITUTIONAL RECEPTIVITY TO MAINTENANCE DECISION SUPPORT

Task 5 - Assess institutional receptivity to maintenance management decision support in the participating states and recommend actions to overcome potential barriers..

6.1 Requirement

During the initial discussions leading up to the decision to proceed with the Pooled Fund Study (PFS), representatives from the states were uncertain how field personnel might perceive the integration of a Maintenance Development Support System (MDSS) into their normal operations. These state representatives were firmly behind the development of the MDSS but felt that it was important to understand the perspective of the field personnel regarding MDSS and other new technological solutions to support maintenance. From those early discussions and the first meeting of the Technical Panel, the PFS team placed high priority on the collection of a solid assessment of perception of technological change within the entire spectrum of personnel within their states. This chapter reviews with the development and the results of the survey conducted to assess these perceptions.

6.2 Selection of an Information Collection Technique

Research into the different styles and methods of designing, conducting and analyzing surveys ranged from searching the Internet to personal interviews. Research sources included:

- staff at the Center of Innovation, including Della Kapocius, Grant/Research Consultant, and Brenda Badman, Marketing Consultant, who have designed, reviewed or conducted multiple surveys
- Dr. Robert Tangsrud, Assistant Professor at the University of North Dakota in the Department of Marketing, provided general information on market surveys and provided a textbook titled “Market Research”.3
- Creative Research Systems at http://www.surveysystems.com
- StatPac Survey Software at http://www.statpac.com

The research indicated that survey questions must not show bias or in any way attempt to direct the replies given. The approach would have to be consistent, using similar phrasing in the question constructions and similar procedures for acquiring the answers, particularly in how the recipient is asked to tally or mark their responses. Some questions may be ranked on a scale of 1-10 giving a description on each end of the ranking as to the inference. Other questions should provide a list of entries to be ranked from most to least importance.

Using the resources listed above, the following elements were used within the design and delivery of the survey for Task 5:

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[3] *Market Research,* Alvin C. Burns and Ronald F. Bush, Prentice Hall, 1998—ISBN -0-13-896606-0, 661 pgs.

- Goals & Objectives—These were defined in the development of Task 5 in the research plan;
- Methodology—Timing and possible lack of Internet access indicated that the best method of delivery would be through the mail. Since some of the questions pertained to technological receptivity, it was also deemed possible that an Internet-based survey might provide skewed results in that those most likely to respond would likely be those most comfortable with using a computer. Delivery through the mail required that recipient names and addresses be provided by each state;
- Target audience—This was determined by each state;
- Length of survey—Research indicated that shorter surveys received a better percent of return but if the topic is deemed of importance to the surveyed, they will take the time and effort for a longer survey. For the Task 5 survey the number of questions and the style in which the responses were requested evolved into a three page survey;
- Questions—Focus should be on a single issue or topic; questions need to be fairly brief, clear and concise and not open to multiple interpretations; questions need to use core vocabulary of the audience and be grammatically simple sentences;
- Confidentiality—It was determined that this would be accomplished by assigning an identification number to each survey that would in turn relate to the individual completing the survey. Meridian will maintain this list. The survey responses were tabulated and then individual surveys were destroyed since the analyses were conducted on the whole population and not the individual responses;
- Approval by the Technical Panel; and
- Production and Delivery—This must be presented in a fashion that tells the survey recipient that the survey is important enough to warrant his or her response.

6.3 Development of the Survey

Meridian created the survey using the information gathered in section 6.1. The primary intent of the survey was to assess user receptivity to technological change and MDSS in particular. The survey design team determined it was important to assess the existing environmental background (relating to computers and communications), the user's perception of existing tools (policies, decision support information resources, communications, and computing resources), and the user's view of new technology and its impact on daily operations. To facilitate analysis of the survey, the team also felt that the collection of non-intrusive demographics (job title, years of experience, age, and location) was needed. There were multiple modifications and reviews of the document before the first draft document was shared with North and South Dakota Technical Panel members at a meeting on February 21st. Information to be gathered included how decisions were derived, levels of computer interaction, policy and procedures guideline usage, and perceived needs.

The draft survey was sent to the Technical Panel members who responded with some modification. This iterative editorial process went through three cycles during April and May and was tentatively approved on May 29th. The survey was distributed to a small list of recipients within the state of

North Dakota on June 5th. After closer scrutiny by members of the Technical Panel, Meridian received notification that the survey needed further modifications to better satisfy the design requirements in section 6.1. Meridian redrafted the survey with the assistance of Mr. Dave Huft (SDDOT Technical Panel Chair). The redrafting resulted in a survey where the majority of the content remained the same but the display format and question structure differed from the survey that was distributed to personnel from the North Dakota DOT.

6.4 Implementation of the Survey

Once the question set was completed for the survey, the surveys were composed electronically and prepared for distribution. Each of the state coordinators took the responsibility to develop a distribution list for their state. The decision had been made that Meridian would distribute the lists by mail; this meant that the surveys needed to be mailed to a recipient. However, one of the objectives of the survey configuration was to retain confidentiality. Meridian prepared a letter for inclusion with each one of the surveys that included instructions on the survey and a statement that:

1. respondents were to remain anonymous and therefore should not put their name or signature on the survey,
2. the demographic information requested was for survey analysis only; and
3. once the information from the response sheet was entered into a spreadsheet the original would be destroyed.

A couple of the states provided Meridian a complete mailing list; the remainder asked that a packet of surveys be sent to supervisory personnel in a district or sub-district. The packet might contain 2 to 6 surveys for distribution to lead field operators or other supervisors in the same operational unit. Because the distribution format was different in each state, Meridian had to adjust the demographics questions on each of the five state survey sets to assure that either through the mailing address or through responses on the survey that the required demographics information could be recorded on the analysis sheet. The combination of the slight differences in the demographics section of the survey and the need for a state-specific cover letter meant that the distribution of surveys was unique for each state. This did not pose an issue because Meridian received the distribution lists over a period of time and no two states delivered their mailing lists at the same time.

Once Meridian received a mailing list from a state coordinator, the distribution team set up by Meridian quality controlled the list and requested clarification on any addresses that were questionable. Once the mailing list was evaluated, Meridian could count the number of surveys that needed to be printed and the number of separate mailings required. The distribution team printed and numbered each of the surveys and recorded the survey number and its delivery location. They printed the mailing labels (specifically designed with no reference to Meridian or any of the participating states), affixed the labels and postage on the envelopes, and mailed the surveys. Meridian inserted enough postage paid, return envelopes in each mailing envelope to allow each respondent to complete and return the survey. Surveys were distributed within one working day from the receipt of the mailing lists. The number of surveys and the mailing date are shown in Table 6.1.

The date for North Dakota is for the second survey. The original distribution of 28 surveys on June 5, 2003 was not considered as part of the eventual analysis.

State	Surveys Mailed	Date
Indiana	266	June 28, 2003
Iowa	159	July 28, 2003
Minnesota	227	July 14, 2003
North Dakota	179	October 23, 2003
South Dakota	331	June 18, 2003

Table 6-1 Surveys Mailed to States

Approximately four percent of the 1162 surveys mailed out were returned by the Postal Service as undeliverable. Meridian, working with the state coordinators, was successful in obtaining correct addresses for half of these undeliverable surveys and having them successfully delivered the second time.

6.5 Analysis of Survey Responses

Answers from the returned surveys were logged in a spreadsheet and consolidated into totals for each answer on the survey. The consolidation was done for each state, thus this report illustrates the number and distribution of answers for each question by state in order to portray the similarities and differences between answers from DOT personnel in the five member states. For those questions where answers were ranked from 1 to 10, this report presents both (1) the number of responses in each decile answer category and the per cent of the responses for each state that fall within each of the decile answer categories. The format used for the presentation of the results includes:

- a restatement of the question;
- the qualifiers represented by the end points of the answer range as written on the survey (this was left off the Yes/No questions);
- the bar charts containing the results;
- an analysis and discussion.

The results from all of the states were summed on the spreadsheet and percentages were derived from the entire set of responses. Information from these composite averages appears in the analysis and discussion section of several of the questions.

The survey sent to North Dakota preceded the survey that was sent to the other four states and contained a slightly different set of questions than was used by the latter surveys. Where a question occurred on the North Dakota survey that was exactly the same as one on the other four surveys, the results were included in the graphics and discussions. North Dakota is in the process of re-issuing the survey that was distributed to the other states.

The report represents the results from the surveys returned from the respondents. The report does not contain any evaluation of statistical significance of the data other than what one can confer from observation and intuitive correlation of answers.

Policies and Procedures

QUESTION 1: BASED ON YOUR EXPERIENCE AND EXPERTISE, HOW WOULD YOU RATE THE USEFULNESS OF YOUR DEPARTMENT'S CURRENT "PUBLISHED" POLICIES AND PROCEDURES FOR WINTER MAINTENANCE ACTIVITIES (RATE ON A SCALE OF 1 TO 10)?

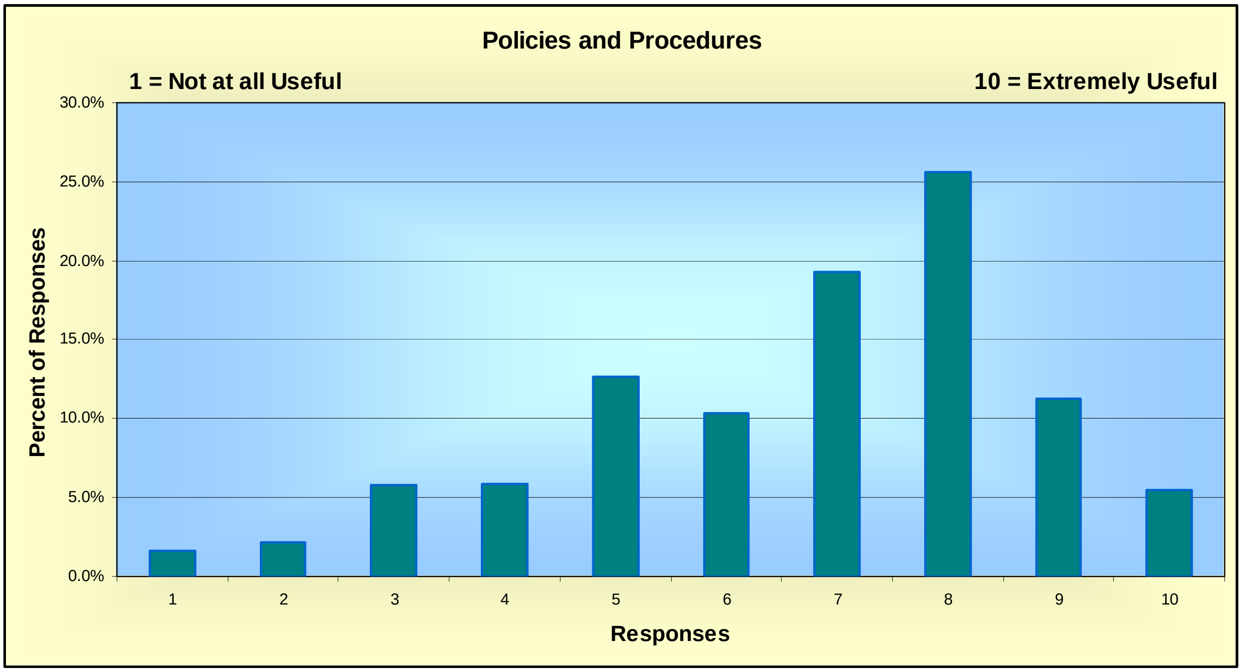

Figure 6-1 Perceived Usefulness of DOTs' Policies and Practices

Over 50% of all respondents rated the usefulness of the policies and procedures in their state as 7 or higher indicating the "published" policies and practices are considered very useful in guiding maintenance decisions. The average response was 6.68.

Use of Policies and Procedures

QUESTION 2: DO YOU GENERALLY FOLLOW YOUR DEPARTMENT'S FORMAL WINTER MAINTENANCE POLICIES AND PROCEDURES OR DO YOU MODIFY THEM TO ADDRESS LOCAL MAINTENANCE ISSUES (RATE ON A SCALE OF 1 TO 10)?

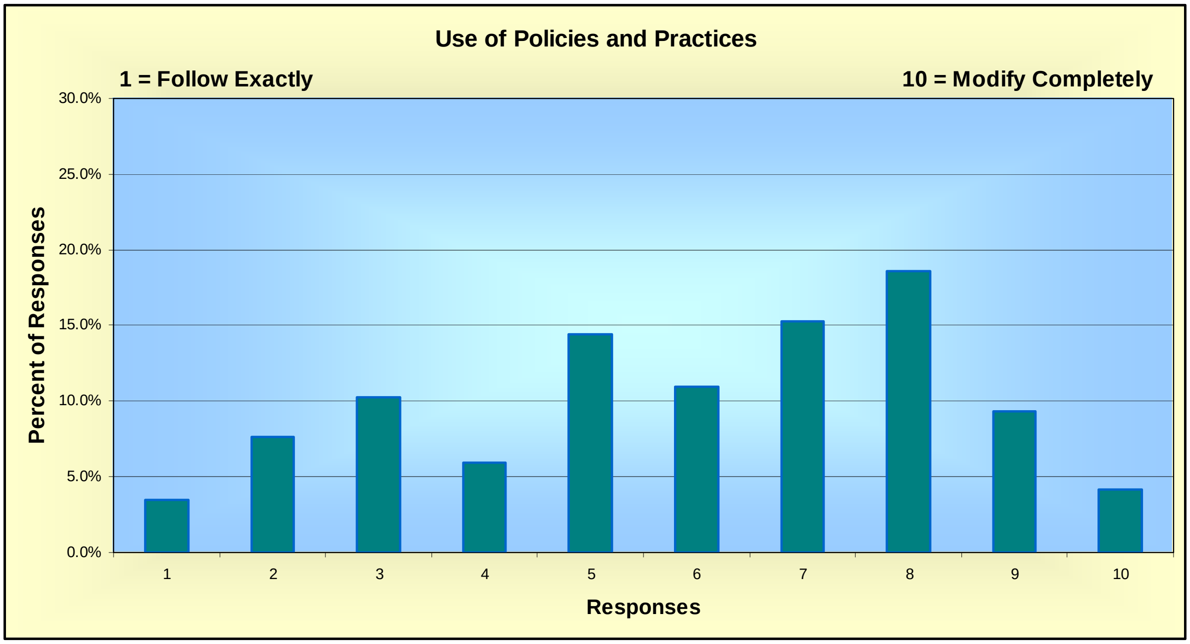

Figure 6-2 Use of Policies and Procedures

Responses from all five states tend to indicate two separate response categories. Although the dominant response is on the side of modification of "published" policies and procedures, there is a significant portion (40%) of the respondents who tend not to deviate from the "published" guidance (answer of 5 or less). The average of all answers was 5.9. Responses from individual states have much the same distribution as the total, although Minnesota, North Dakota, and South Dakota all demonstrated a bimodal distribution. Demographics were stored in the spreadsheet but were not used on the analysis prepared for this report. The next step in the analysis will be to process the data again using demographic filters to assess whether differences caused by job description or geographic location create different emphases.

When the first two questions were evaluated together, they offer an interesting assessment of how policies and practice fit into maintenance operations. Question 1 demonstrated that users viewed the state's policies and practices as important guidelines for their work, yet more than 50% of the users indicated they modify the policies and practices to address their local requirements.

Receptivity to Improvements

QUESTION 3: HOW RECEPTIVE IS YOUR ORGANIZATION TO SUGGESTIONS FOR IMPROVEMENTS TO CURRENT METHODS AND SYSTEMS (RATE ON A SCALE OF 1 TO 10)?

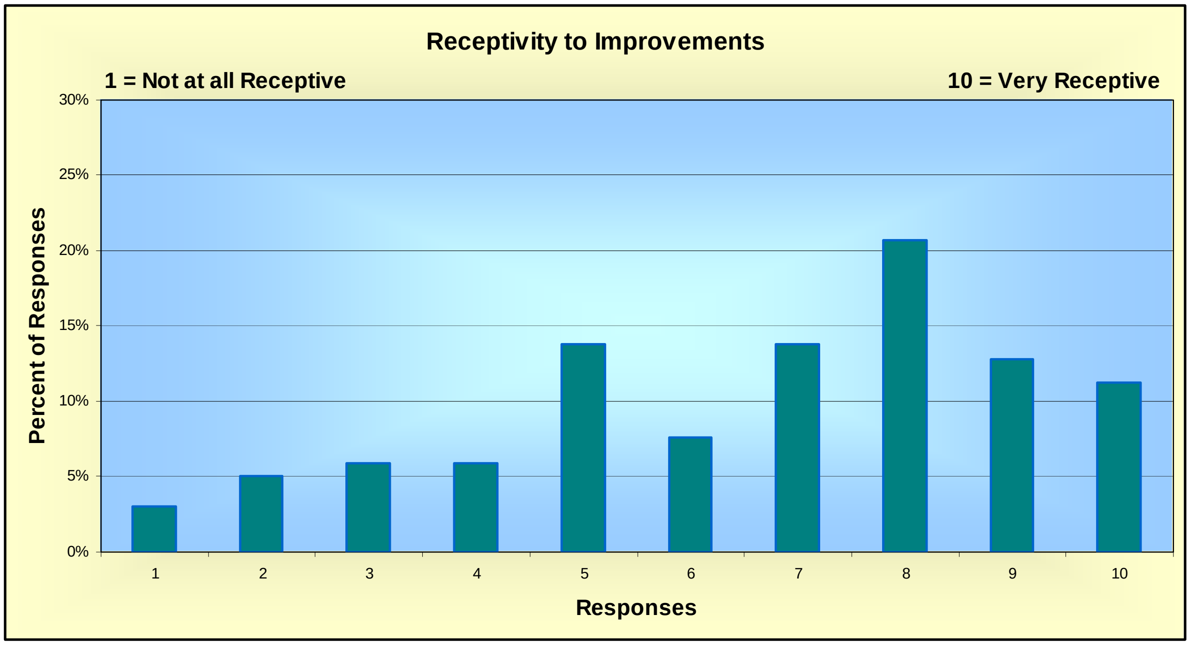

Figure 6-3 Receptivity to Improvements

The responses indicate that the surveyed DOT personnel feel their organizations are quite receptive to suggestions for improvement. Forty-five (45) per cent of all responses were decile ranking 8 or greater and the average answer was 6.6. The percentage of respondents who felt their organizations were not very receptive to improvements was 21% (decile class 4 or less). It is interesting that there is a slight spike for an answer of 5 which was a characteristic shown in the individual plot from each state.

Comfort with Computer Technology

QUESTION 4: PLEASE INDICATE YOUR LEVEL OF COMFORT WITH DESKTOP COMPUTER TECHNOLOGY (RATE ON A SCALE OF 1 TO 10).

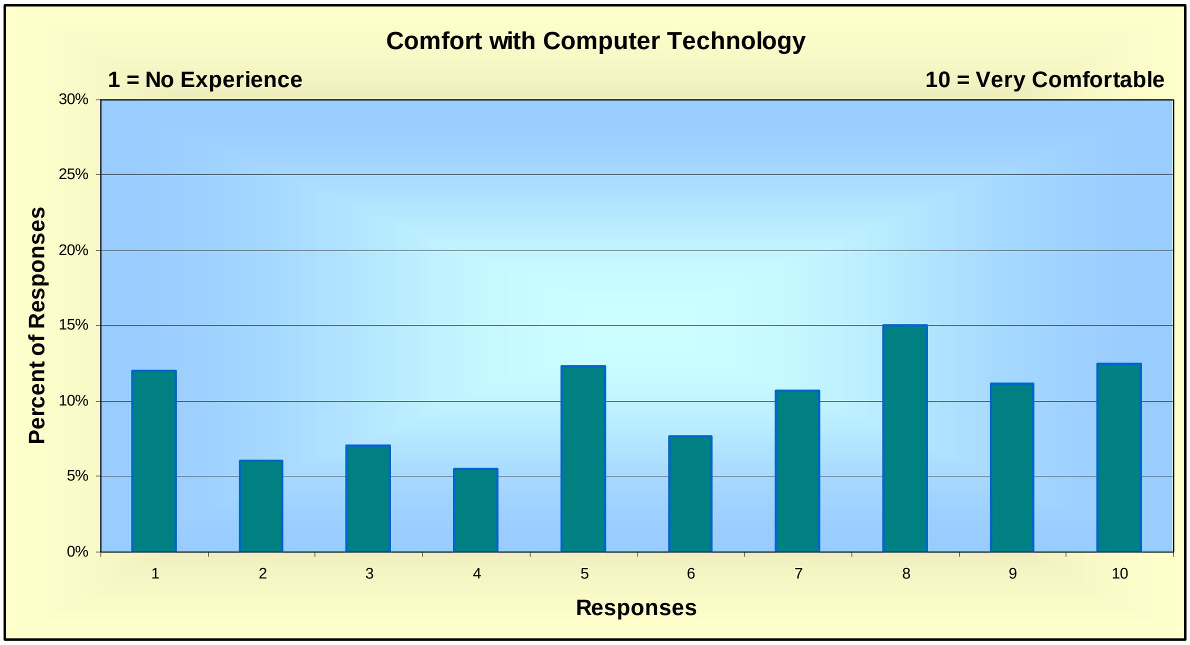

Figure 6-4 Level of Comfort with Computer Technology

The majority of respondents indicated they were reasonably to very comfortable with desktop computer technology (58% responded with decile answers of 6 or greater) with 40% indicating a strong comfort level (decile ranking of 8 or greater). However, responses from Indiana and South Dakota suggest there were a significant portion of respondents within those states that are not comfortable with desktop computer technology. The nearly 20% responding with answer 1 for each of these states (not shown) suggested that these users may not have access to computers in their operations or at home. In Indiana the group with absolutely "no experience" seems to be isolated from the remainder of the staff who demonstrate a similar response curve above answer 1 as do the states of Iowa, Minnesota, and North Dakota. At the time of the interviews in Indiana during the summer of 2003 personnel in the sub-district offices had access to computers but users at the unit level did not. In South Dakota 59% of the respondents indicated a comfort level of decile 5 or less.

Level of Coordination

QUESTION 5: PLEASE INDICATE THE LEVEL OF WINTER MAINTENANCE COORDINATION BETWEEN YOUR SHOP OR OFFICE AND SURROUNDING SHOPS OR OFFICES (RATE ON A SCALE OF 1 TO 10).

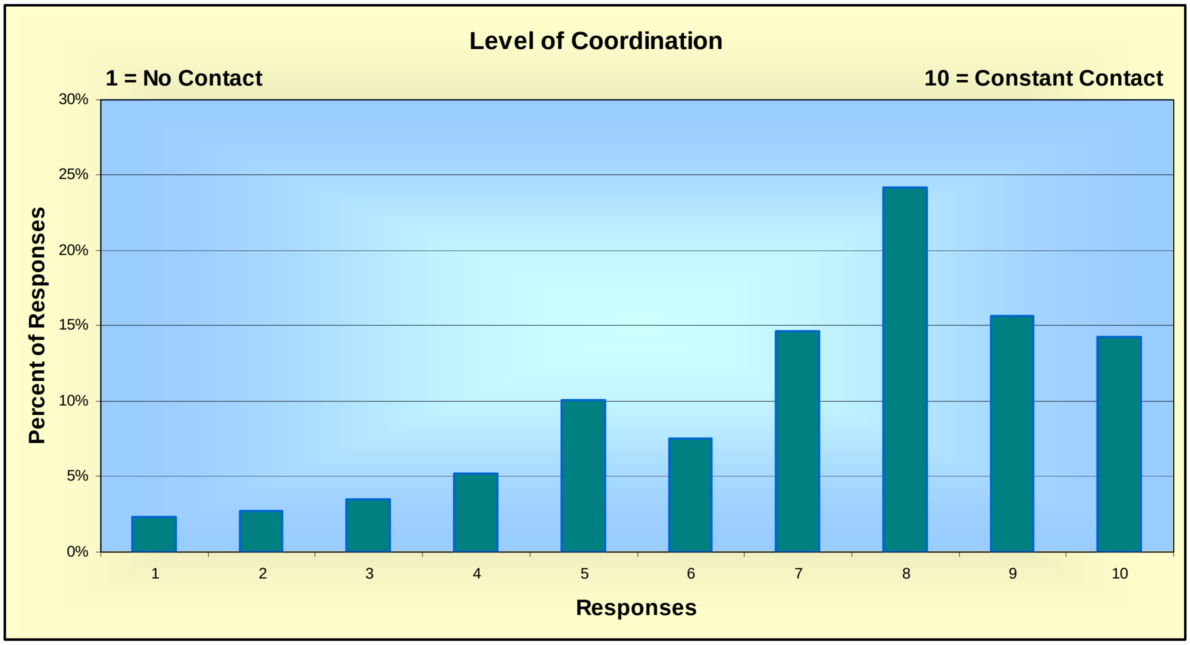

Figure 6-5 Level of Coordination between Shops or Offices

Nearly constant contact between agencies seemed to be the operational norm across all five states. The average response was 7.1 with 69% of all respondents answering 7, 8, 9, or 10. Very few seem to operate with minimal communication; demographics may assist in isolating those responses to provide a geographic reason why communication is limited.

Quality of Information

QUESTION 6: HOW WOULD YOU RATE THE QUALITY OF INFORMATION YOU RECEIVE TO HELP YOU MAKE DECISIONS TO DO YOUR JOB IN WINTER MAINTENANCE (RATE ON A SCALE OF 1 TO 10)?

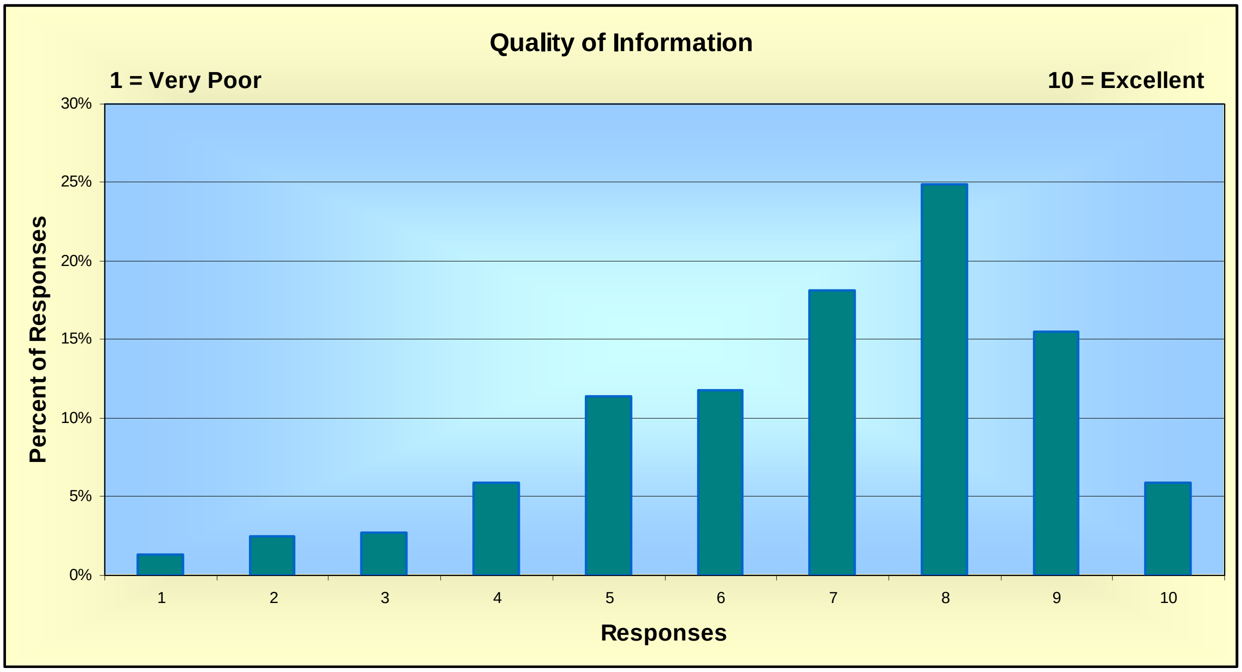

Figure 6-6 Quality of Information Received for Decision Support

Respondents viewed the quality of the information they receive as very good. The average response was 6.9 for all states with 65% responding with answers of 7 or higher and 75% responding with answers above the average (6 or higher). The results indicate that respondents feel that when they assess the entire set of information which they use to make decisions, the information itself is very good. The question addresses the integration of user's perspectives to all source material. Question 11 of the survey looks at the user's perception of several of the key components of the entire set of information.

Timeliness of Information

QUESTION 7: HOW WOULD YOU RATE THE TIMELINESS OF INFORMATION YOU RECEIVE TO HELP YOU MAKE DECISIONS TO DO YOUR JOB IN WINTER MAINTENANCE (RATE ON A SCALE OF 1 TO 10)?

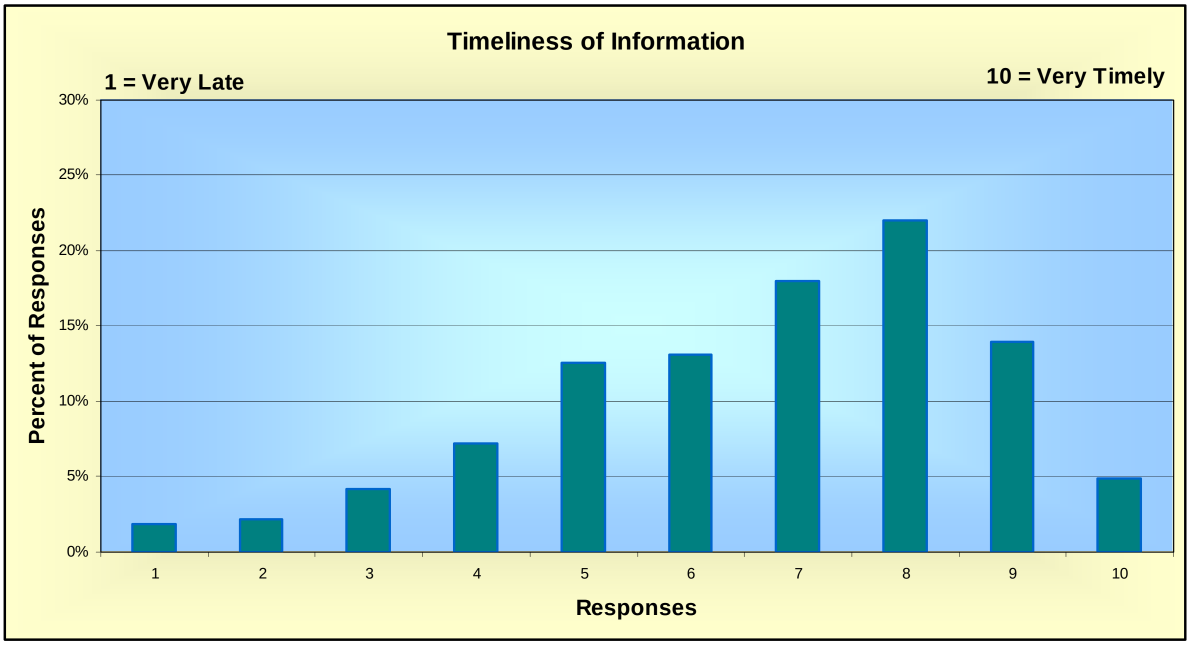

Figure 6-7 Timeliness of Information Received for Decision Support

Respondents viewed the timeliness of the information they receive as reasonably good but not as good as the quality in question 6. The average response was 6.7 with 57% or the responses 7 or higher and 71% indicating 6 or higher. Iowa, South Dakota, and North Dakota had bimodal distributions. The dominant pattern duplicated the composite pattern above but each of these states had a secondary maximum at a response of 5. When the analysis is redone with the demographics filters applied, the results may assist in understanding what factors may cause this separation in the sense of timeliness of information.

Value of Technology

QUESTION 8: CONSIDERING RECENT DEVELOPMENTS IN TECHNOLOGY IN THE TRANSPORTATION INDUSTRY, HOW HELPFUL DO YOU THINK TECHNOLOGY COULD BE IN ASSISTING YOUR DECISIONS IN WINTER MAINTENANCE (RATE ON A SCALE OF 1 TO 10)?

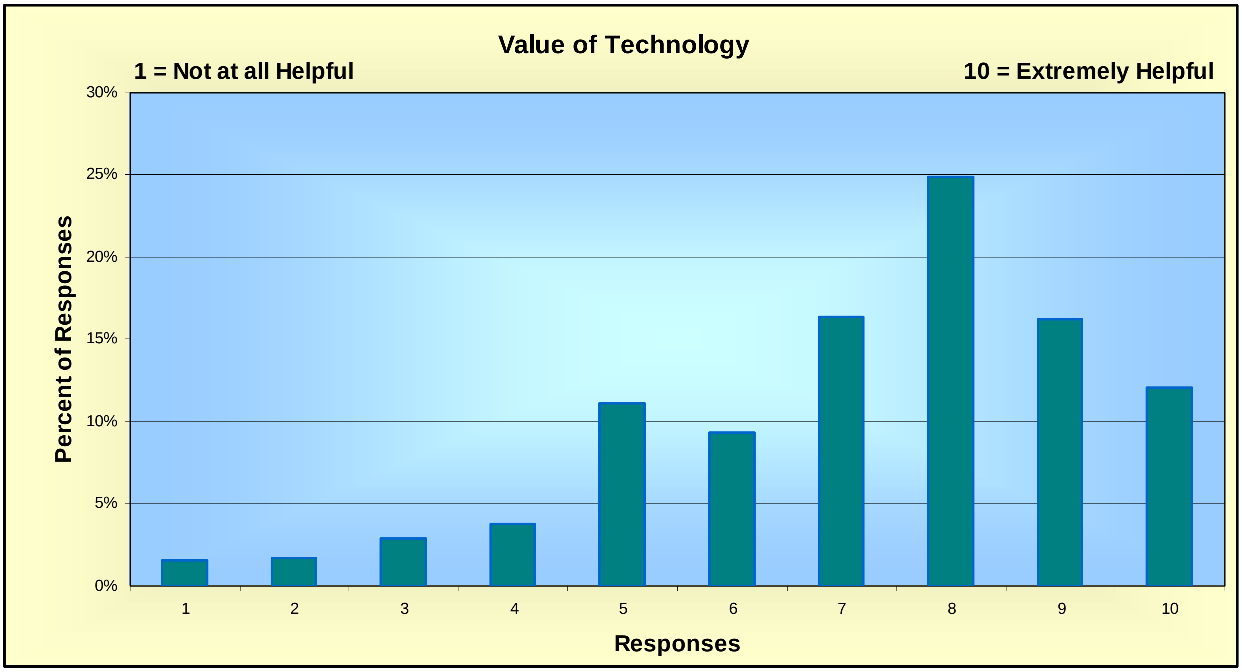

Figure 6-8 Value of Technology in Assisting Decision Support

Respondents viewed the recent developments in technology as very helpful in assisting their decision making. The average response was 7.2 for the composite results of all five states. Nearly 80% perceived the technological developments as more helpful than not (decile answers of 6 or above) and 70% responded with answers of 7 or higher. The investigators view this as a key result of the survey. The result indicates that most users in the five states are quite receptive to technological advances and find new solutions to their operational responsibilities of value.

MDSS Awareness

QUESTION 9: ARE YOU AWARE OF WORK BEING DONE ON THE DEVELOPMENT OF MAINTENANCE DECISION SUPPORT SYSTEMS FOR WINTER MAINTENANCE IN YOUR DEPARTMENT OF TRANSPORTATION? (CIRCLE ONE) YES NO

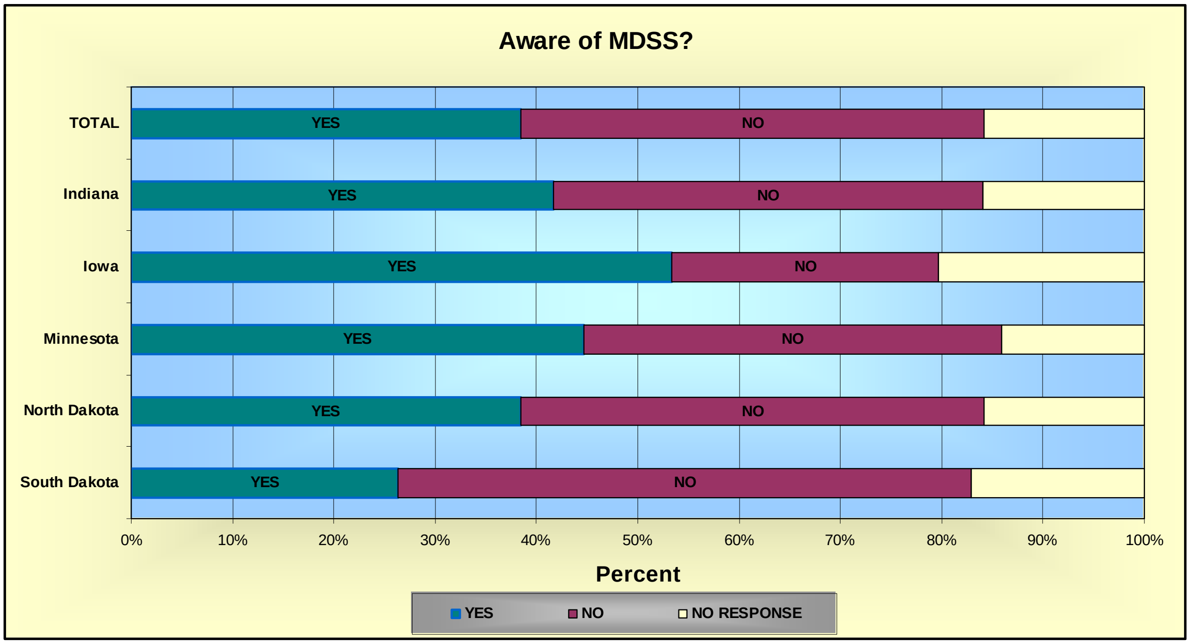

Figure 6-9 Awareness of Maintenance Decision Support Systems

Interestingly, around 15% of all respondents did not answer this question. Since a "no response" answer was rare on other questions it appeared that many individuals filling out the survey were not familiar with the Maintenance Decision Support System terminology and opted to ignore the question. Based upon this premise, a "no response" answer is most likely equivalent to a "No" response. Thus, one-half of the respondents in Iowa were aware of MDSS; 4 in 10 were aware in Indiana, Minnesota, and North Dakota; and one-quarter of the respondents were familiar with MDSS in South Dakota. The composite of all answers indicated that 38% of all respondents were aware of work being done on maintenance decision support systems.

Authorized Decisions

QUESTION 10: FROM THE LIST BELOW, PLEASE INDICATE WHICH DECISIONS YOU ARE PERSONALLY AUTHORIZED TO MAKE IN WINTER MAINTENANCE (CHECK YES OR NO FOR EACH DECISION TYPE):

- *When to start operations*
- *When to stop operations*
- *When to suspend operations (for example, because of server conditions)*
- *When to resume operations*
- *Whether to schedule more than one shift per day*
- *What personnel to assign to highway routes*
- *What treatment (plowing, chemical, sanding, etc.) to use*
- *What rate of treatment to apply (for example, gallons or pounds per lane mile)*

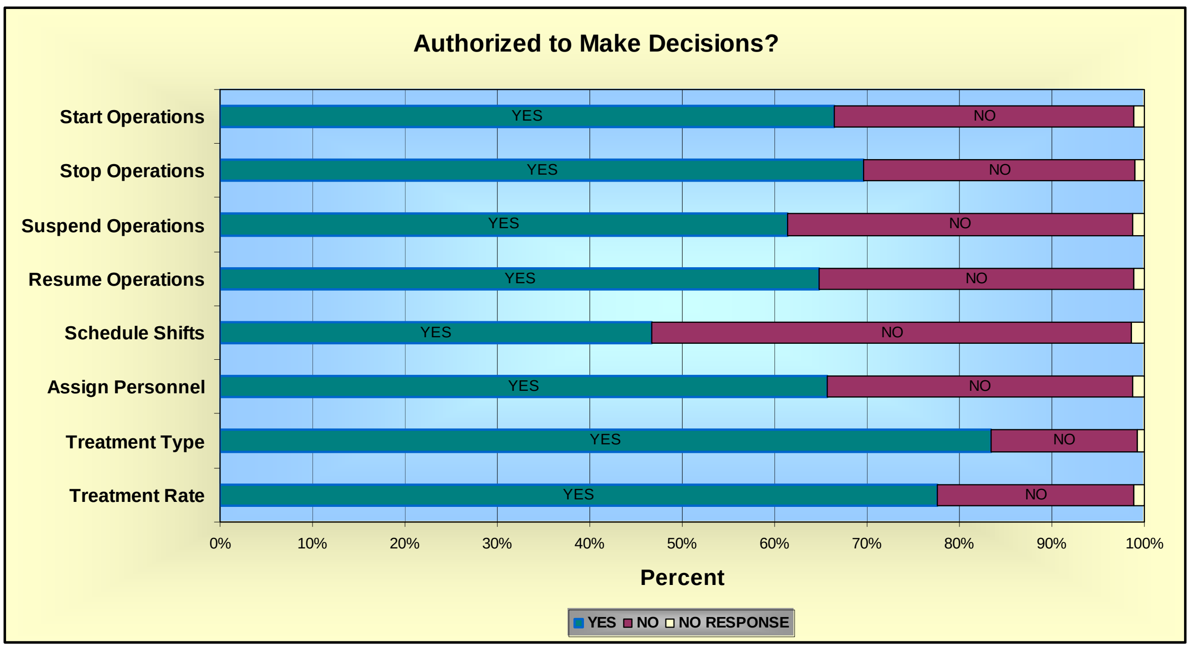

Figure 6-10 Authorization to Make Winter Maintenance Decisions

The objective of this question was to assess the level of authority that the survey respondents had or felt they had in making a number of key operational decisions. The panel felt it was important to understand what portion of maintenance personnel felt they had the authority to make the types of decisions that would be supported by a maintenance decision support system. This first analysis (Figure 6.10) evaluated the responses of all respondents within each state and did not break out the responses based upon job classes, experience level, or geographic areas.

The individual query for each decision category was a simple yes or no response. Nearly all respondents answered with a yes or no answer. An average of 1% of the surveys did not circle one of the two options for one or more of the categories in question 10. The investigators viewed these no response answers as inadvertent oversights and not an indication of insufficient information to enter an opinion as was assumed in question 9.

Out of the entire group of respondents, two-thirds felt they had authorization to determine when to start, stop, suspend, and resume operations. Two-thirds also felt they were authorized to assign personnel to fulfill route requirements. Around 80% of the group indicated they had the authority to determine treatment type and rate of application of materials. Finally, less than half of the group said they had the authority to reallocate or split shifts when forecasted weather conditions required continual scheduling over several normal shifts. Since the respondent group was composed of personnel from a variety of job classifications, the combined results tend to reflect a separation of duties attributable to different job classifications. The analysis of these same questions by separate job classes may provide a clearer definition of authority relationships than is provided here.

The responses were evaluated by state and the answer distributions separated into state classes is provided in Figure 6.11. Since the answers were 99% either a yes response or a no response, Figure 6.11 only shows the percentage of yes responses. When the each of the answers is separated by their totals within the five individual states, the results show that the respondents in the separate states viewed their level of authorization differently. The investigators realize that part of this difference may be the distribution of responses based upon job classes, but the marked differences more likely represent differences in operational policies and procedures amongst the five states. This result needs to be a significant consideration in the design of the MDSS graphical user interface.

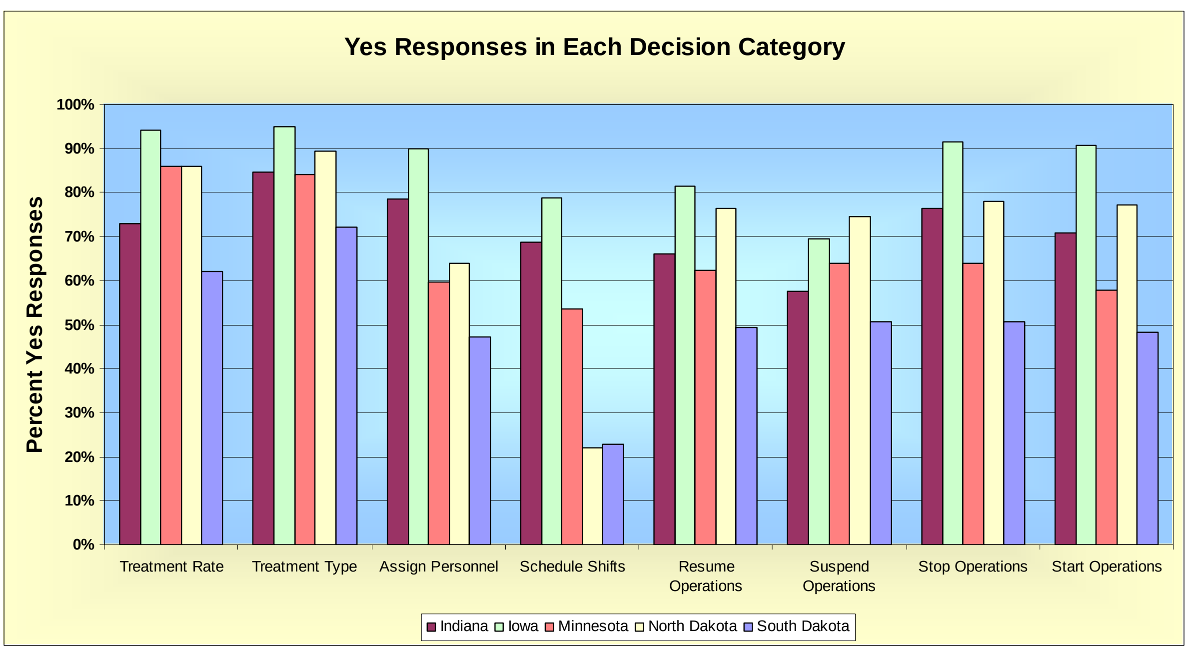

Figure 6-11 Percent "Yes" Answers for Each Decision Category by State

Importance of Information

QUESTION 11: FROM THE LIST BELOW, PLEASE RATE THE IMPORTANCE OF EACH TYPE OF INFORMATION YOU USE TO MAKE DECISIONS FOR WINTER MAINTENANCE (CHECK ONE BOX FOR EACH INFORMATION TYPE):

- *Road/weather information systems (RWIS)*
- *General weather forecasts*
- *Maintenance-specific weather forecasts*
- *Road condition reports from DOT*
- *Road condition reports from highway patrol*
- *Complaints from public*
- *Availability of personnel*
- *Skill levels of personnel*
- *Availability of materials (chemicals, sand, etc.)*
- *Availability of equipment*
- *DOT maintenance policies and procedures*
- *Other (please specify)*

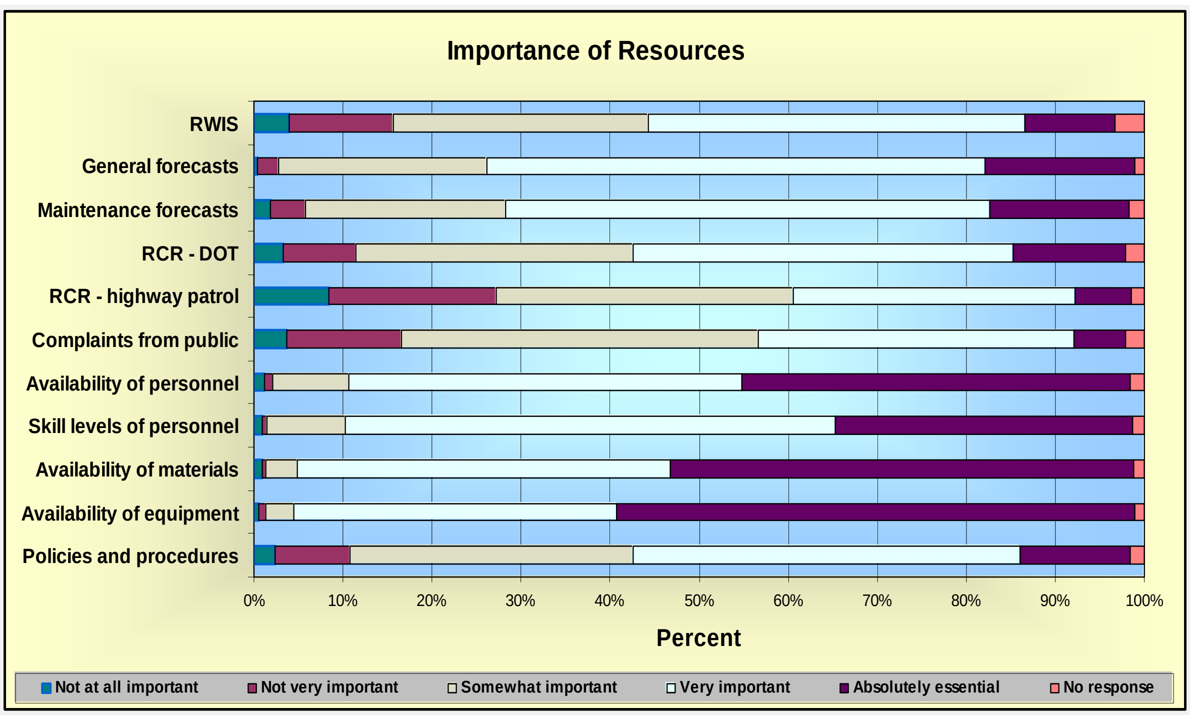

Figure 6-12 Importance of Information Resources in Users' Decision Making Process

Meridian, along with the Technical Panel, considered it important to determine how DOT users perceived different resources relative to one another. The original plan had been to assess information resources only, but that plan was amended to include resource capacities within the DOT. The survey design team felt the user view of internal DOT resource information would be valuable information for the Departments of Transportation and it would provide a baseline to compare the information resources.

Figure 6.12 presents the responses from all respondents in the survey. Answers for all the information type categories except “other” are shown in the figure. The “not at all important” results are on the left side of each bar and the “absolutely essential” results are near the right end. For completeness, the figure presents the “no response” percentage at the far right end of each bar. Since “no response” amounted to 3% or less, this section of the bar is very small.

For the majority of the resource categories, the dominant number of responses occurred in the “somewhat important” and “very important” answers. On the graph these two categories are highlighted with cross-hatching and vertical line highlights, respectively. As these two marker responses shift to the left on a bar graph, the answer indicates a predominance of answers indicating this information category is highly important in the decision process. As the marker fields shift right, the graph indicates respondents viewed the category having less importance.

The first six categories are external information resources with the first five categories representing specific types of road/weather information. The last five category entries are internal DOT resources. Ignoring the policies and practices category, the bar graph representation makes it quite evident the respondents to this survey place a higher value on the status of their daily operational resources than on external information resources. But that difference is only a matter of degree. A point midway in the crosshatched bar segment represents a value halfway between the “no value” and “essential” ends of the response spectrum. For the internal resource answers this cross-hatched center point lies between 4% and 8% indicating that 92 to 96% of all respondents place their value on the essential side of the response range. For the two forecast categories, 80 to 85% of the respondents were on the “essential” half of the range while the RWIS, road condition reporting, and public complaints categories indicated that 60 to 75% of the responses were more positive than negative.

Responses within all categories when analyzed state by state tended to cluster together and no distinct differences existed from state to state. The only exception was in the road condition reporting by the highway patrol category. Here there were some state differences.

The policies and procedures issue had been asked in questions 1 and 2 and the response in this question provided a similar response to the first use of the question.

Use of Internet or Intranet

QUESTION 12: DO YOU USE THE INTERNET OR INTRANET AT THE OFFICE? (CIRCLE ONE) YES NO

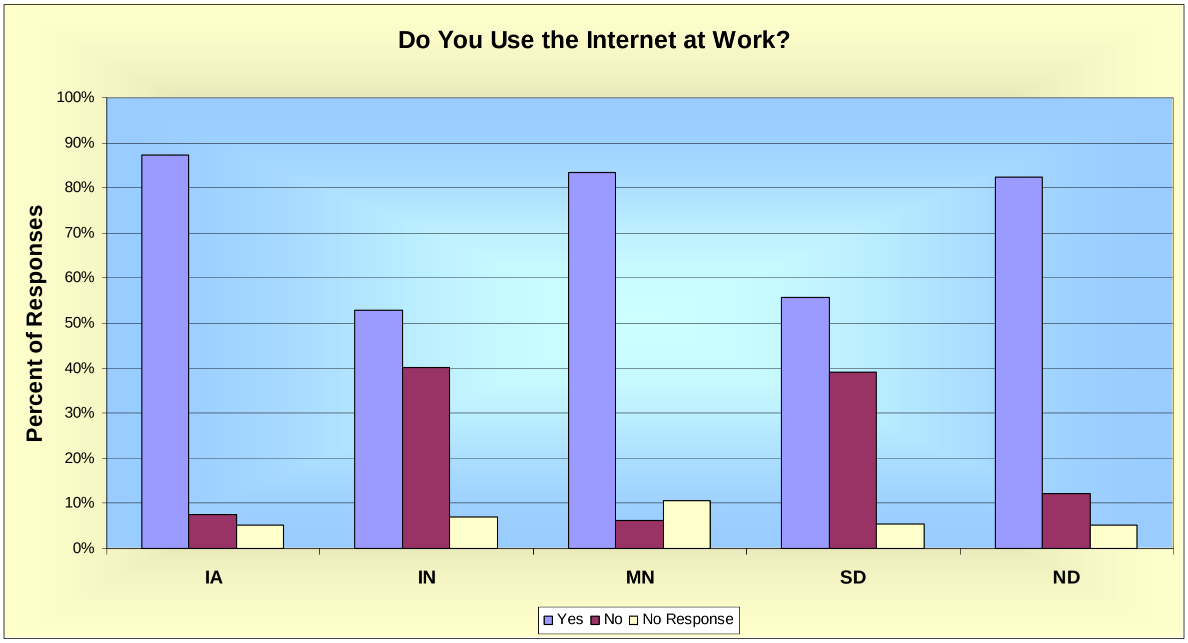

Figure 6-13 Use of Internet at Work

Eighty to 90% of the respondents in Iowa, Minnesota, and North Dakota indicated they use either the Intranet or Internet at the office. In Indiana and South Dakota that percentage was between 50 - 60%. This result suggests differences in the evolution of the information technology programs in the various states. Communications and network infrastructure have typically been the constraints to a more extensive distribution of computing resources and subsequent familiarity with Internet resources and services. In the reevaluation of the survey data to address the influence that demographics, Meridian wants to use the answers to this question as a conditional criterion to review the answer distributions for several of the questions. Like demographics, the availability of computing experience may have a significant impact the results of the survey.

Type of Internet or Intranet Connection

QUESTION 13: IF YOU USE THE INTERNET OR INTRANET AT THE OFFICE, PLEASE DESCRIBE YOUR TYPE OF CONNECTION (CHECK ONE):

Connection Type	IN (%)	IA (%)	MN (%)	ND (%)	SD (%)	ALL (%)
Low-speed dial-up modem	9	21	10	27	33	27
High-speed phone (DSL, ISDN, etc)	19	41	28	19	8	19
High-speed cable	5	4	13	5	5	5
High-speed local- or wide-area network	19	19	37	20	14	20
Other (please specify):	4	5	1	3	4	3
No Response	44	10	11	26	37	26

Table 6-2 Type of Connection to the Internet

The responses to question 13 were quite variable. The fact that 26% of all respondents did not answer this question suggests that they either do not work in a location that has a computer or they were not sure about the connection in their office. That fits with the response on question 12 where 168 respondents indicated that they do not have access to the Internet at their work location. Twenty-six percent of the total responses equal 179 actual responses.

Of those who responded with a connection type, two-thirds had some form of moderate to high-speed interface.

Limits to Internet or Intranet Use

QUESTION 14: WHICH OF THE FOLLOWING LIMIT YOUR USE OF THE INTERNET OR INTRANET AT THE OFFICE (CHECK "YES" OR "NO" FOR EACH LIMITATION)?

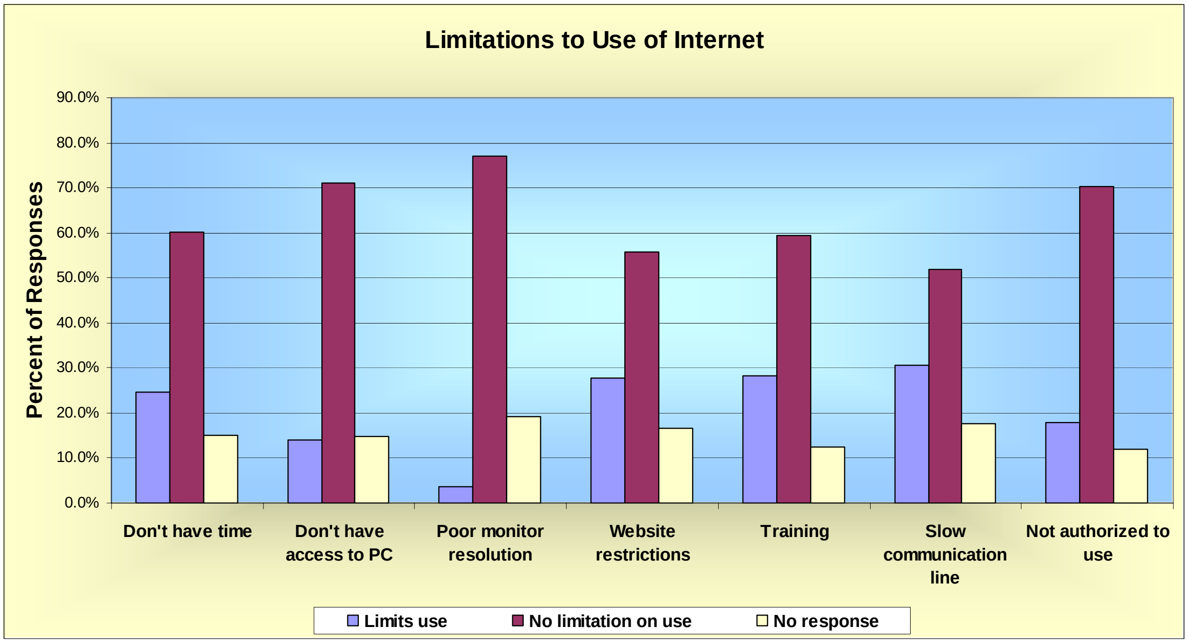

Figure 6-14 Factors that Limit Use of the Internet

The format of the question makes the analysis of the responses somewhat confusing. A "limits use" answer indicates the topic under consideration does limit the respondent's ability to use the Internet/Intranet at the office. Thus, by a factor of two to one users do not see the listed factors as a limitation to their use of the Internet.

Out of the limitations that were in the survey, screen resolution was definitely not seen as an issue in any of the states. Access to a computer was an issue in Indiana (32%) and a minor issue in South Dakota (17%). Authorization to use the Internet affected roughly 20% of the respondents from all states. Slow communications was reported as a limitation by 30% of all respondents and was considered an issue by 43% of the respondents in Iowa. Nearly 40% of the South Dakota respondents felt they need additional training to enhance their use of the Internet while training was seen as a need by about 20% of respondents in the other states. Web restrictions were seen as a limitation by an average of 25% of the respondents, somewhat less in Iowa and a bit more in South Dakota. Time was viewed as a minimal limitation in all states except South Dakota where 40% of the answers stated that finding time to use the computer was a limitation for use of the Internet in the office. The survey was not able to determine the source of this time constraint, that is, whether it was responsibility related or whether the computer was shared and users had difficulty finding time to use the device.

Effect of Internet and Intranet Limitations

QUESTION 15: ON A SCALE OF 1 TO 10, HOW SEVERELY DO THESE LIMITATIONS TO USING THE INTERNET OR INTRANET AFFECT YOUR ABILITY TO DO YOUR JOB?

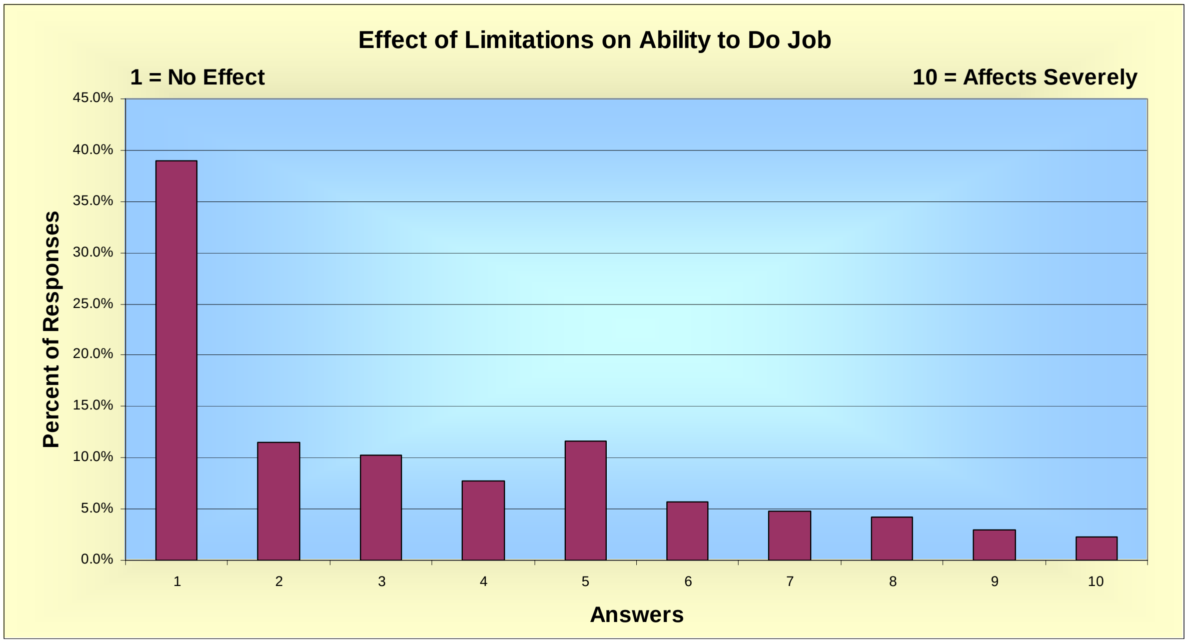

Figure 6-15 The Effect of the Internet Access Limitations on Users' Ability to Do Their Jobs

Although the factors in question 14 did affect one's ability to use the Internet or Intranet in some cases, users did not see these limitations as having much effect on their ability to do their job. Eighty percent of the respondents recorded answers in decile rankings 1 through 5 with a 39% of all answers falling in the first or "not at all" selection. It appears that as long as users were able to gain access to the information that they felt was important in question 11, actual access to the Internet/Intranet was not a limiting factor to them.

CHAPTER 7: OPERATIONAL MAINTENANCE DECISION SUPPORT SYSTEM REQUIREMENTS

Task 6 - Provide high-level functional and user requirements for an operational Maintenance Decision Support System and propose an architectural framework for the system.

7.1 Define the Basic Functional Infrastructure of the MDSS

The fundamental architecture of the Functional Prototype (FP) and the Pooled Fund Study (PFS) Maintenance Decision Support System (MDSS) design are structurally quite similar. The conceptual design of the FP (Figure 7-1) utilizes weather data to drive an intelligent weather forecasting system that prepares point and time specific outputs at discrete points in a road network. These weather forecast outputs are used as input to decision support and road condition modules which then suggest an appropriate maintenance action for the weather situation based upon the FHWA Rules of Practice[4] and subsequently simulate the effect of this maintenance action on future road conditions.

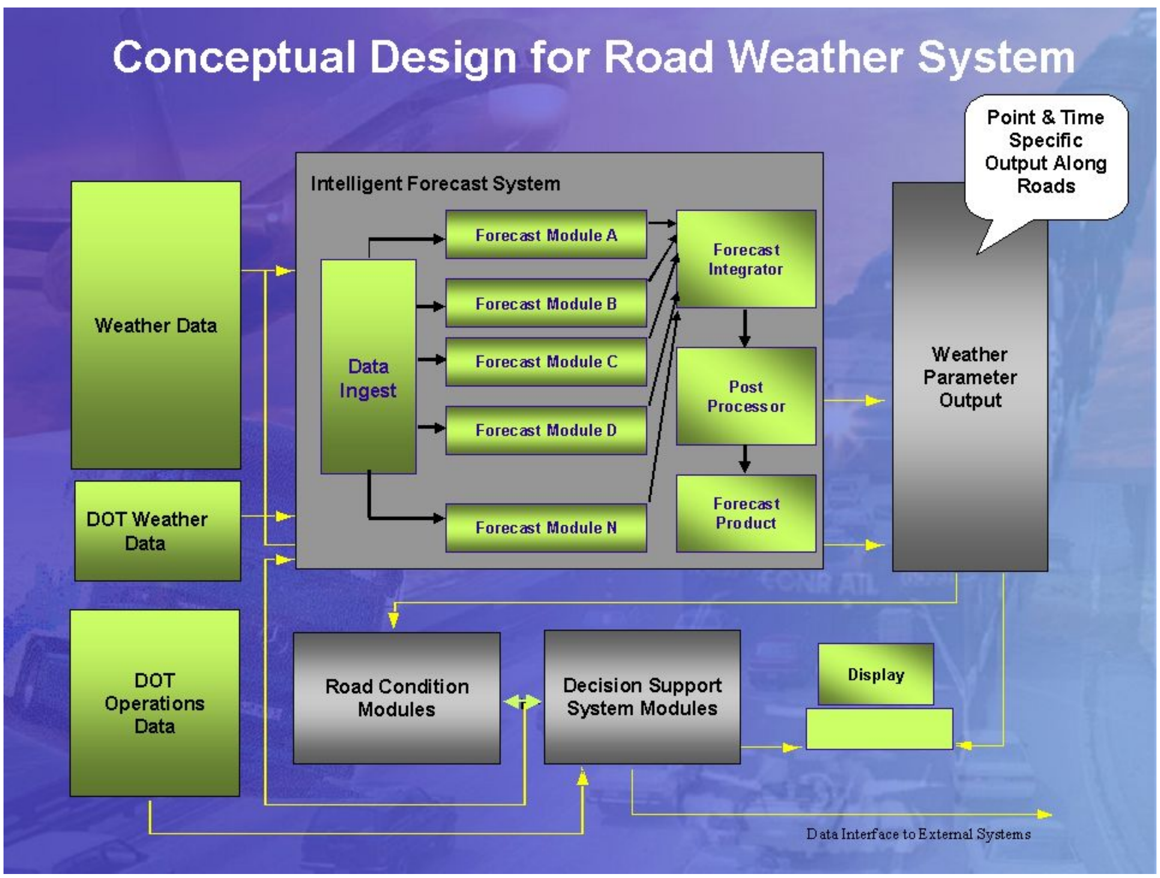

Figure 7-1 Functional Prototype Conceptual Design as Published by the National Center for Atmospheric Research (www.rap.ucar.edu/projects/rdwx_mdss/mdss_description.html)

[4] FHWA, 1996: "Manual of Practice for an Effective Anti-icing program: A guide for Highway Maintenance Personnel", FHWA, June 1996. Publication No. FHWA-RD-95-202.

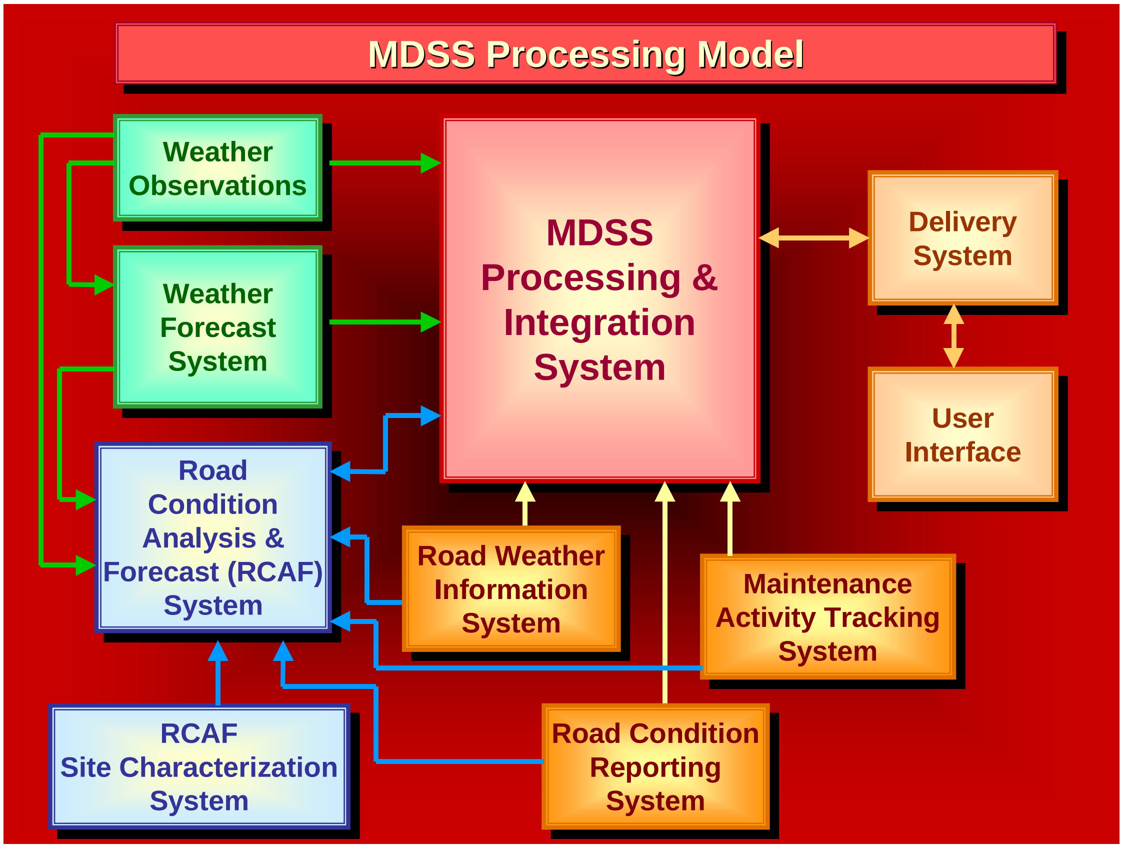

Figure 7-2 Pooled Fund Study MDSS Conceptual Design

Figure 7-2 depicts the conceptual design of the PFS MDSS. The color codes represent its five fundamental functional components. Note that these are the same five components as the Functional Prototype. The primary differences between the two approaches lie within the internal design of the weather components and the 'MDSS Processing and Integration' component of the decision support system. In the design of the weather component, the Functional Prototype uses a totally automated ensemble forecasting technique that drives a hybrid statistical and heuristic forecasting system; the Pooled Fund Study uses a similar weather forecasting technique but modifies the weather forecast outcomes using the expertise of professional meteorologists in addition to the application of decision rules. In the design of the 'Process and Integration System' the Functional Prototype uses the FHWA Rules of Practice to generate the appropriate response scenario. The fundamental processing scheme is 1) weather information as input, 2) determine the appropriate response based on previous maintenance experience (Rules of Practice adjusted to local policies and practices), and 3) output the "maintenance rule". This is defined as a quasi-rigid modeling technique: current response based upon an average or normalized response from previous experience. The Pooled Fund Study approach is a more adaptive or dynamic modeling technique. It views winter maintenance practices as the necessary actions to minimize the impacts of snow, ice, slush, and water on the pavement surface in order to obtain the highest level of safety and mobility. This approach argues that each weather induced situation is unique and the appropriate response must address the particular conditions created by the existing and forecasted weather conditions, the current pavement surface conditions (temperature and existing road conditions), and the present state of the snow, ice, slush, water on the surface (chemical concentration, layer thickness, water phase) (Figure 7-3). The process involves modeling the balance between what is added or removed from the pavement surface, both in the form of materials (shown as blue lines) and heat (shown as red lines).

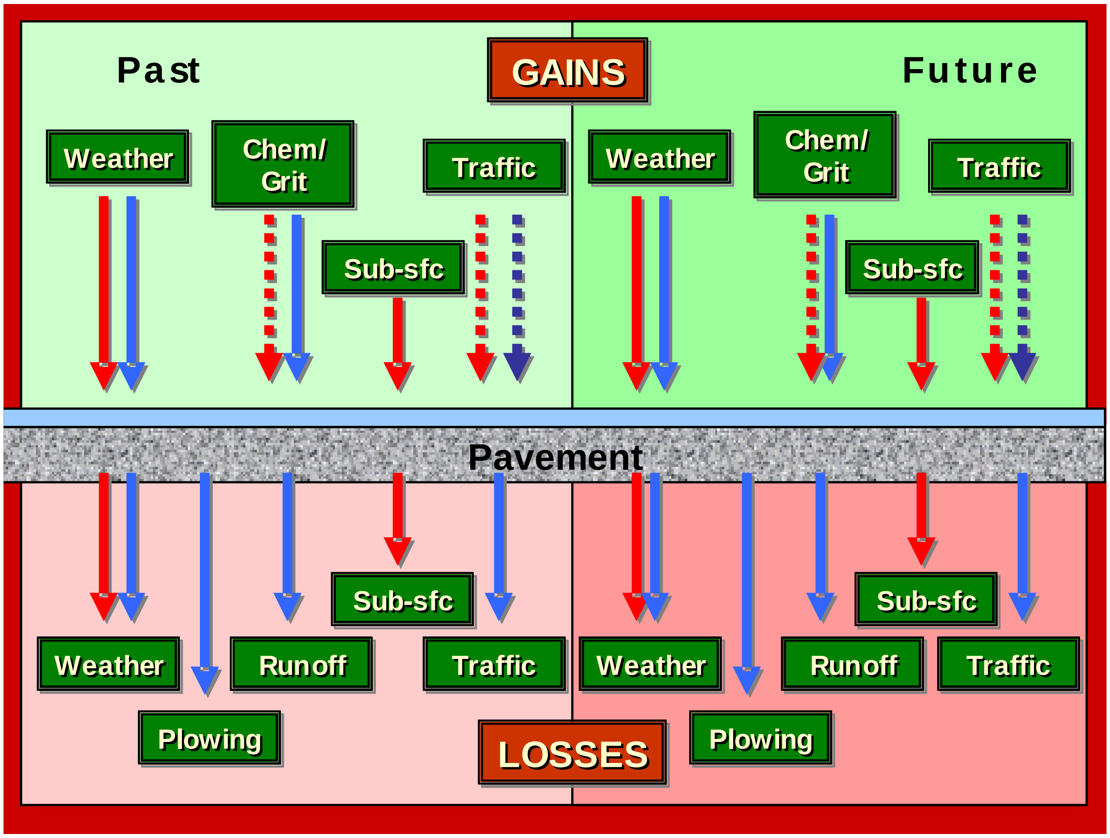

Figure 7-3 Schematic Depiction of Factors Associated with Pavement Condition and Its Change as Found within the Pooled Fund Study Approach

The outcome from the PFS approach is based upon input from its weather component, the maintenance information component, and the road condition component, providing decision options through knowledge-based analysis that represent the most effective and efficient response scenarios for the current situation.

The Pooled Fund Study architectural design is a simulation of actual practices that occur in the field. Table 7-1 illustrates how the MDSS functional design transfers actual maintenance actions into simulated processes in the MDSS package. The table considers weather events or maintenance actions that occur over a period of time. Each event or action creates a road condition that must be simulated in the MDSS model. The table indicates the situation as one would observe it and the concomitant state of the layer with which the model deals. The last column in the table indicates what processes must be executed to emulate the effects of the event or action in the first column. At the end of each description is a list of modules that are necessary to produce the simulation. To save space, the module names are abbreviated with a description of the modules included in Table 7-2. Table 7-1 only addresses a simple snow situation, yet similar simulation analyses may be associated

Action Or Event	Situation (After Event/Action)	Layer State (After Event/Action)	Processing
None	Dry pavement	Temp < 32 F; small residual salt conc.	None
Anti-ice with salt brine	Thin brine layer or swaths	Water layer with known salt concentration	Compute total salt concentration in solution on sfc and amount of water in layer (Mtls Ap, Chem, HiCAPS, Residue, & Traffic)
Allow water to evaporate	Dry pavement with salt layer	Thin layer of salt bonded to pavement	Compute amt of salt bonded to pavement (Chem, HiCAPS, Residue, & Traffic)
Traffic but no snow	Dry pavement with decreasing salt layer	Thin layer of salt bonded to pavement	Compute reduction of salt due to traffic (Residue, HiCAPS, & Traffic)
Snow begins	Predominantly damp pavement with snowflakes melting as they reach pavement	Water layer with brine concentration: residual bonded salt below brine layer; and thin film of melting ice crystals on top of brine layer	Add snow (estimate temp.& water content), increase snow layer, convert snow to brine as salt goes into solution, calculate ice/brine components of layer, and adjust residual bonded chemical (Chem, HiCAPS, Residue, & Traffic)
Snow continues	Predominantly damp pavement with snowflakes melting as they reach the pavement	Layer transitions from brine plus salt phase through eutectic point to dissolved salt in water state with decreasing salt concentration	Compute the transitional states of snow and salt components in relation to the increasing liquid layer (Chem, HiCAPS, Residue, & Traffic)
Snow continues	Predominantly damp pavement with snowflakes forming slush	Layer transitions from salt-water solution to ice/water/salt mixture	Determine the conc. at freeze point and from there compute percent ice in ice/water/salt mix (Chem, HiCAPS, Traffic)
Snow continues	Slush transitions from wet slush to predominantly icy or sticky slush	Ice crystal component of layer mix increases from near 0% ice towards 100% ice	Compute percent ice as more ice crystals are added and the salt conc. decreases due to dilution (Chem, HiCAPS, Traffic)
Treat with pre-wetted salt	Salt dissolves in slush forming wetter slush or salt water layer	Ice crystal component of layer mix gradually decreases as salt and pre-wet chemical goes into solution	Compute percent ice as chemicals cause increase in chem. conc. (Mtls. Ap., Chem, HiCAPS, Traffic)
Snow continues	Slush transitions from wet slush back to predominantly sticky slush	Ice crystal component of layer mix increases once again towards 100% ice	Compute percent ice as more ice crystals are added and the chem. conc. decreases due to dilution (Chem, HiCAPS, Traffic)
Plow and apply salt	Thin layer of slush left after plowing that transitions to wetter slush	Slush cover is reduced to thin film and ice percentage decreases as chemical goes into solution	Reduce depth of layer to plowed depth and compute concentration as chem.. goes into solution (Mtls. Ap., Plow, Chem, HiCAPS, Traffic)
Snow begins to taper off, winds pick up, and temperature drops	Slush transitions from wet back to more ice and pavement temp cools	Ice crystal component increases due to additional snow (falling and blowing) and lower pavement temperatures	Compute percent ice as more ice crystals are added and the chem. conc. decreases due to dilution and lower pavement temperature (Blowing, Chem, HiCAPS, Traffic)
Plow snow	Reduce layer to thin film of slush	Ice percent should remain the same even after slush is reduced to a thin film	Adjust the thickness of the film and continue to compute the chemical conc. and the percent ice in the mixture (Plow, Chem, HiCAPS, Traffic)
Allow pavement to become damp or dry	Wind, evaporation of water component, sublimation of ice component, and traffic reduce thin layer causing it to change to damp or dry pavement	Evaporation, sublimation, and traffic action reduce the water component and permit an increase in the chemical concentration	Compute the thickness of the layer and the chemical composition of the remaining mixture plus the ice percentage (Chem, HiCAPS, Traffic)
Allow pavement to become dry	Dry pavement with salt layer	Thin layer of salt bonded to pavement	Compute amt of salt bonded to pavement (Chem, HiCAPS, Residue, & Traffic)

Table 7-1 Illustration of How the Pooled Fund Study Functional Design Transfers Actual Maintenance Actions into Simulated Proceseses within the MDSS Environment

with other winter weather scenarios (e.g., freezing rain, frost, blowing snow, refreeze, snow showers, etc.)

Module Abbreviation	Module Name
Blowing	Blowing/drifting snow
Chem	Chemical concentration computations
HiCAPS	Road condition and pavement temperature model
Mtls. Ap.	Input of materials applied to road surface (type(s) and rate(s))
Plow	Plow type and plow activities
Residue	Bond of chemicals to pavement surfaces
Traffic	Traffic volume and rate

Table 7-2 Definition of Module Abbreviations Used within Table 7-1

7.2 Designate the Data Flow Through the MDSS Architecture

Within version 4.0 of the National ITS Architecture (NITSA), Maintenance Decision Support is presently defined to be an equipment package for the Maintenance and Construction Management subsystem. According to the NITSA documentation "This equipment package recommends maintenance courses of action based on current and forecast environmental and road conditions and additional application specific information. Decisions are supported through understandable presentation of filtered and fused environmental and road condition information for specific time horizons as well as specific maintenance recommendations that are generated by the system based on this integrated information. The recommended courses of action are supported by information on the anticipated consequences of action or inaction, when available"[5].

The NITSA has identified detailed data flow constructs associated with the Maintenance and Construction Management (MCM) subsystem and various terminators. The NITSA defined maintenance decision support equipment package is found within two market packages of the MCM; the Winter Maintenance Marketing Package (Figure 7-3) and the Roadway Maintenance and Construction Marketing Package. The Winter Maintenance Marketing Package is the present design focus for the Pooled Fund Study.

Inspection of Figure 7-3 reveals that several of the conceptual items addressed in the Pooled Fund Study Processing Model designed by Meridian and described earlier become apparent in the Winter Maintenance Marketing Package. These include the presence of the "Maintenance and Construction Administrative Systems" and the "Other MCM" components which are analogous to the Pooled Fund Study's "Maintenance Activity Tracking System". This latter PFS component will be critically important in conveying information on the actual maintenance practices employed to the Road Condition Analysis and Forecast System, as well as to the MDSS Processing and Integration System. The "Weather Service" and the "Surface Transportation Weather Service" components in the NITSA document are represented in the Pooled Fund Study's "Weather Observation" and "Weather Forecast System". Within the NITSA decision schema, the maintenance decision maker is embedded within the Maintenance and Construction Management process, where in the Pooled Fund Study the decision maker is located within the "Delivery System" and "User Interface" modules. This leaves the Pooled Fund Study "Road Condition Analysis and Forecast System" and the "Road Condition

[5] Iteris, 2002: ITS Physical Architecture, p. 2-169, June 2002.

Analysis and Forecast System" as the only non-NITSA elements in the high-level overview of the MDSS architecture. However, this appears to be a possible shortfall in the NITSA, as this data flow does not explicitly exist anywhere within the national architecture, but has been identified by both the Functional Prototype and the Pooled Fund Study as a crucial element in a successful MDSS design. This discrepancy may be due to an implicit expectation that the road condition forecasting is to be found only external to the NITSA within the Surface Transportation Weather Services terminator.

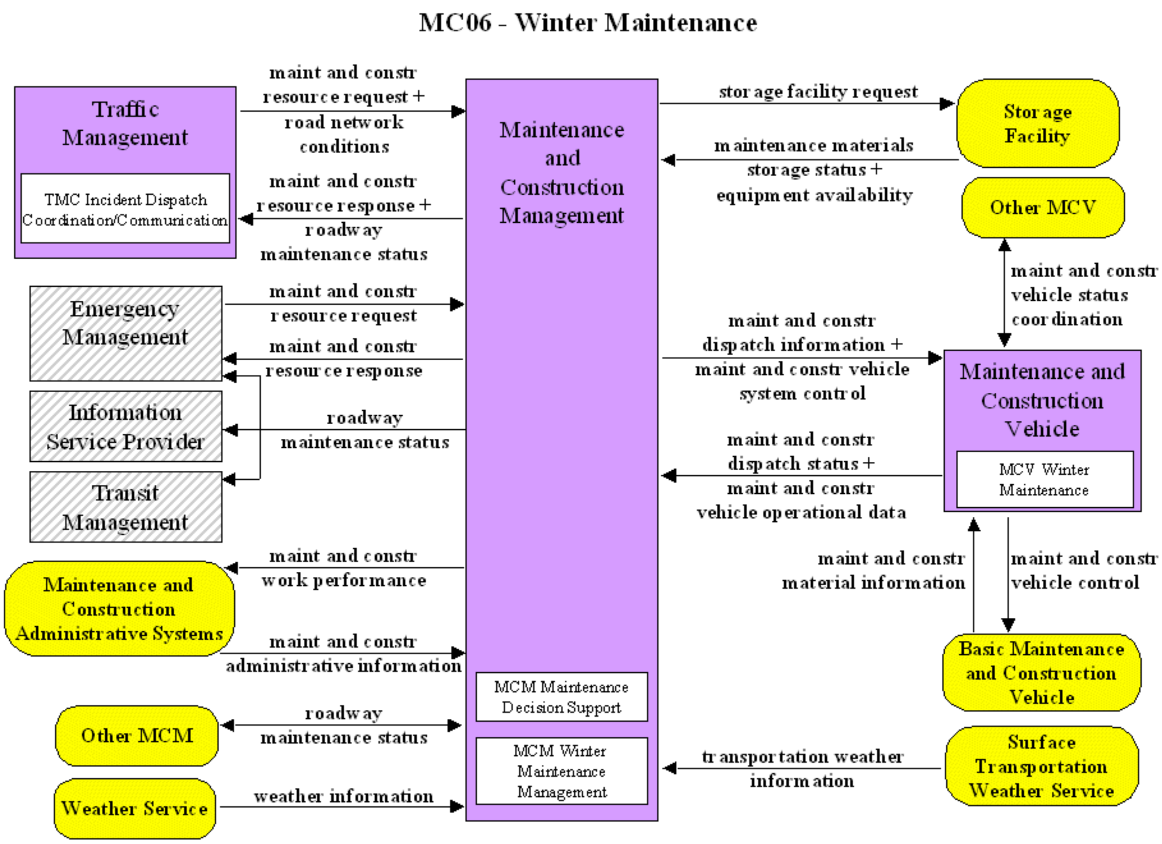

Figure 7-4 National ITS Architecture (Version 4) Winter Maintenance Marketing Package

Before turning attention to the data flow diagrams associated with the present Pooled Fund Study design, it is worthwhile to review the data flow diagram in the NITSA that specifically addresses maintenance decision support (Figure 7-4). In inspection of this data flow diagram, it is seen that three processes are directly interfaced by the NITSA MDSS. These include 1) Manage Maintenance and Construction Resource Needs, 2) Determine Roadway Maintenance and Construction Needs, and 3) Determine Winter Roadway Treatment Needs. A fourth process is found in the data flow diagram that flows into the "determine roadway maintenance and construction resource needs". This process is the "collect roadside equipment status" process and provides data on a host of information delivery and collection platforms along the roadway. Of significance in this diagram are the presence of twelve existing identified data flows into or out of the maintenance decision support and the presence of a process specifically identified to assess the need for winter roadway treatment. It is logically within this process that the "road condition forecast" process should be found.

Unfortunately, except for the data flows in and out of the later process, no further definition of this process is specified.

The twelve NITSA identified maintenance decision support data flows from Figure 7.4 are:

- env_and_weather_data_for_decision_support—In
- env_info_for_decision_support—In
- m_and_c_activity_status_for_mdss—In
- m_and_c_resources_avail—In
- m_and_c_view_of_road_network_for_mdss—In
- maint_dec_support_parameter_updates—In
- mdss_recommended_actions_for_operator—Out
- mdss_recommended_actions_for_personnel—Out
- mdss_recommended_actions_for_resource_needs—Out
- mdss_recommended_actions_for_roadway_maint_needs—Out
- mdss_recommended_actions_for_winter_treatment_needs—Out
- terf_mdss_recommended_actions—Out

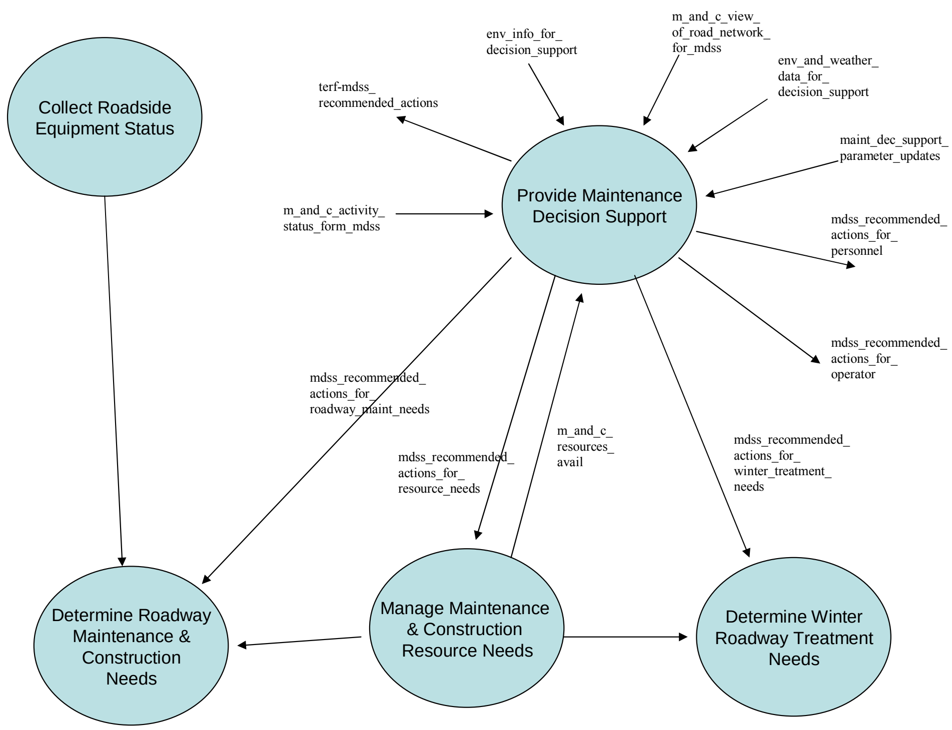

Figure 7-5 Data Flows Associated with the "Provide Maintenance Decision Support" Process Specification from the "Determine Maintenance and Construction Needs" Logical Architecture Process of the National ITS Architecture

Of the twelve maintenance decision support data flows, six are designated as inputs (the first six) and six are listed as outputs to the maintenance decision support process. While these data flows are not necessarily all of equal weight in importance, **it is significant that of the six input items, only one is specifically related to weather**. The remainder of the input data flows pertain to other critical information needed in the decision making process, i.e., activity status, resources available. This further supports the present Pooled Fund Study design efforts that emphasize the role of both weather and non-weather elements as central to the decision making process.

Having identified and discussed the place MDSS holds within the National ITS Architecture, it is critically important that the Pooled Fund Study ensure the resulting MDSS design meets with the respective architectures within each state. Assuming the state architectures follow reasonably close to the NITSA, incorporating the data flows that exist within the NITSA will ensure this goal is met. However, it is equally important an MDSS be capable of incorporating expanded capabilities or revisions to the NITSA. The following were specific important considerations followed in developing the data flow diagrams of the Pooled Fund Study with respect to the NITSA:

- Focus initially on winter maintenance,
- Maintain best consistency possible with the NITSA defined data flows when describing the present MDSS,
- Decision support involves a collection of data flows beyond weather, and
- Weather services (federal and private) are terminators and are considered external processes to the MDSS.

The latter bullet is important for two reasons. First, it identifies that the development of weather elements for MDSS involve processes that exist entirely beyond a state DOT unless states are prepared to establish their own dedicated meteorological services divisions. While some state DOTs have staff meteorologists, these individuals play only a limited role in the development and delivery of forecast products. Considering the significant investment in personnel and equipment that will be necessary for weather support to MDSS, it is not envisioned that this role will shift to state DOTs in the foreseeable future. The second important aspect of this bullet is that the coordination of the interface between the weather terminator and the MDSS equipment package must be carefully monitored for potential standards that might be set. Of the approximately ten standards development organizations involved in ITS at present, none are actively involved as major standards organizations involving weather information. Following the premise that MDSS components should be capable of plug-and-play, developing standards that manage the data flows is imperative. The Pooled Fund Study and the Functional Prototype development efforts constitute a significant effort in evolving the necessary standards for MDSS and its affiliated plug-and-play capabilities.

With the previous discussion as background, the elements in Figure 7-2 are presented in Figure 7-6 as a context diagram of the Pooled Fund Study data flows and provides a focused description of the MDSS context. In Figure 7-6, the references to construction activities have been eliminated and the various maintenance management terminators are consolidated in the “Maintenance Administrative Systems” terminator. Similarly, all associated references to maintenance vehicle terminators have been consolidated into the "Maintenance Vehicles" terminator. Also, the "Surface Transportation Weather Services" terminator has assimilated the "Weather Services" terminator for the Pooled Fund Study efforts. Hence, the private sector surface transportation weather services provider is considered as the conduit for all weather information e.g., National Weather Service, that may be passed through to the MDSS display and information systems. The data flows linking the MDSS to the terminators reflect elements of the NITSA data flows identified earlier. However, a new data flow has been added to the "Surface Transportation Weather Services" terminator entitled "Weather_Data_Request". This is an important addition to the data flow as it provides a link back to real-time weather resources to provide for interactive updating of tactical surface transportation weather services. These tactical weather services, identified as the processes within the surface transportation weather services terminator, are developed in the Level 2 data flow diagrams (Data Flow Diagrams).

It is significant that at this high-level of the data flow, the maintenance personnel involved in the MDSS can be at any level. The specific functionality for the various classifications of maintenance personnel will be defined as the processes within the MDSS are developed. In fact, it is conceivable from this context diagram that the operator of the maintenance vehicle could be operating the MDSS.

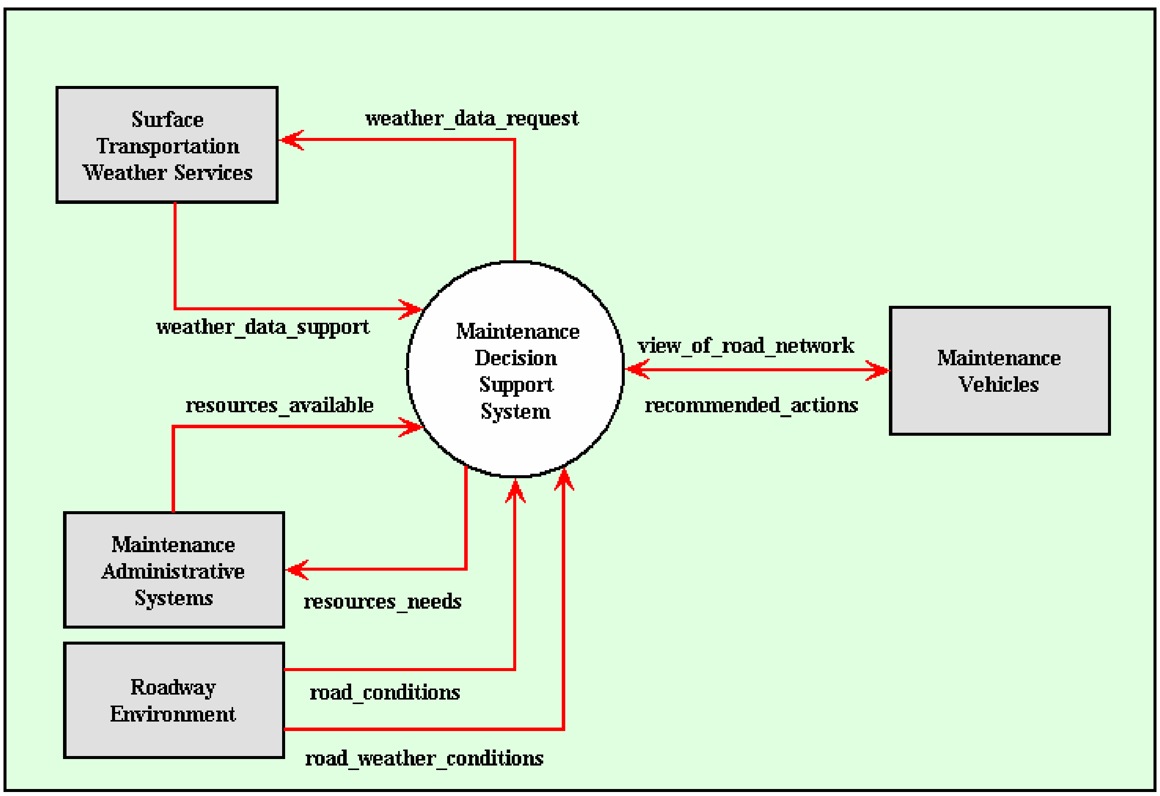

Figure 7-6 Pooled Fund MDSS Context Diagram, Adapted from the National ITS Architecture

At this point, the traditional method of data flow diagramming would limit the Level 1 and beyond data flow diagrams to those processes found within the MDSS and not those found within the terminators. However, the impact of the weather information content and processing on the design development of the MDSS functionality requires that an exploration of the data flows within the Surface Transportation Weather Services terminator be developed in parallel to that of the MDSS. Figure 7-7 provides the Level 1 data flow representation of the Pooled Fund Study MDSS. The core processes serve as the foundation for the menu structure found in the Windows environment and for the interface functions to the three terminators. The nine core processes are:

- Weather data action listener – interface process to the weather data stream that continually monitors for weather data traffic to and from the surface transportation weather services provider.
- User input listener – as the name implies, this process is where the user interacts with the MDSS client software through either mouse or keyboard inputs.
- Graphics generator – process responsible for generating all computer graphic displays.
- Message dispatch – process responsible for sending information to users outside the MDSS client server.
- Scenario generator – core process responsible for decision support.
- Window manager – classic window manager processor that managers all window traffic associated with the user and display functions. Analogous to a data router in that all messages are processed through the window manager.
- Road condition processor – interface process to extract road condition information from the road condition reporting system.
- Inventory analyst – interface process to extract and store information pertaining to the maintenance inventory database.
- Maintenance practice evaluator – interface process to acquire and interpret information pertaining to maintenance practices.

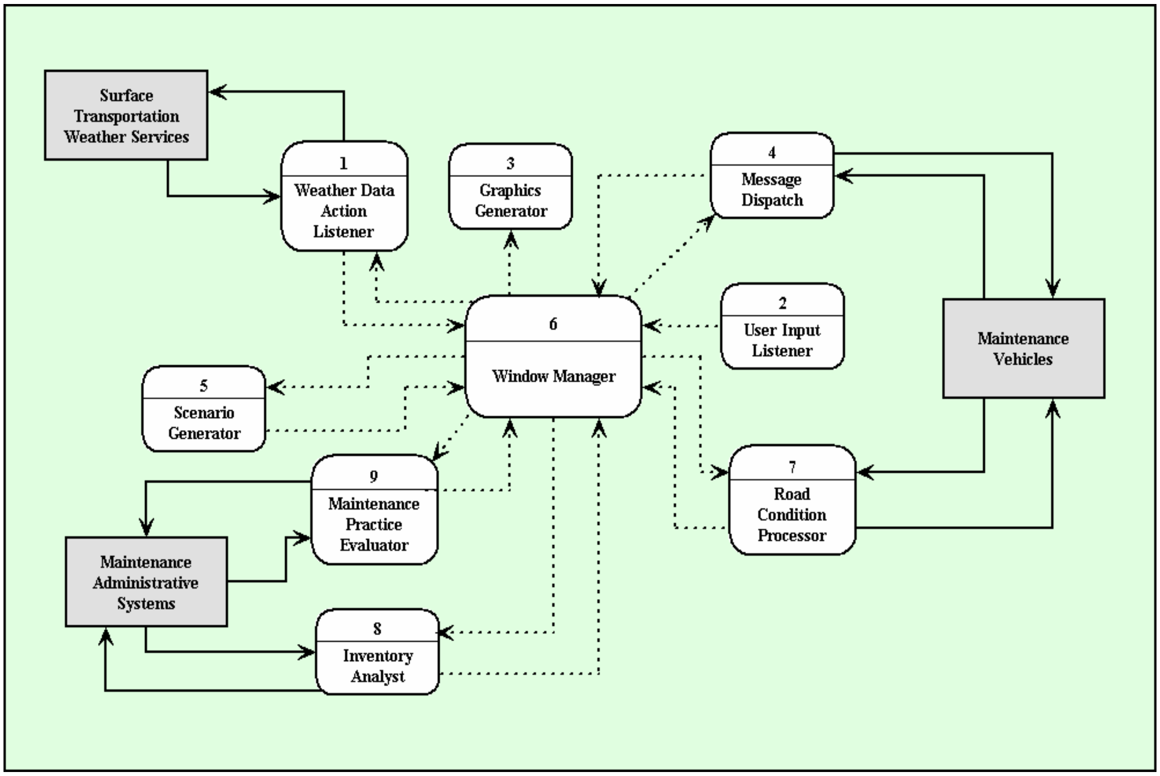

Figure 7-7 Pooled Fund Study Level 1 Data Flow Diagram

As can be seen from Figure 7-7, the majority of the flows in the Pooled Fund Study application involve traditional window-based transactional services. This is consistent with the Functional Prototype design where no limited decision support processing is found on the client-side workstation, only decision support displays. However, within the Pooled Fund Study, there are processes that are directly related to activity of decision support involving client-side processing. The “Scenario Generator” specifically is designed to handle client-side decision support through dynamic interaction with local and remote data sources including weather, maintenance activities and current road conditions. However, to support these actions requires the presence of frequently updated data on maintenance treatment activities, maintenance vehicle locations, materiel inventories and detailed (time and space) road condition reports. Without the “Scenario Generator” the client-side applications largely default to something similar to the Functional Prototype’s graphical user interface.

The next level of detail is provided in Level 2 data flow diagrams (Data Flow Diagrams). At this level specific processes found within each of the in the Level 1 diagram are mapped according to their relationship to input and output data flows as well as through internal processes, data flows, and controls. The detail provided in the Level 2 data flow diagrams provides insight into the functional design found within the Pooled Fund Study and serves as the basis for software development. Algorithmic detail at the 2nd level is not obvious, although a clear connection between processes is visible and a representation of data exchanges required is available. The functional capabilities presented in the data flow diagrams depict an architecture that separates the operational function into distinct modules. This design concept is intended to promote the incorporation of modules from various development sources and provide flexibility for independent module revisions without a requirement for overall software upgrades

7.3 Define modules of the MDSS that can be immediately developed

As mentioned in Chapter 1, the challenge of developing a Maintenance Decision Support System is to provide a more effective and efficient maintenance effort by:

1. Assessing site-specific current road and weather conditions using all available observations and reasonable inferences based upon those observations and physical laws;
2. Providing highly time- and location-specific weather forecasts along all transportation routes;
3. Predicting how road conditions will change due to the combined effects of the forecast weather and the application of candidate road maintenance treatments;
4. Notifying state agencies of approaching adverse conditions and suggesting optimal maintenance treatments that can be achieved with resources available to the transportation agencies; and
5. Evaluating the reliability of predictions and the effectiveness of applied maintenance treatments for specific road and weather conditions so that the decision support logic can be improved.

Meridian has been working toward the idea of an MDSS long before the initiation of the current PFS project. Development efforts within Meridian over the last five years have largely focused on building a tool set for meteorologists that can support the high-end spatial and temporal weather information that will be required to support operational MDSS activities. Much of this development is completed, allowing Meridian to address many of the weather aspects of Bullets 1 and 2 above with a relatively modest increase in staff. One very notable exception to this is blowing snow, which Meridian has done relatively little to address up to this point.

Many of the other core modules of the MDSS needed to support these requirements can be immediately developed, albeit some will be of only limited complexity initially. Meridian has already developed a pavement model (HiCAPS; Highway Condition Analysis and Prediction System) that is an ideal candidate for application at the core of the MDSS infrastructure. HiCAPS simulates many of the processes depicted in Figure 7.3 that act to change the pavement condition. This includes coupled modeling of the mass and heat balances acting upon the road surface as well as the accumulation, condensation, deposition, evaporation, sublimation, runoff, compaction, and plowing of moisture in liquid, ice, snow, or frost forms. HiCAPS also has an internal data assimilation system that helps it to utilize incoming RWIS observations in the most effective manner.

Meridian will modularize the components of the current HiCAPS model so as to function better as modules within the open MDSS framework. This will include separating out the data assimilation modules of HiCAPS from the physical core of the model. The resulting data assimilation modules will be enhanced so that the MDSS can better integrate RWIS observations, road condition reports, maintenance activities data, roadway environment characterizations, and high-resolution (often remotely-sensed) weather information in order to provide improved high-resolution analyses of the present state of the road network in between the available observations (addressing the goals of Bullet 1 above). Although useful in their own right, these ongoing analyses of the pavement conditions are essential to accurately forecasting the outcome of proposed maintenance treatments.

The modules that will require the most development, at least during the initial development phases, are those that deal with the interactions between the moisture present on the roadway and the maintenance activities that have been carried out previously or are proposed in response to a pending weather situation. These modules are essential to addressing the goals of Bullets 3 and 4 above. Meridian will likely adopt certain components of the FHWA Functional Prototype MDSS in order to jump start this effort. However, the Functional Prototype leans heavily on application of the FHWA Rules of Practice in selecting an appropriate treatment. Meridian hopes to develop a more dynamic approach for selecting candidate maintenance actions. Where supporting research information is available, Meridian also intends to develop more sophisticated modules for modeling the complex interactions between applied chemicals, grit, traffic, plowing, and the various phases of moisture upon the roadway. This is the area in which Meridian has identified the bulk of the basic research needs to support MDSS (see Chapter 8).

Meridian is well positioned to support MDSS development requirements for user notification of impending events (required for Bullet 4). Over the last two years Meridian has developed an automated alert system that has been used in its operational forecast support setting. This system ingests live weather and pavement information and forecasts and interprets a set of easily configurable alert rules written in a common computer language. Users of the system who are associated with those rules are notified whenever the specified criteria are met at a time and location of interest to them. Meridian views automated monitoring and alerting as the only viable option given the widely varying spectrum of alert requirements different users of the MDSS will have. Development of this system has been a learning experience for Meridian's development staff, as it has revealed many additional complexities of the alert process when used in a forecast setting.

Two of the most difficult aspects of the MDSS development effort will be the integration of resources and materials information into the decision logic (needed to fully address Bullet 4), and development of a method for evaluating the reliability of predictions and the effectiveness of applied maintenance treatments. Both of these efforts will require near real-time information from the field that is not currently available, but which must be addressed in at least some limited fashion during the PFS MDSS effort.

7.4 Structural components necessary to implement the MDSS architecture

The data flow diagrams described in the previous section provide the conceptual layout of the Pooled Fund Study software. The implementation of the Pooled Fund Study software will exist in a client-server environment comprised of a client computer system located within the maintenance facility and a server that may either be located within a state DOT or provider computer facility. This latter system will be further connected to additional support systems that extend to weather service providers that will present a significant extent of the data and computational support for the client side applications. The development software language for the PFS will provide an executable program that will permit an effective distribution, using accepted state application distribution such as a central application server. The hardware required to support the Pooled Fund Study will be diverse and dependent upon the final configurations of the distributed client application and the computational requirements of server systems to support the MDSS applications. Table 7-3 depicts the anticipated minimum client-side resources required to implement the PFS software applications. This configuration is present primarily as a result of most state agencies using Microsoft Windows as their operating systems. However, the client-side applications are anticipated to be platform independent. The speed of the computer processor, the amount of core memory available and the video display resolutions will largely determine the efficiency of the system such that lesser configurations can be used, but degradation in performance will result. The amount of disk storage is less critical with the amount available dependent upon the degree of local data desired to remain resident on the client system.

Requirement
PC with Windows 2000, NT or XP operating system
866 MHz processor or faster
512 MB RAM or greater
1 Gbytes disk or greater
Video display of 800x600 resolution or greater

Table 7-3 Anticipated Minimum Client-Side Resources

Communication requirements will include Internet connections necessary to support data exchanges between the client and server computers. Recommended communications speed is 128 Mbytes per second. Slower communications speeds will result in a significant degradation of software performance.

CHAPTER 8: DEVELOP NEW SYSTEM COMPONENTS

Task 10 - Develop and test new system components that satisfy those requirements requiring fundamental research, incorporating ongoing and emerging technology improvements associated with weather forecasting and maintenance practices.

8.1 Identification and Prioritization of Fundamental Research Needs

Many of the integral processes that must be represented in a comprehensive MDSS are unfortunately not well understood at present. Winter road maintenance is a truly interdisciplinary activity, with at least a rudimentary knowledge of civil engineering, meteorology, and chemistry all being essential for good decision making. This is one of the driving factors behind the present MDSS development effort, as it is difficult for state Departments of Transportation to replace the acquired expertise of retiring maintenance personnel. Likewise, the interdisciplinary nature of winter maintenance has also left numerous holes in the research of fundamental processes pertinent to winter road maintenance, as they do not fall into the core national research initiatives of any one discipline.

Although performing the breadth of research needed to support MDSS activities is beyond the scope of the PFS study, it was nonetheless useful to identify and prioritize the present research needs. Toward this end, Meridian compiled and prioritized an initial item list of research. A priority rating of 1 in Table 8-1 indicates an important need that will require immediate attention both in this project as well as in the larger research community. A priority rating of 10 indicates a low present priority, although these processes will be of fundamental importance once some of the high priority processes are better understood. The list in Table 8-1 should not be viewed as a final and complete itemization of research needs, rather as the short list of currently identifiable broad research areas. There are numerous important facets to many of these research needs, and the growth of understanding in these areas will almost certainly point out the need for research in entirely new areas. During the Phase II development effort, Meridian's scientists will become better acquainted with the research information that is available for application in MDSS, and will therefore provide further documentation on what research has been done, what remains to be done, and where the various research needs might be most appropriately addressed (i.e., within which laboratories, institutions, or sectors, or even within the individual Departments of Transportation).

Title	Research Need	Priority
Chemical Concentration & Freeze Point Computation	Computation of chemical concentration of the liquid component of slush for all routinely used chemicals and chemical admixtures. Module needs to compute the freeze point of the mixture of chemicals.	1
Percent Ice in Slush Mixture	Computation of the ice percent of the mixture of ice and dissolved chemical solution for all routinely used chemicals and chemical admixtures	1
Traction Index	Develop an index based upon the "effective" coefficient of friction caused by the state of the contaminant layer	2
Blowing snow	Simulate the effects of blowing snow due to topography, local wind patterns, construction factors, vegetative cover, and snow fences; simulate the amount of snow within the contaminant layer caused by a variety of wind conditions under differing snow densities; simulate the effect of traffic on the snow blowing or moving across the highway	3
Chemical Residue	Create a simulation of the bonding process of different chemicals or chemical admixtures on various types of pavement as the solvent (water) evaporates from the highway surface; simulate the residual bond over time for different traffic volumes and speeds; simulate the dissolution of this bonded chemical once moisture is added to contaminant layer due to dew, frost, absorption, or some form of precipitation	3
Frost	Gain an improved understanding of the processes relating to road and bridge deck frost formation. Develop an improved model to simulate the formation of frost on bridges or highways	3
Latent Heat Effects of Chemical Application	Develop a simulation of the heat of fusion required as salt induces the state change from ice to water over time and how this heat flux affects the pavement temperature; output from this simulation needs to loop back into freeze point and percent ice computation modules	3
Plowing Techniques	Simulate the plowing action of the spectrum of plow types with the intent to output the residual material after plowing is complete; consider the effects of different road surface types and their interaction with the plow action	3
Material application Estimation	For each type of material spreader, create an algorithm or simulation package to determine the effective amount of material placed on the road surface	4
Road condition reporting	Develop a module to capture and transmit road conditions along a stretch of highway and relatively short time intervals (on the order of once an hour or less); module needs to store and display road conditions along any segment of highway	4
Chemical Migration & Dissolution in Slush	Develop a simulation process that mimics the movement of chemical through a contaminant layer and approximates the process of chemical dissolving or mixing in a snow or slush layer	5
Chemical Mixing as a Function of Traffic Volumes	Develop a simulation of traffic's effect on the contaminant layer at varying degrees of slush consistency; part of the module should also determine how much material is removed from the contaminant layer at different traffic volumes and speeds	5
Grit Migration	Simulate the positioning and movement of grit materials within the contaminant layer; simulate the amount of residual grit material over time and determine where and how it migrates under different traffic situations	6
Long wave radiation balance	Perform research to determine what factors impact the energy balance equations in the long wave portion of the spectrum; observations indicate the temperature of the lower atmosphere influences the net long wave radiation; this parameter is not currently considered in the long wave radiation flux	6
Bonding of snow to pavement surfaces	Develop and understanding of the bonding process and determine what conditions are needed at the threshold point and how the process occurs as conditions change; evaluate the influence of different types of pavement and characterize the critical bonding conditions	7
Traffic Simulation	Create a simulation model that estimates the traffic volume and speeds as a function of time and special events; simulation should estimate the same traffic flows under varying weather and contaminant layer situations; output from the simulation becomes input into nearly all modules addressing contaminant layer values	7
Contaminant layer composition during precipitation	Simulate the state of the contaminant layer during precipitation events such as snowfall; determine how snow melt occurs and how the concentration changes with time through the layer	8

Table 8-1 MDSS Related Research Needs

8.2 Development of Components Requiring New Research and Development

As mentioned earlier, the breadth and magnitude of these research needs puts most of them well beyond the scope of this project. The present PFS MDSS development effort must forge ahead despite significant holes in the community's scientific understanding of many of the important processes. In many areas a cursory suite of research data is available on which to begin constructing certain MDSS components. During Phase II Meridian will gather, integrate, and document existing research information into a preferred initial approach for modeling or parameterizing many of the processes listed in Table 8.1. The documentation of these approaches will be supplied in Final Reports or Technical Memorandums from the anticipated Phase II and III PFS efforts.

8.3 Integration, Evaluation, and Revision

As new MDSS components are developed they will be regularly integrated into new releases of the developing MDSS software package. The impact these new components have on the MDSS in terms of functionality, accuracy, software performance, and user perception will be evaluated and documented following defined tracking procedures. The results of the evaluation process will be used to refine the component. This process of revision, integration, and evaluation will be repeated until the MDSS component is determined to be mature.

CHAPTER 9: SUMMARY

9.1 Project Objectives

The Pooled Fund Study (PFS) is a pooled effort of the states of South Dakota (lead), North Dakota, Minnesota, Indiana, and Iowa to demonstrate the benefits that may be achieved by using a decision support tool to assist the maintenance decision process. The research team is comprised of a Technical Panel (consisting of representatives from the five states and the FHWA and Meridian Environmental Technology, Inc. (Meridian) as research contractor. At the beginning of the study the research team established a three-year plan composed of the 14 research tasks listed in Section 1.5 Research Tasks. The panel also specified the following four research objectives:

1. To assess the need, potential benefit, and receptivity in participating state transportation departments for state and regional Maintenance Decision Support Systems.
2. To define functional and user requirements for an operational Maintenance Decision Support System that can assess current road and weather conditions, forecast weather that will affect transportation routes, predict how road conditions will change in response to candidate maintenance treatments, suggest optimal maintenance strategies to maintenance personnel, and evaluate the effectiveness of maintenance treatments that are applied.
3. To build and evaluate an operational Maintenance Decision Support System that will meet the defined functional requirements in the participating state transportation departments.
4. To improve the ability to forecast road conditions in response to changing weather and applied maintenance treatments.

The research plan for Phase I encompassed work outlined in Tasks 1 – 6 and part of Task 10. Table 1.1 indicates that nearly all of the Phase I research was directed toward research objectives 1 and 2. These objectives focused on:

- an evaluation of the MDSS environment
- the definition of specific study requirements
- the collection of support materials for the project.

9.2 Project Scope and Research Plan

The initial definition requirement was the specification of the project objectives and organizational logistics. The first step was to establish a clear definition of the research team and the responsibilities of members within this team. The definition of the Technical Panel provided the instrument to facilitate and guide the research efforts. Meridian, working with the Technical Panel, developed a contact list of the remaining support members of the research team in each of the states and established seven objectives for the Phase I work. Meridian prepared a list of all envisioned information resource materials needed for the study and proposed potential methods to collect the materials. This documentation laid the foundation for research efforts in all of the Phase I tasks.

Objective 3 in the list in section 9.0 required the deployment of a test MDSS program over multiple winters. In preparation, the states decided on the mode of implementation within their respective states. This decision included the test area, the participants, and the method of participation of their field personnel. The exchange and coordination of information amongst all participants was seen as an essential requirement of the study infrastructure, thus, Meridian established an Internet reflector address to permit an information exchange mechanism. This was followed by a web site which served as a repository for study documents and a public relations interface for the Pooled Fund Study.

9.3 Evaluate the FHWA's Functional Prototype

The work on the Functional Prototype served as an important resource in the evaluation of the MDSS environment. Meridian performed a critical evaluation of the version 1 release of the Functional Prototype, including both the software and the documentation. The review included the installation of the software and testing its operation and performance. The key findings were:

- the installation and initial execution of the FP is not simple and requires knowledgeable staff to perform the configuration of data sources and software
- technical documentation of processing logic and algorithms within modules is limited making future enhancements more difficult
- three components of the FP are prime candidates for inclusion in the PFS MDSS
  - graphical user interface
  - chemical concentration algorithm
  - road condition treatment module framework
- the design does not follow the guidelines of the National ITS Architecture making future enhancements and interoperability with other solutions considerably more difficult
- the decision support is based upon guidelines from the Manual of Practice
- the graphical user interface is well designed and provides an effective interface between the user and the decision support software

9.4 Acquisition of Maintenance Information

Task 3 of the Pooled Fund Study Research Plan sought to develop a knowledge base for the design and development of the decision support process. The content of the knowledge base included maintenance needs, practices, procedures, and guidelines. It was determined that this resource information needed to come from both published information and expertise retained by experienced field maintenance personnel. Meridian collected and consolidated published information from the following sources:

- the needs assessment work done in the FHWA Surface Transportation Weather Decision Support Requirements (STWDSR) project

- maintenance manuals and associated documentation from the states
- literature regarding maintenance practices and existing support programs

The STWDSR document became an essential foundation for the maintenance needs component of the knowledge base and Meridian used the document extensively to prepare a more detailed needs assessment evaluation. The Meridian investigators reviewed the maintenance manuals supplied by the states and determined the common elements of the manuals from the five states. The documentation provided by the five states provided considerably different levels of detail. The documentation provided by Indiana and Minnesota were quite comprehensive and detailed and become significant resources for subsequent research.

The primary information resource was the experience and expertise of the field personnel in each of the states. Over the life of the PFS, it will be necessary to transfer as much of this expertise as possible from the field people to the development team. Much of this information and the particular approaches of local maintenance staff have to be integrated into the implementation of the MDSS. Much of the effort of Task 3 focused on the development of a method to initiate the transfer of this expertise into the PFS knowledge base. The PFS panel determined that the most effective method was a series of interview sessions with Meridian personnel serving as interviewers and field personnel acting as participants. Meridian developed a set of questions based upon the background research from the STWDSR needs assessment review and the evaluation of the material in the maintenance manuals. Over a period of three months Meridian held interview sessions at 10 separate locations. The DOT participants were field supervisors or team leaders. The results of the interviews were compiled into a summary that characterized the detailed responses in eight primary categories:

- decision lead time
- level of service
- materials
- equipment
- reporting/logging
- scheduling
- weather
- winter scenarios

The detail from these interviews was integrated into the knowledge base and will be instrumental support for the development of the decision support logic in the PFS MDSS.

9.5 Assessment of Road Condition Reporting Capabilities

The other information resource required in the Phase I Research Plan was an assessment of the resources to collect maintenance specific information from the field and integrate it into the proposed

MDSS program. Meridian reviewed the existing road reporting activity in each of the states and summarized the current programs and development efforts in progress. All states have a road reporting service of some nature. Road reporting in Indiana, Iowa, and Minnesota is a continuous process whereas Indiana, North Dakota and South Dakota provide updates during specified time periods. The transfer of the information from the collection mechanism also varied from continuous updates to periodic transfer for public consumption and a lack of standardized data exchange protocol limits the exchange of road reporting data between states or to a centralized collection and display facility.

Meridian also reviewed the existing and planned maintenance activity tracking capabilities in the PFS states. Current programs use manual procedures to log and transfer maintenance actions and are primarily limited to the use of materials to support inventory control. Initial efforts have begun or are in planning to implement or expand experimental programs using Automated Vehicle Location (AVL) monitoring and reporting capabilities but none of the programs enjoys widespread participation yet. Meridian summarized the status of the maintenance tracking programs and indicated the gap that exists between maintenance data requirements and the data acquisition capabilities of operational capabilities.

9.6 Institutional Receptivity to Maintenance Decision Support

Technology has become more pervasive both in maintenance operations and in the tools provided to support decision processes. The members of the PFS team felt it was important to assess the receptivity of technology and technological innovations within their maintenance staffs. Meridian, working with the Technical Panel, determined that the assessment needed to encompass a broad spectrum of DOT personnel and a formal survey was the best instrument. The team determined the design of the survey and the questions within it should not show bias or in any way attempt to direct or coax specific answers. After several iterations the team agreed upon the survey composition and it was distributed to 1162 DOT employees in the five states.

The survey was designed to assess the user's current operational environment and receptivity to technology. The results indicate that technology is viewed as an asset and is accepted by most DOT personnel. In fact, the survey results infer that users would like to have access to and use computer resources more than they do now. Many are limited in the use of the Internet and the some of the processing capabilities because of institutional limitations. Roughly 25% of the respondents have no access or limited access to computer resources at their location. This fact impacted a number of questions on the survey because users could not relate to some of the other questions that really required previous Internet experience. For those who do have access to an Internet interface and who use the Internet, they see value in technological resources and programs similar to MDSS in their decision making processes. However, even the more experienced users indicated that operational resources (availability of personnel, equipment, and materials) were more important factors in their decision process than were technological tools such as RWIS and MDSS. The conclusion from the survey was that technology advances are an accepted tool amongst maintenance personnel and users will integrate them into their daily operations if the tool proves its merit.

9.7 Operational Maintenance Decision Support System Requirements

The creation of a comprehensive and fully functional MDSS is a substantial, multi-year project. However, the development process is modular and must follow a high-level system design (i.e. architecture) that incorporates relative functional and user requirements.

The basic functional infrastructure of the MDSS is described in the body of the Phase I report. The fundamental architecture of the FHWA MDSS Functional Prototype is very similar to that of the MDSS Pooled Fund Study except in two areas. The design of the Weather component the MDSS FP uses a completely automated forecasting technique, whereas the MDSS PFS design incorporates a forecasting technique that integrates computer based processing and the expertise of professional meteorologists. The other departure is in the design of the Process and Integration component the MDSS FP. The Functional Prototype uses the FHWA Rules of Practice (based upon "normal" maintenance experience) to generate appropriate response scenarios, where the MDSS PFS views each weather induced situation as unique and the appropriate response is based upon the physics and chemistry of the processes occurring on the pavement surface.

One of the primary design requirements of the Pooled Fund Study was that it meet the standards of the National ITS Architecture (NITSA) and be developed in a modular infrastructure that permits interoperability and interchangeability with modular components subsequently developed by other vendors. To meet this Technical Panel requirement, Meridian evaluated the design within the framework of NITSA. Within v4.0 of the National ITS Architecture, MDSS falls into the Maintenance and Construction Management subsystem. MDSS data flows were identified and correlated to the NITSA. Meridian will work with each participating DOT to ensure that the MDSS complies with their respective state or regional ITS architectures. Non-meteorological decisions modules will also be included.

9.8 Fundamental Research Needs

The multi-disciplinary nature of winter maintenance has unfortunately left many of the fundamental research needs of MDSS outside of the core research focus of any one discipline. As a result, a thorough research-based foundation on which to construct many of the components of a successful operational MDSS is lacking. Meridian has devised the following 'short-list' of research needs as part of the PFS Phase I effort:

- Chemical concentration and freeze-point computation
- Percent ice in slush mixture
- Traction index
- Blowing snow
- Chemical residue
- Frost
- Latent heat effects of chemical application

- Plowing techniques
- Material application estimation
- Road condition reporting
- Chemical migration and dissolution in slush
- Chemical mixing as a function of traffic volumes
- Grit migration
- Long wave radiation balance
- Bonding of snow to pavement surfaces
- Traffic simulation
- Contaminant layer composition during precipitation

These research needs are discussed in more detail in Chapter 8. The fundamental gaps in the research basis for each of these needs vary, with some processes being better understood than others. Performing thorough basic research on all of these topics is well beyond the scope of the present PFS MDSS development effort. However, many of the listed needs are so essential to a successful MDSS that Meridian will nonetheless need to model or parameterize them to some degree. Much of this will need to be done using sound science and inferences building upon the existing research database, although more basic research may also be performed as deemed appropriate by the PFS Technical Panel.

9.9 Recommendations

Phase I focused on the collection of support information and the establishment of a sound design; the next primary objective is the conversion of this foundation work into an operational Maintenance Decision Support System. The expertise gained from the efforts employed during Phase I provided insight into the relative importance of critical factors in the project research plan and what factors may need more emphasis or greater attention going forward. This section summarizes what Meridian views as key recommendations evolving from the Phase I experience.

The knowledge base commenced in Phase I is fundamental to the ongoing development effort and efforts must continue to expand and evolve the knowledge base to support the implementation of an operational PFS MDSS. Particular emphasis must be directed toward the collection of detailed information on DOT resources (equipment, materials, personnel scheduling guidelines), operational techniques, procedures, and local practices. More emphasis needs to be directed toward the development of a clear understanding of the communications and information technology infrastructure and associated operating guidelines within each of the states. The team must review and integrate considerable complex scientific and technological information in order to enhance the functionality of the MDSS. In this process the PFS research team needs to be instrumental in recommending and supporting fundamental research efforts for the benefit of the broader MDSS program.

The PFS research team also needs to put considerable effort into understanding the fundamentals of the graphical user interface (GUI) effort. Interactions with DOT field personnel during Phase I suggest that the expertise level of eventual MDSS users will be quite diverse both in regards to technological issues and computers. Development of the GUI needs to address this fact and possibly permit different interface levels. The design effort must also address the GUI from the user's perspective rather than from the technological viewpoint since the user's perception of the GUI's value will considerably affect its use and effectiveness. User convenience must be a dominant guideline.

Phase I permitted investigators a general view of user receptivity throughout the five states; however, demographic information collected with the surveys needs to be used to refine our receptivity findings. Although, direct survey results were concluded in Phase I, the investigators need to log responses regarding survey topics obtained during the collection of other knowledge base information. It may also be valuable to redo the survey towards the end of the project to assess changes in attitude.

The implementation of the MDSS architecture becomes the focus of efforts in Phase II. Much of the background review efforts and the extended design efforts become critical resources in this implementation. These efforts reinforced the Technical Panel's intent to create a MDSS solution that was modular in design and permitted module interoperability and interchangeability. Based upon Phase I findings Meridian recommends that modularity should remain a primary emphasis of the PFS project and development should follow the guidelines of the National Intelligent Transportation System Architecture (NITSA). Further, the PFS should emphasize the NITSA approach and fully document the design efforts making recommendations to the appropriate committees on standards for modification of the architecture to effectively integrate MDSS into the NITSA. Interprocess communications is a key element of the modular design. Once the module interface structures are defined and the exchange protocols are established, the PFS should make recommendations for the adoption of these protocols standards. The PFS team needs to take the lead in the specification of the MDSS architecture.

The basic MDSS design contains five primary elements: weather, road condition analysis & forecasting, decision logic, maintenance information, and GUI. The maintenance information component is only minimally developed to support the PFS MDSS processing requirements. Meridian needs to work with the states to further define the maintenance data requirements for MDSS, complete the evaluation of the support infrastructure needed to support the transfer of data from the field to a MDSS processing site, and evaluate potential mechanisms to gather the desired information in the field.

APPENDIX A: ACRONYMS

Acronym	Description
AASHTO	American Association of State Highway and Transportation Officials
ATIS	Advanced Travel Information System
AVL	Automated Vehicle Location
CARS	Condition Acquisition And Reporting System
CRREL	Cold Regions Research and Engineering Laboratory
DOT	Department of Transportation
FHWA	Federal Highway Administration
FP	Functional Prototype
GUI	Graphical User Interface
HiCAPS	Highway Condition Analysis and Prediction System
ITS	Intelligent Transportation System
ITS-JPO	Intelligent Transportation System Joint Program Office
IADOT	Iowa Department of Transportation
INDOT	Indiana Department of Transportation
LDM	Local Data Manager
LOS	Level of Service
MCM	Maintenance and Construction Management
MDSS	Maintenance Decision Support System
MnCARS	Minnesota Condition Acquisition And Reporting System
MNDOT	Minnesota Department of Transportation
MOS	Model output statistics
NACE	National Association of County Engineers
NCAR	National Center for Atmospheric Research
NDDOT	North Dakota Department of Transportation
NetCDF	Network common data format
NITSA	National ITS Architecture
NOAA	National Oceanographic and Atmospheric Administration
NSSL	National Severe Storms Lab
PDF	Portable Document Format
PFS	Pooled Fund Study
RCTM	Road Condition and Treatment Module
RCTS	Road Condition and Treatment Subsystem
RWFS	Road Weather Forecasting System
RWIS	Road Weather Information System
SDDOT	South Dakota Department of Transportation
SHRP	Strategic Highway Research Program
SNTHERM	Road Temperature Module
STWDSR	Surface Transportation Weather Decision Support Requirements
TMDD	Traffic Management Data Dictionary
WIST-DSS	Weather Information for Surface Transportation Decision Support System

APPENDIX B: **DATA FLOW DIAGRAMS**

In the following data flow diagrams, the following conventions are followed:

- Grayed boxes denote processes or terminators external to the process.
- Rounded rectangle boxes are Level 1 processes.
- Solid lines are data flows.
- Dashed lines are controls.
- Data flow labels conform to NITSA conventions for MDSS.
- Parallel horizontal lines are data stores.

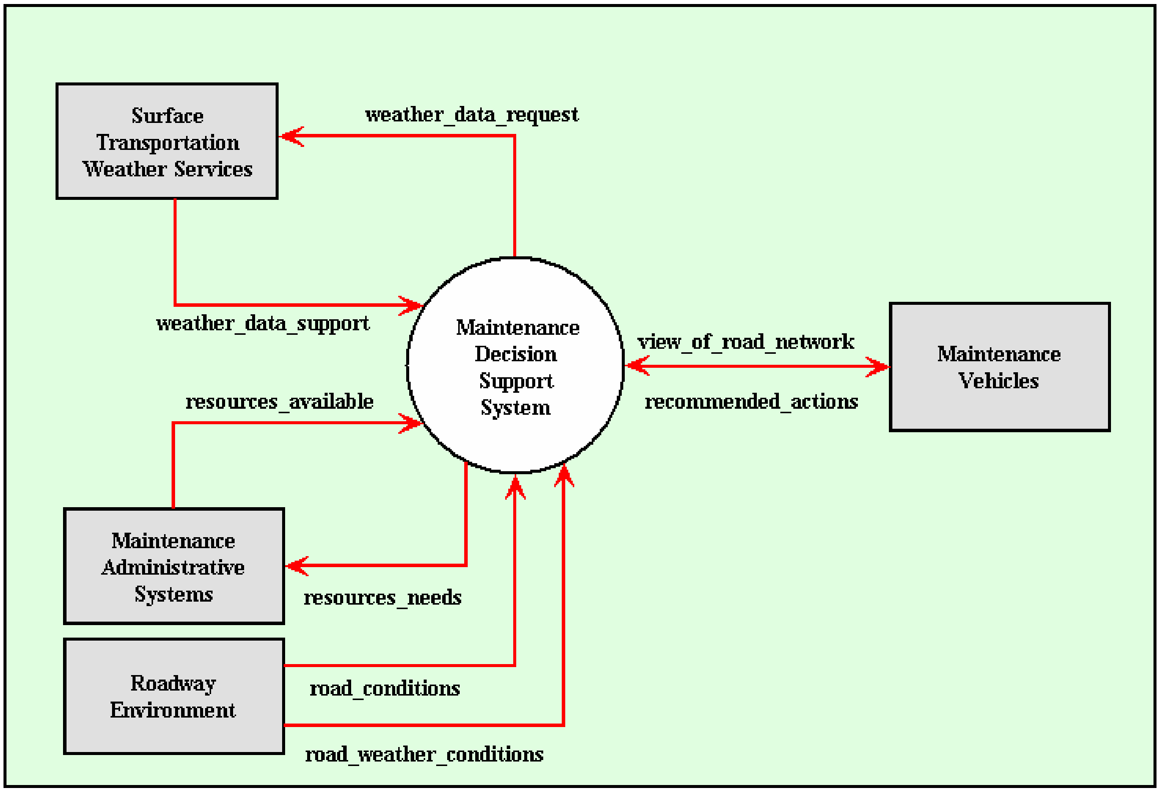

Figure B-1 Pooled Fund MDSS Context Diagram

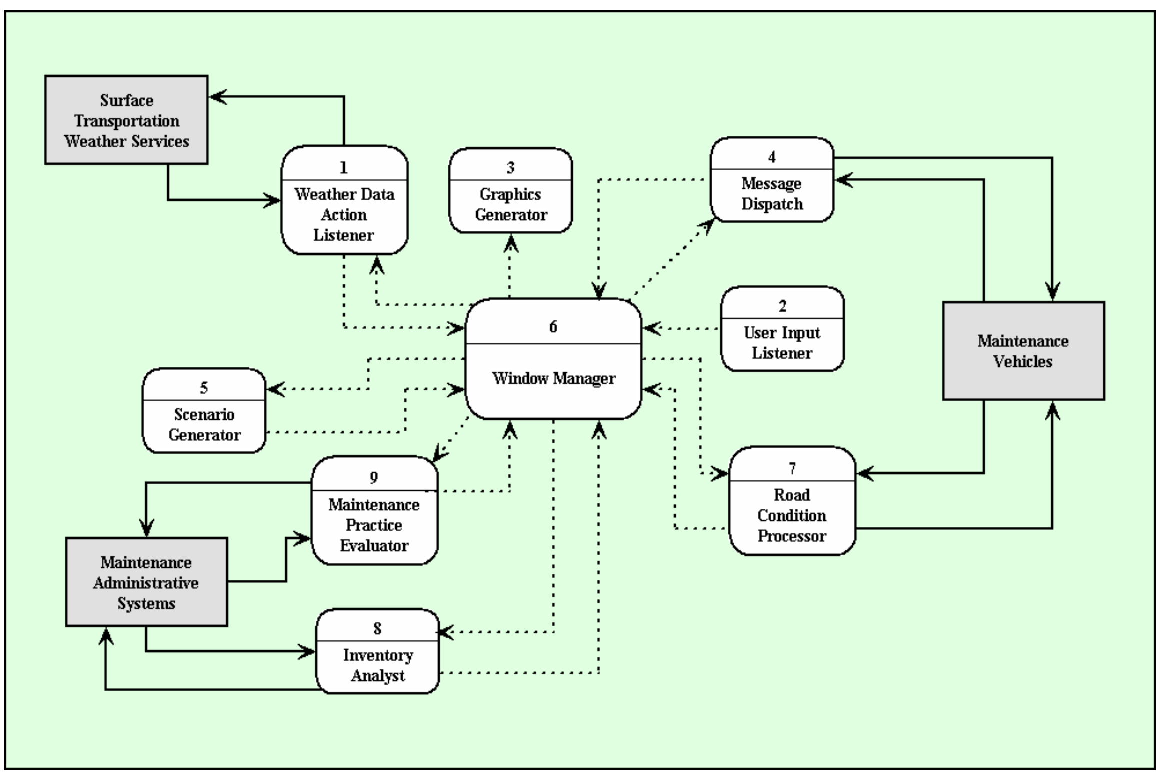

Figure B-2 Pooled Fund MDSS Level 1 Data Flow Diagram

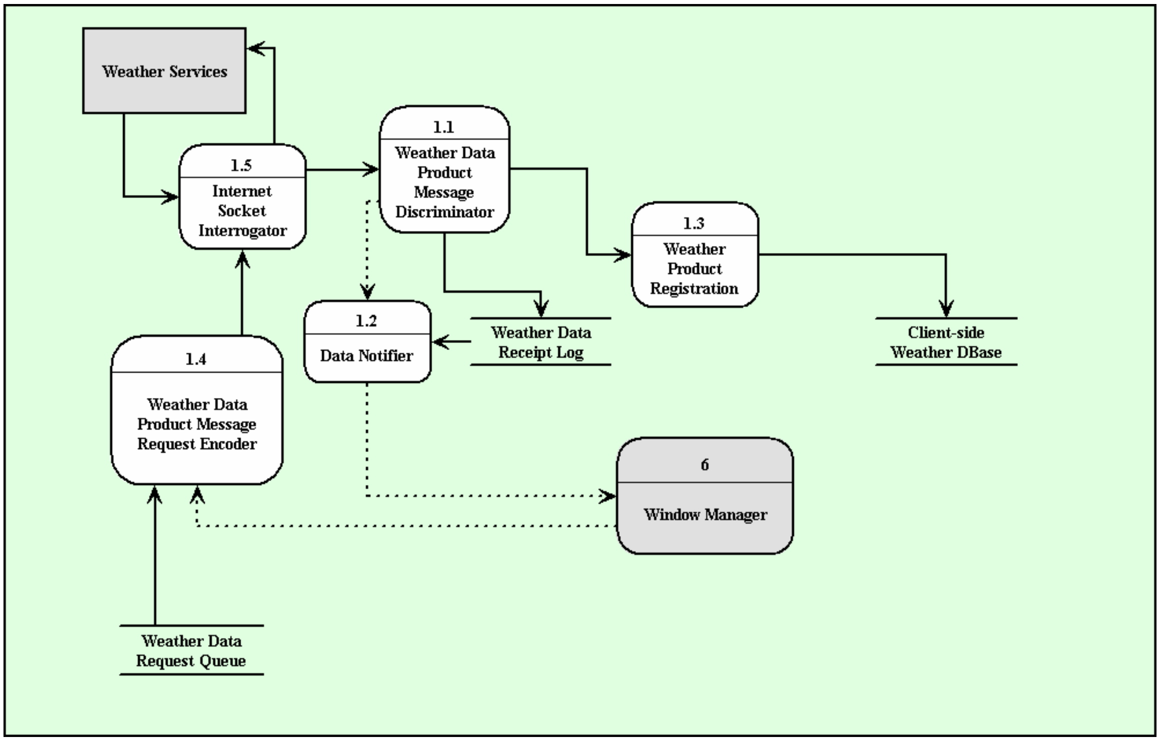

Figure B-3 Pooled Fund MDSS Level 2 Data Flow Diagram for the Weather Data Action Listener Process

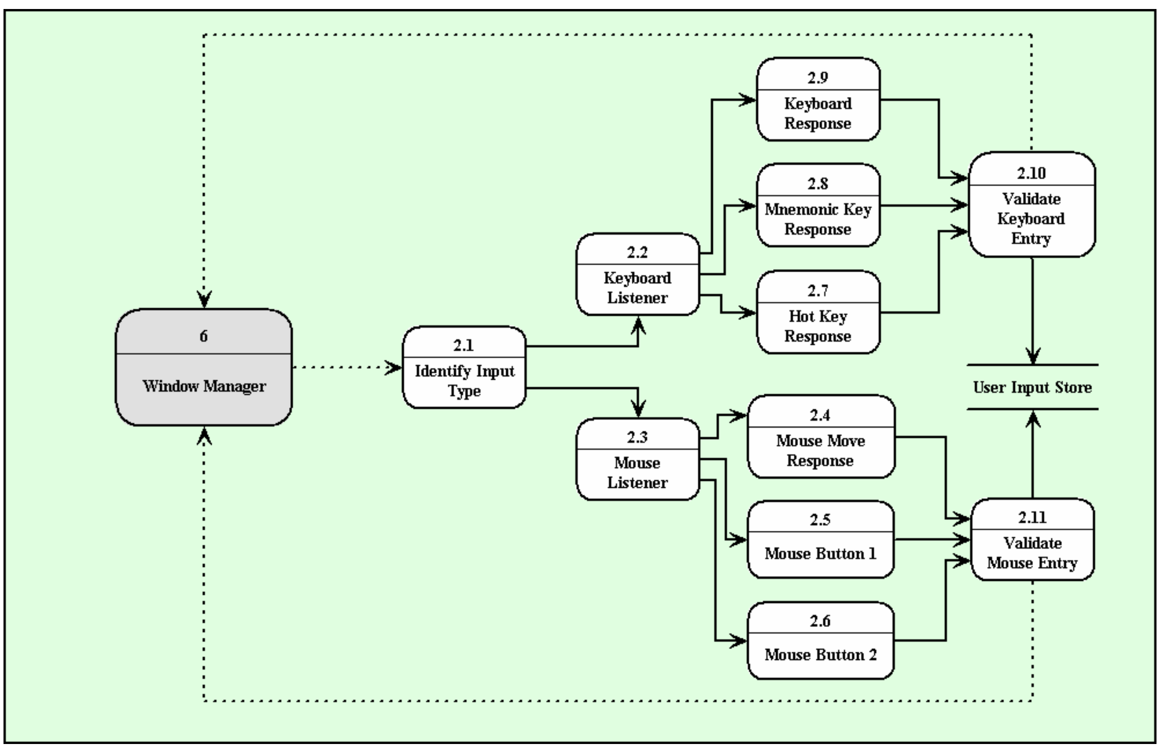

Figure B-4 Pooled Fund MDSS Level 2 Data Flow Diagram for the User Input Listener Process

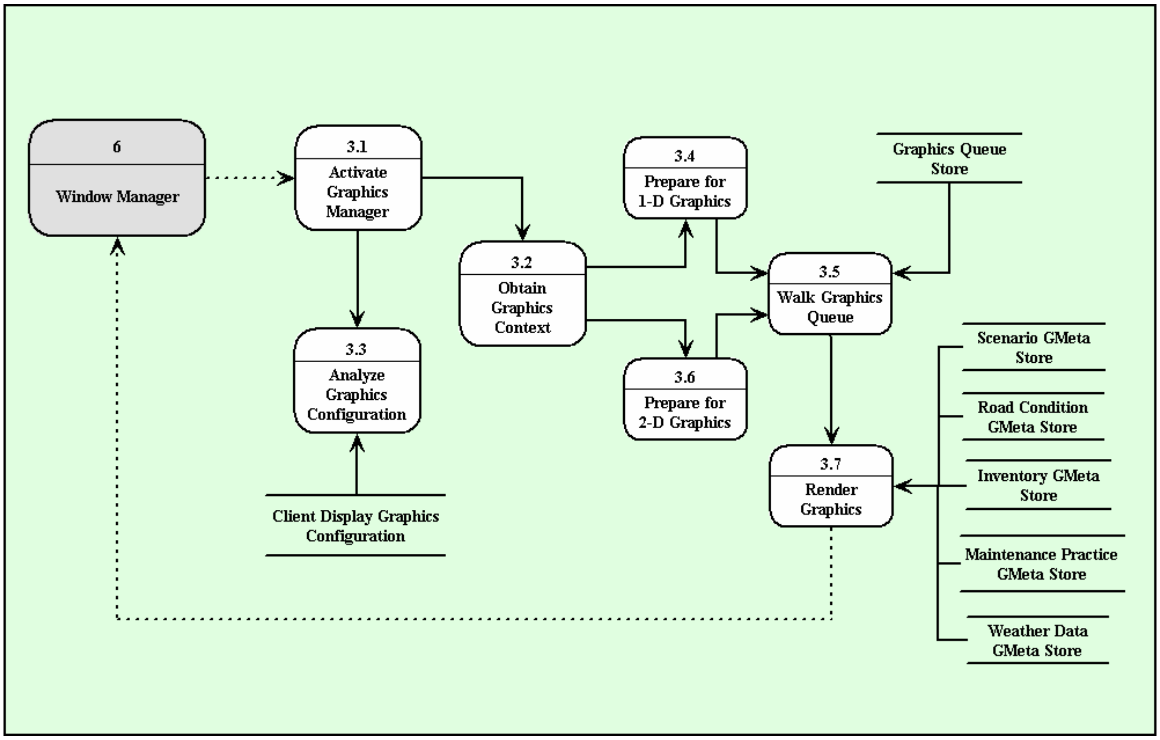

Figure B-5 Pooled Fund MDSS Level 2 Data Flow Diagram for the Graphics Generator

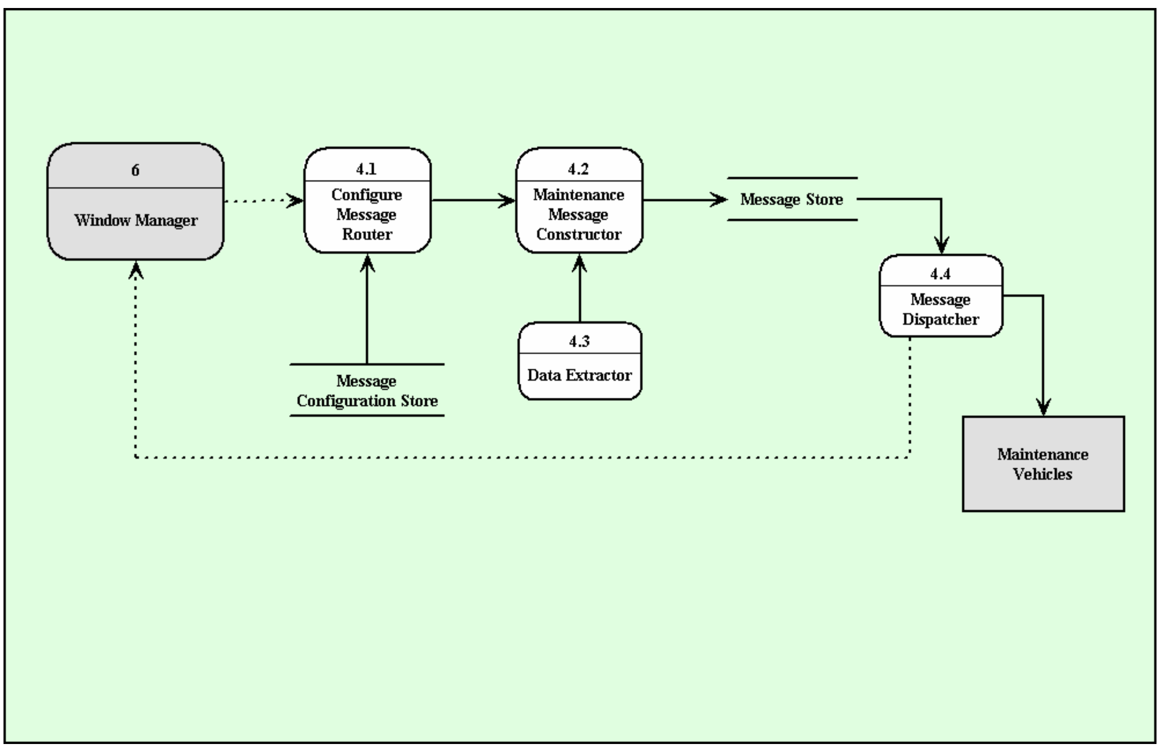

Figure B-6 Pooled Fund MDSS Level 2 Data Flow Diagram for the Message Dispatch

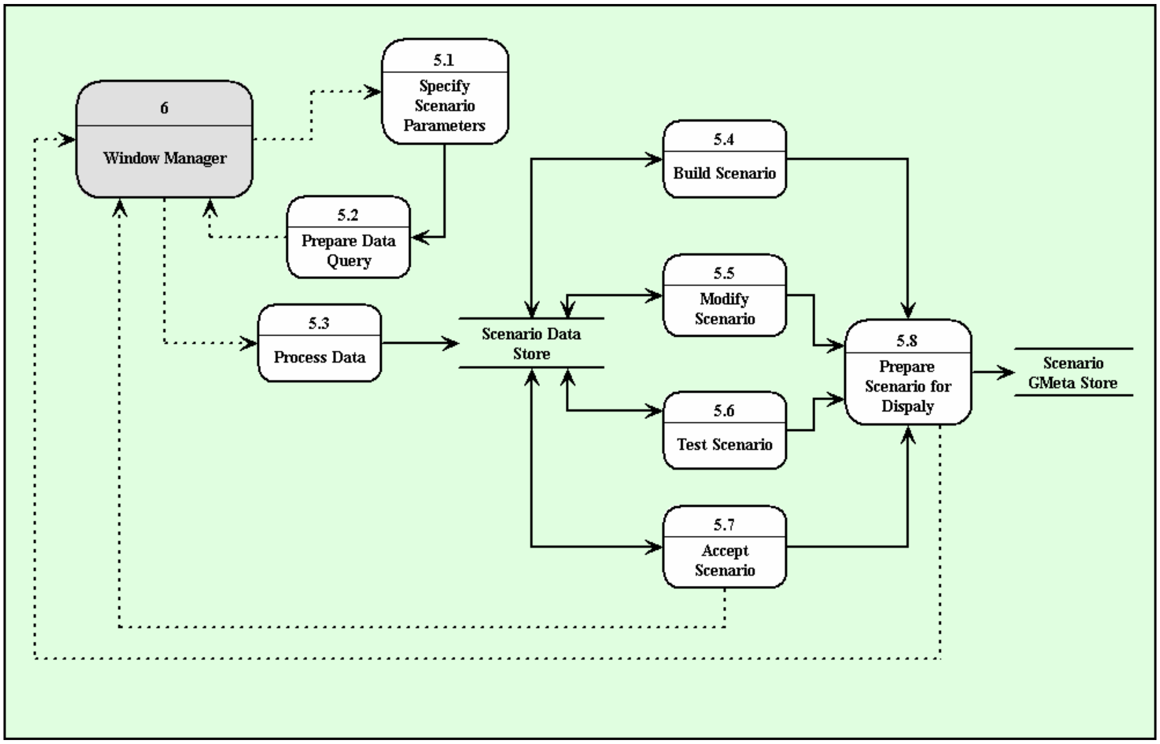

Figure B-7 Pooled Fund MDSS Level 2 Data Flow Diagram for the Scenario Generator Process

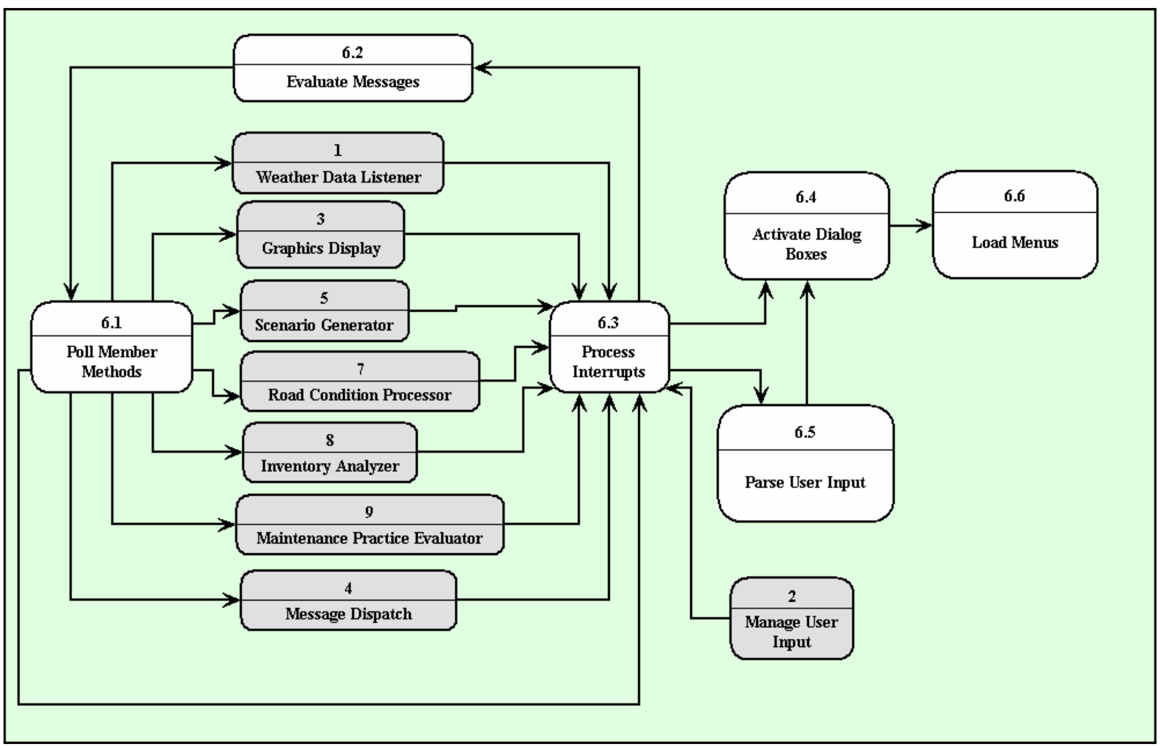

Figure B-8 Pooled Fund MDSS Level 2 Data Flow Diagram for the Window Manager Process

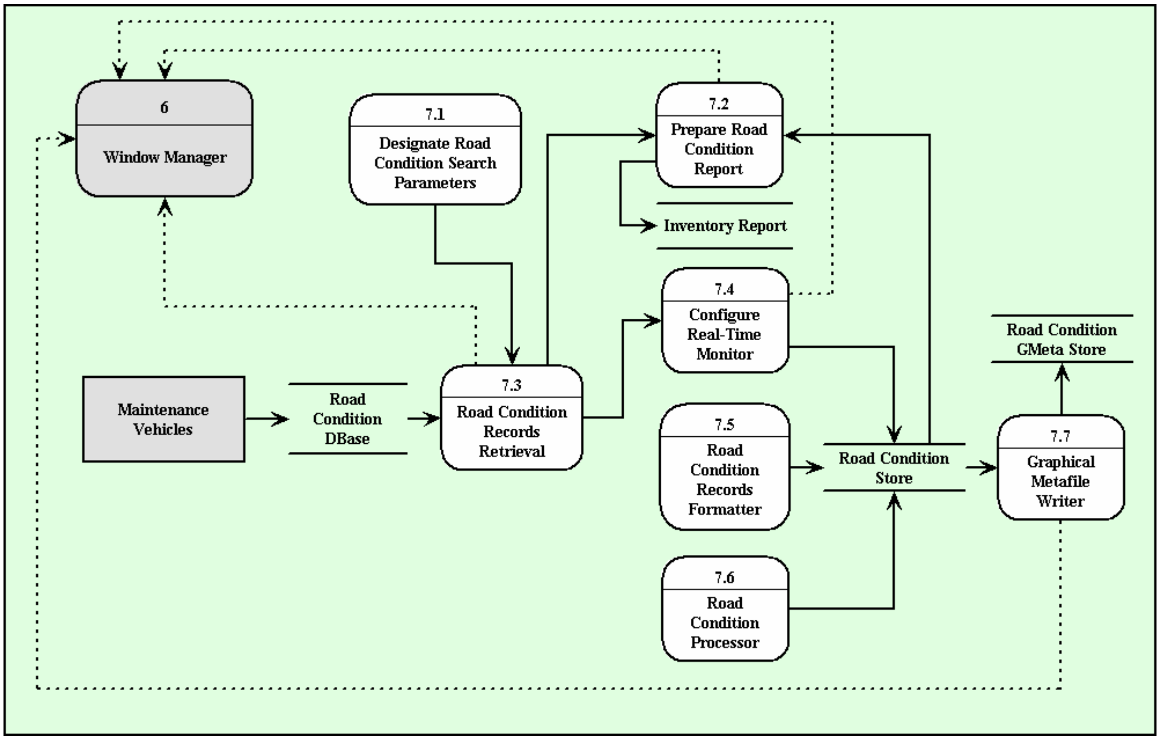

Figure B-9 Pooled Fund MDSS Level 2 Data Flow Diagram for the Road Condition Processor

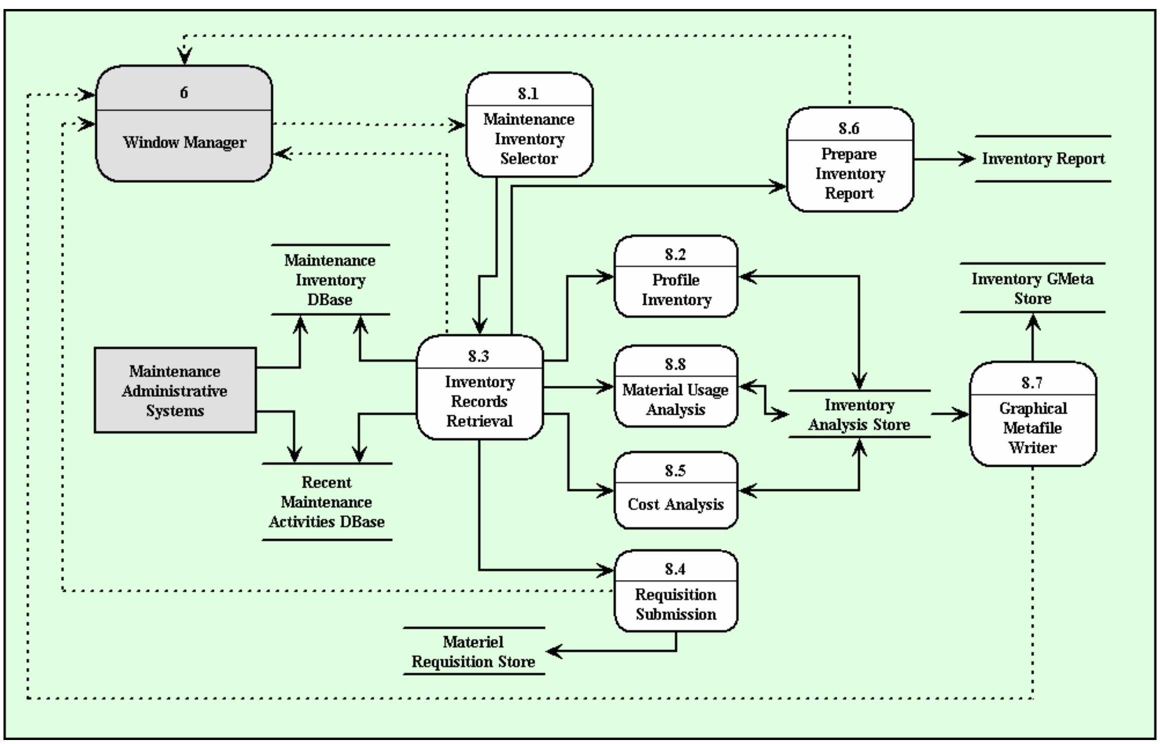

Figure B-10 Pooled Fund MDSS Level 2 Data Flow Diagram for the Inventory Analyst Process

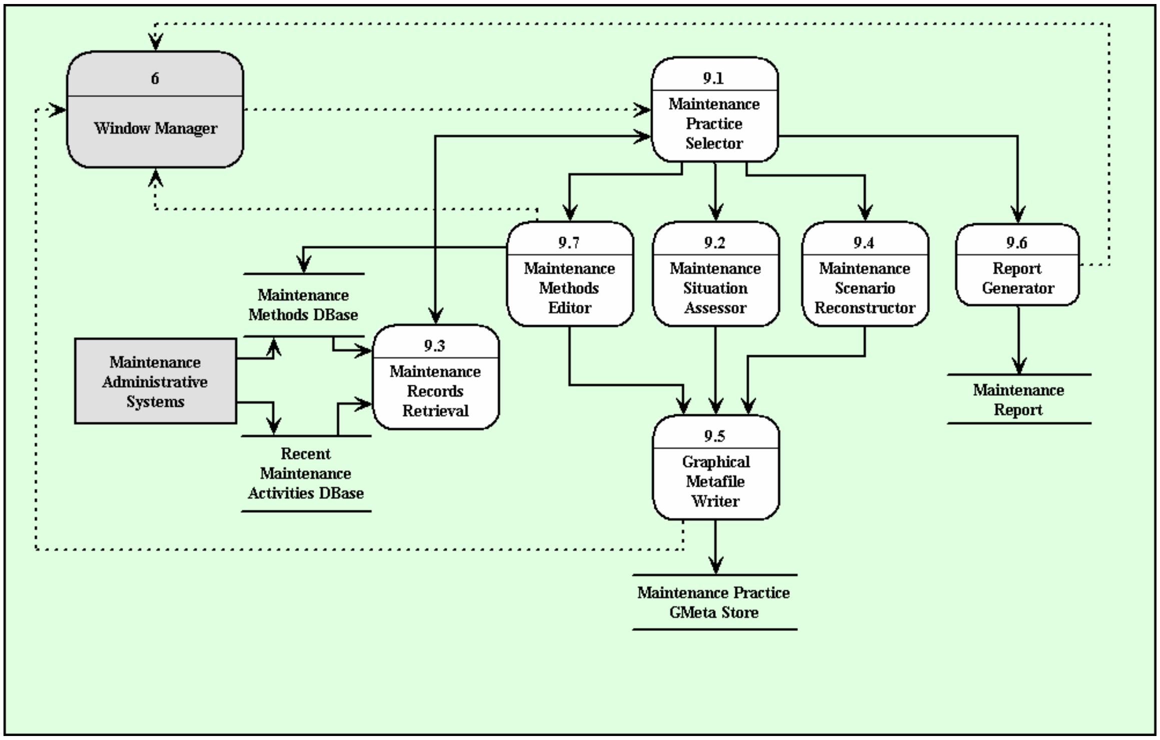

Figure B-11 Pooled Fund MDSS Level 2 Diagram for the Maintenance Practice Evaluator Process

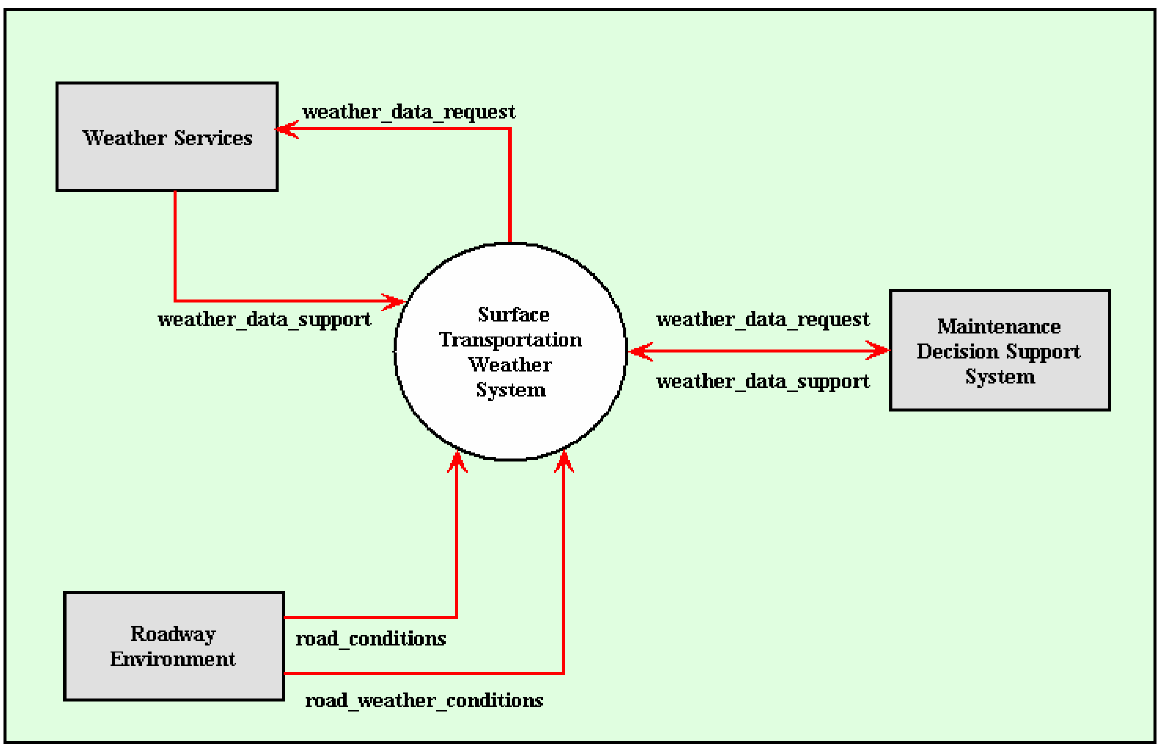

Figure B-12 Pooled Fund MDSS Context Diagram for the Surface Transportation Weather System (STWx)

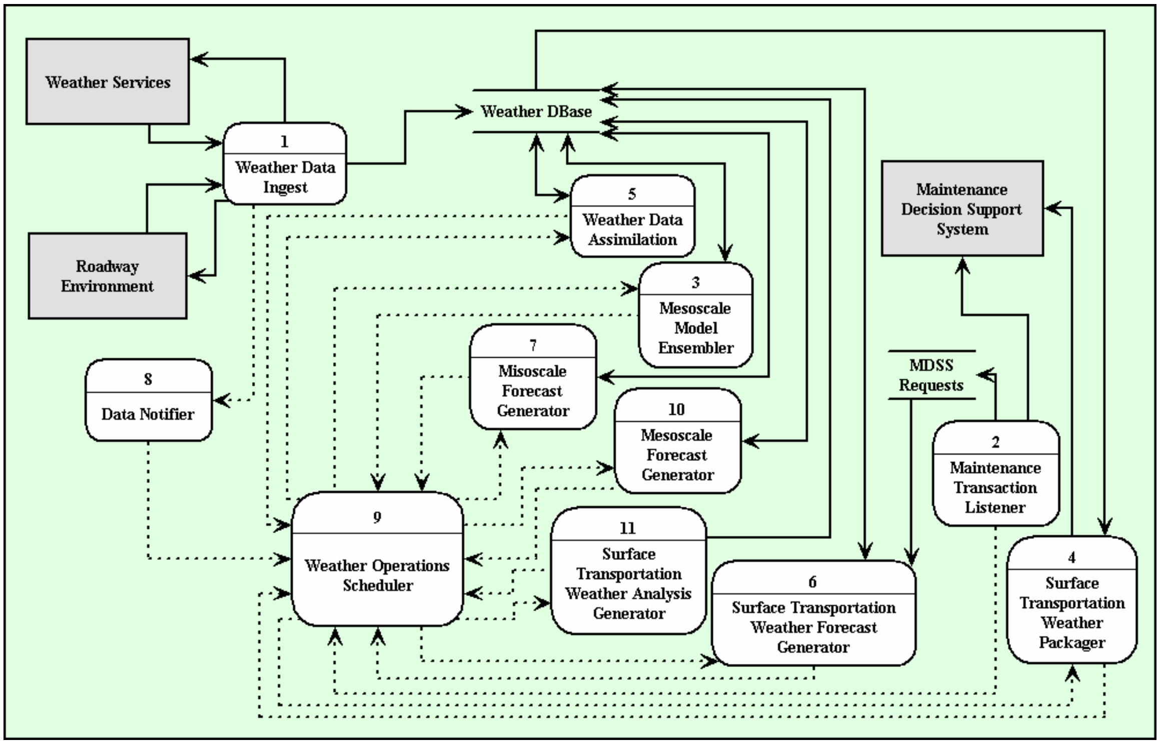

Figure B-13 Pooled Fund MDSS STWx Level 1 Data Flow Diagram

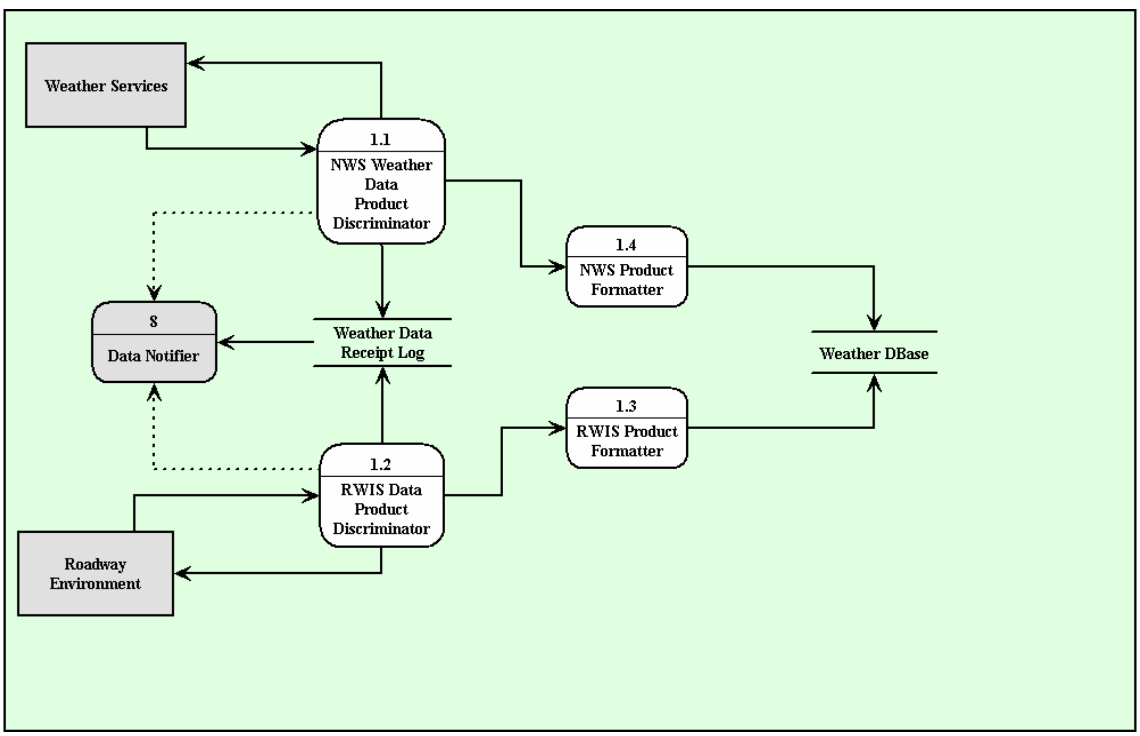

Figure B-14 Pooled Fund MDSS STWx Level 2 Data Flow Diagram for the Weather Data Ingest Process

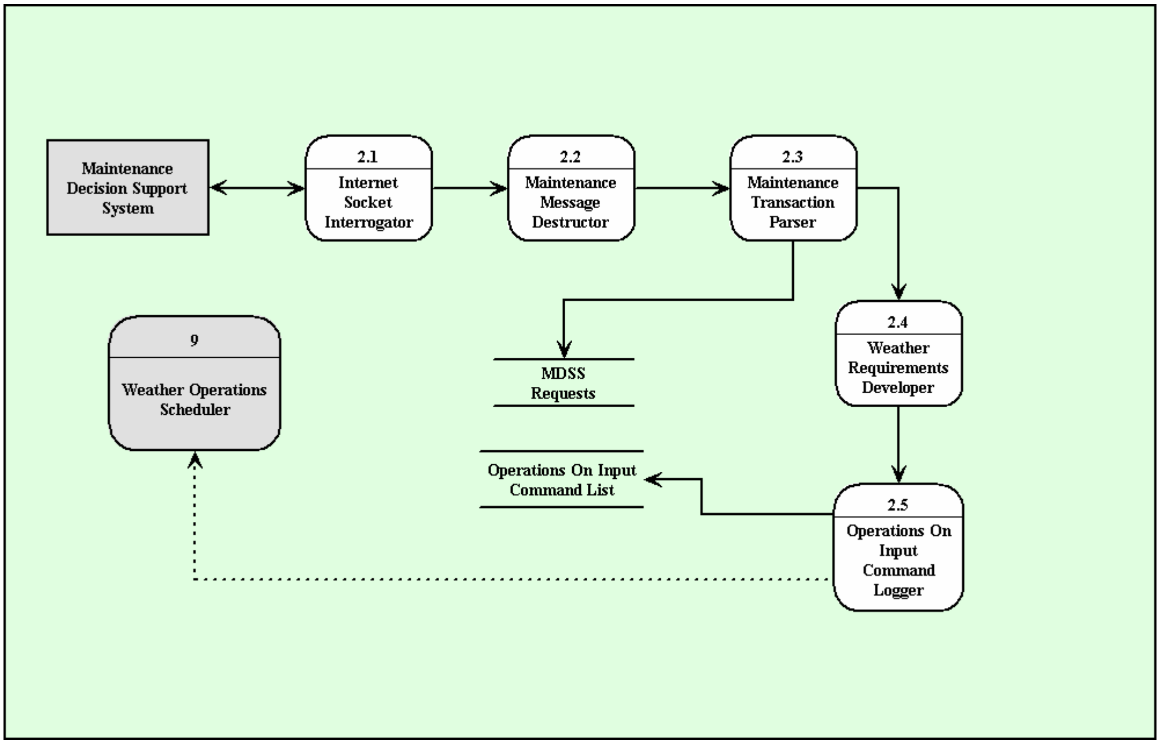

Figure B-15 Pooled Fund MDSS STWx Level 2 Data Flow Diagram for the Maintenance Transaction Listener

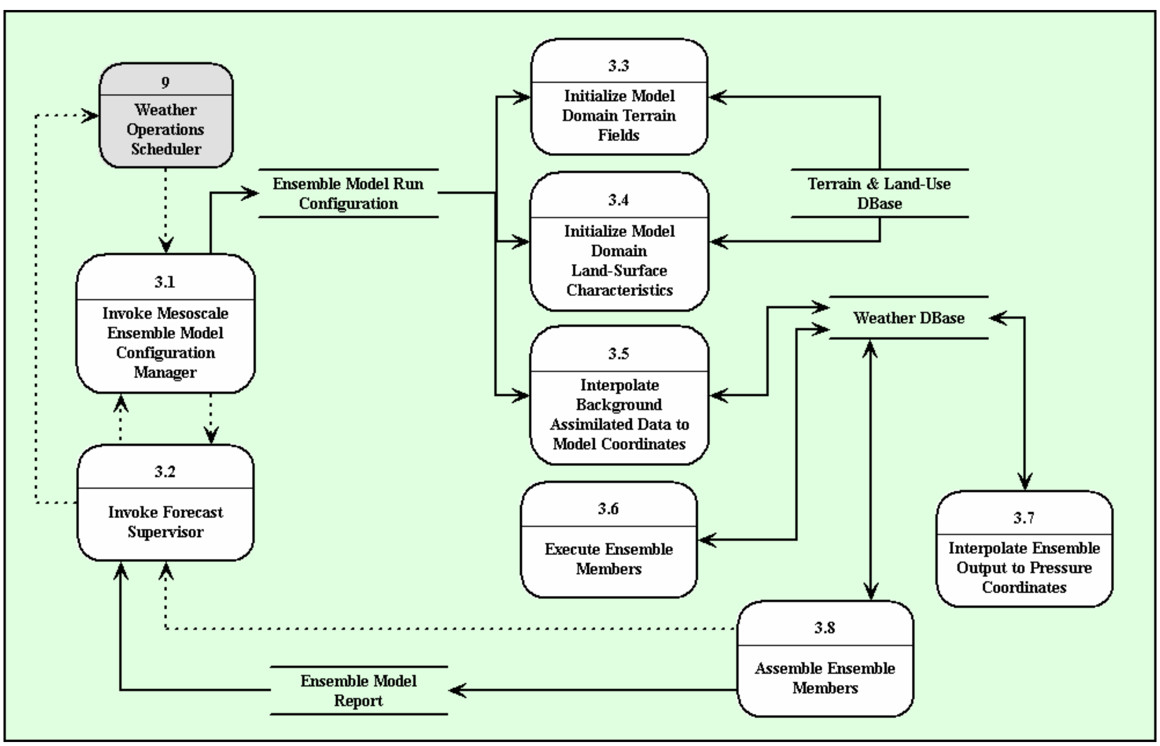

Figure B-16 Pooled Fund MDSS STWx Level 2 Data Flow Diagram for the Mesoscale Model Ensembler

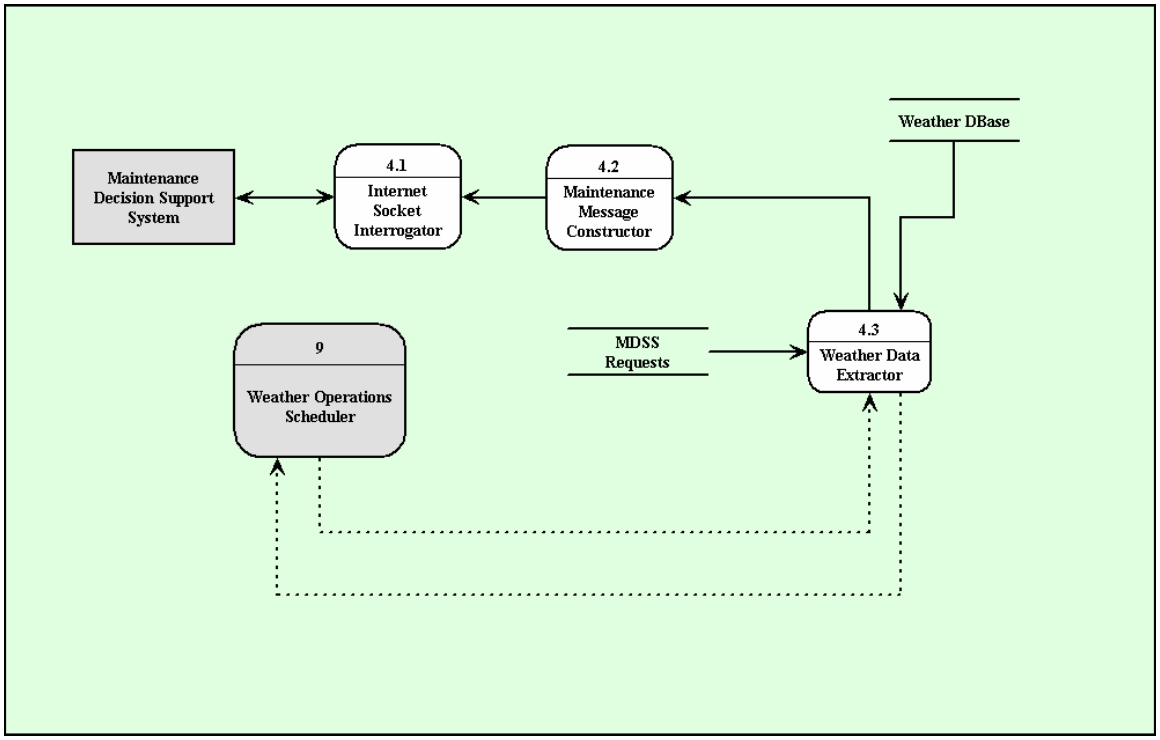

Figure B-17 Pooled Fund MDSS STWx Level 2 Data Flow Diagram for the Surface Transportation Weather Packager Process

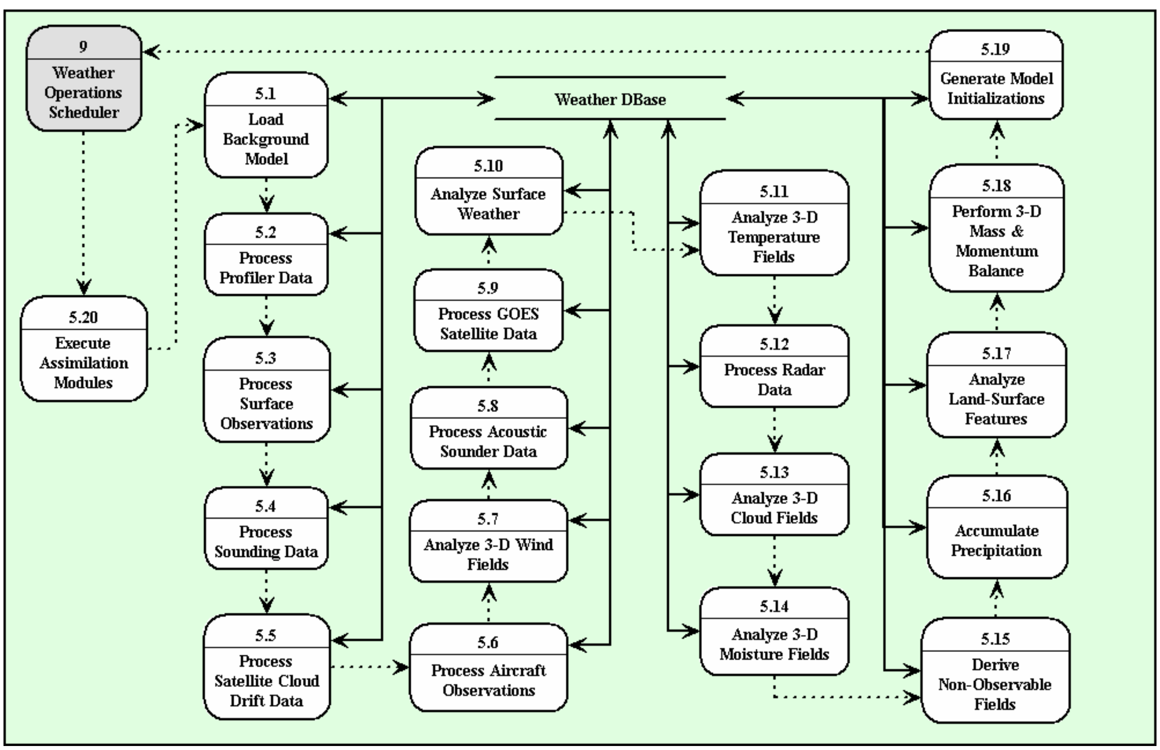

Figure B-18 Pooled Fund MDSS STWx Level 2 Data Flow Diagram for the Weather Data Assimilation Process

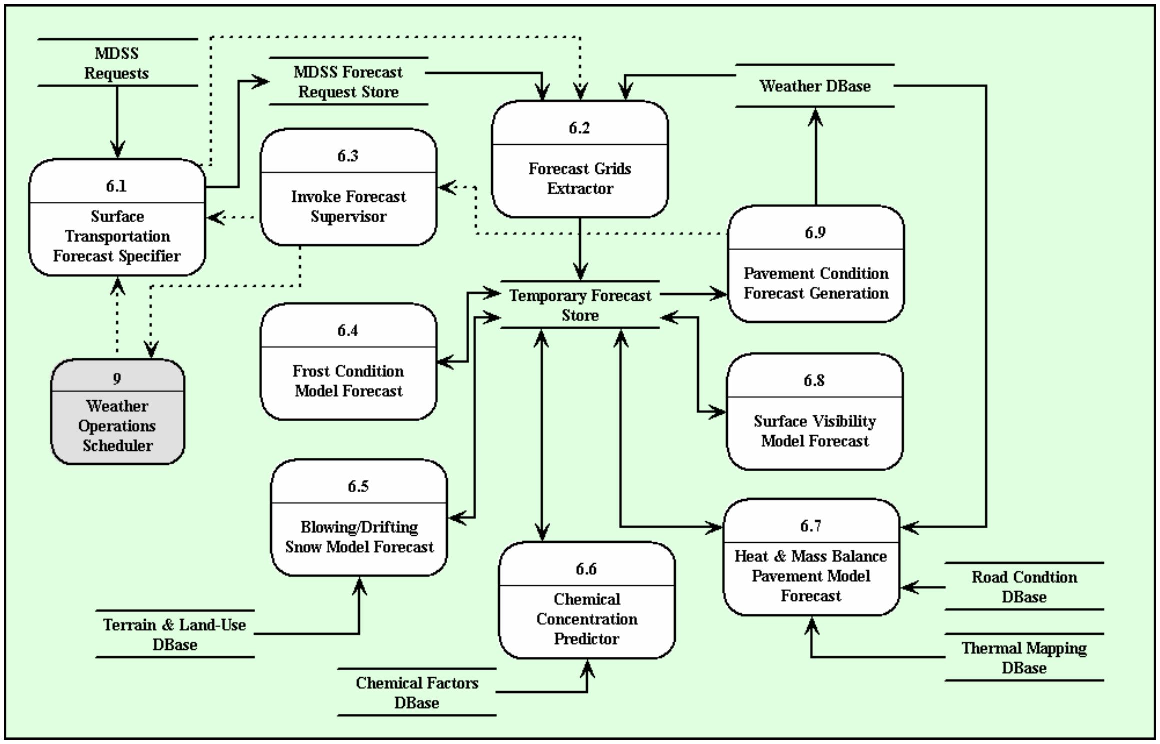

Figure B-19 Pooled Fund MDSS STWx Level 2 Data Flow Diagram for the Surface Transportation Forecast Generator Process

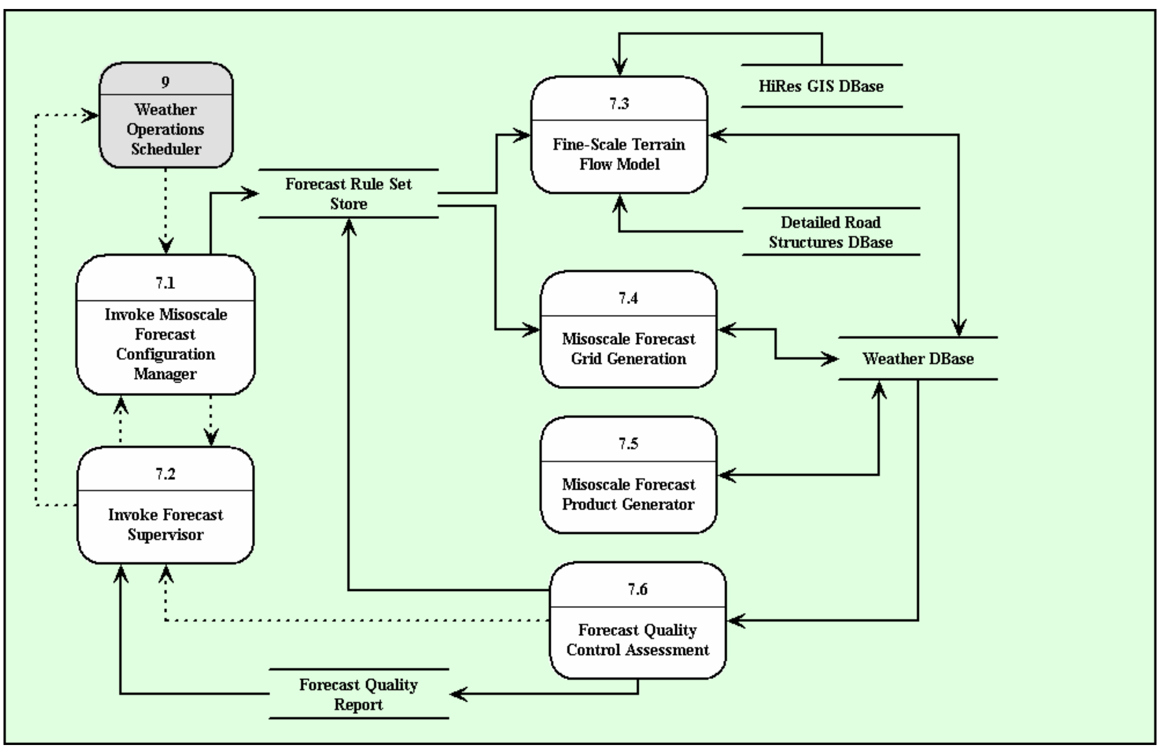

Figure B-20 Pooled Fund MDSS STWx Level 2 Data Flow Diagram for the Misoscale Forecast Generator Process

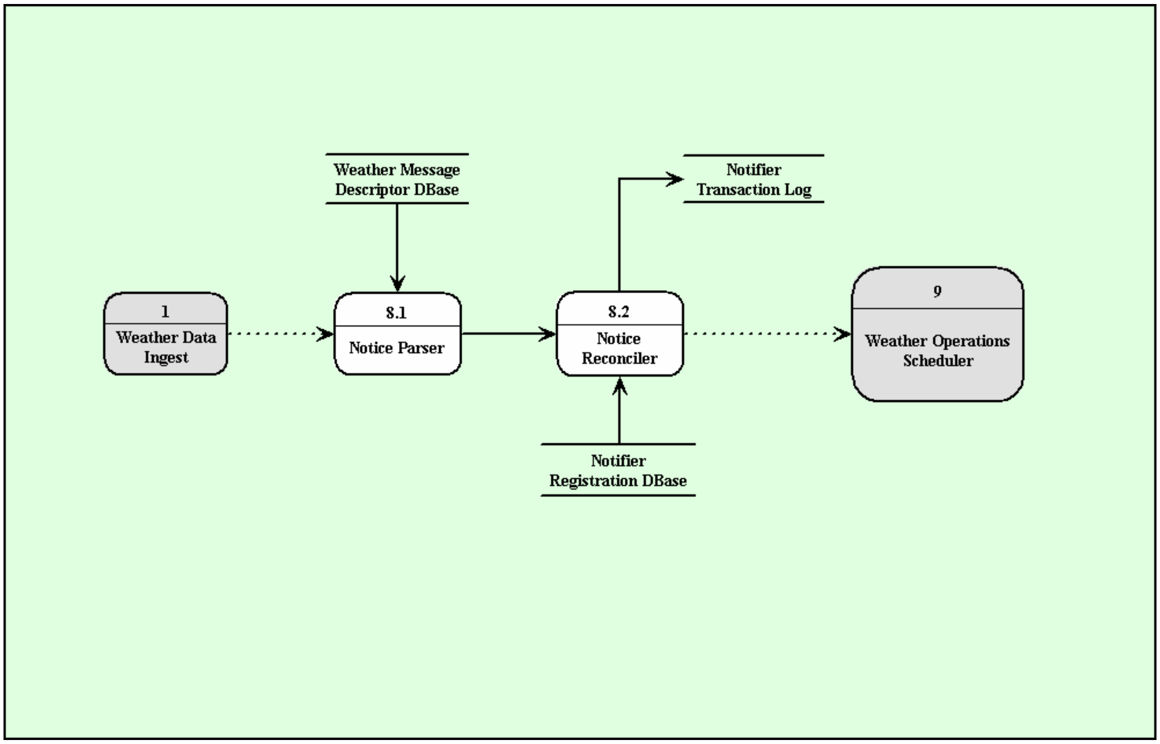

Figure B-21 Pooled Fund MDSS STWx Level 2 Data Flow Diagram for the Data Notifier Process

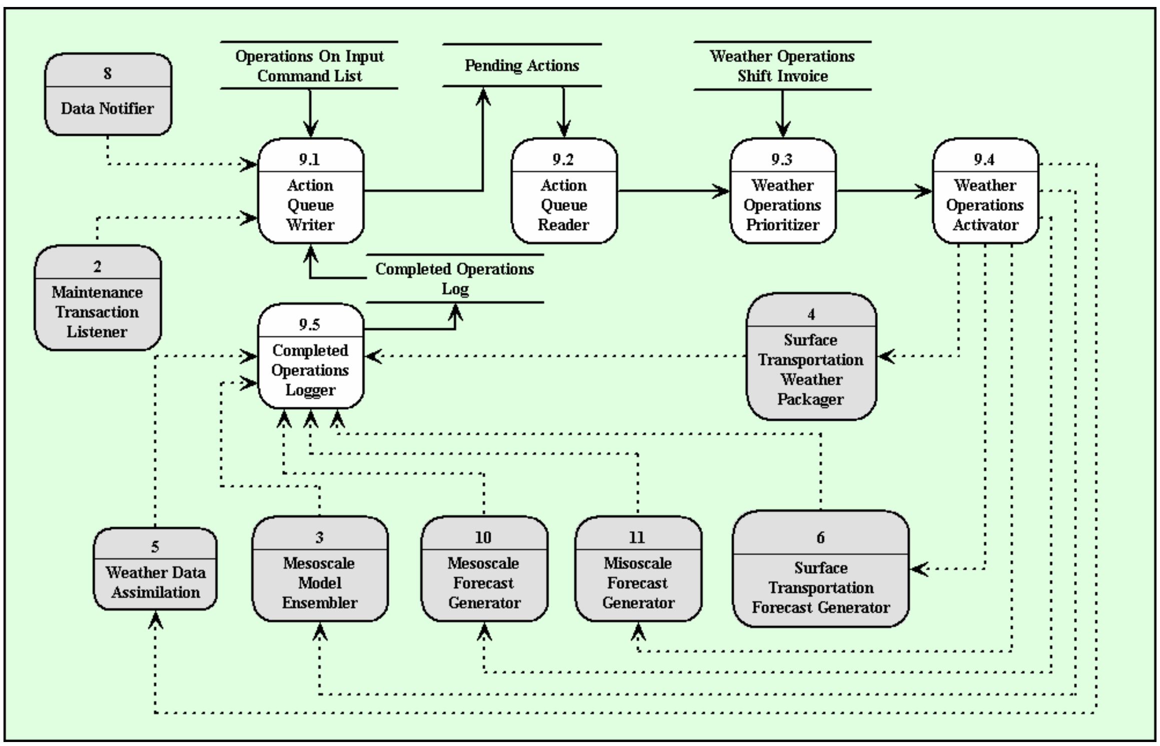

Figure B-22 Pooled Fund MDSS Level 2 Data Flow Diagram for the Weather Operations Scheduler Process

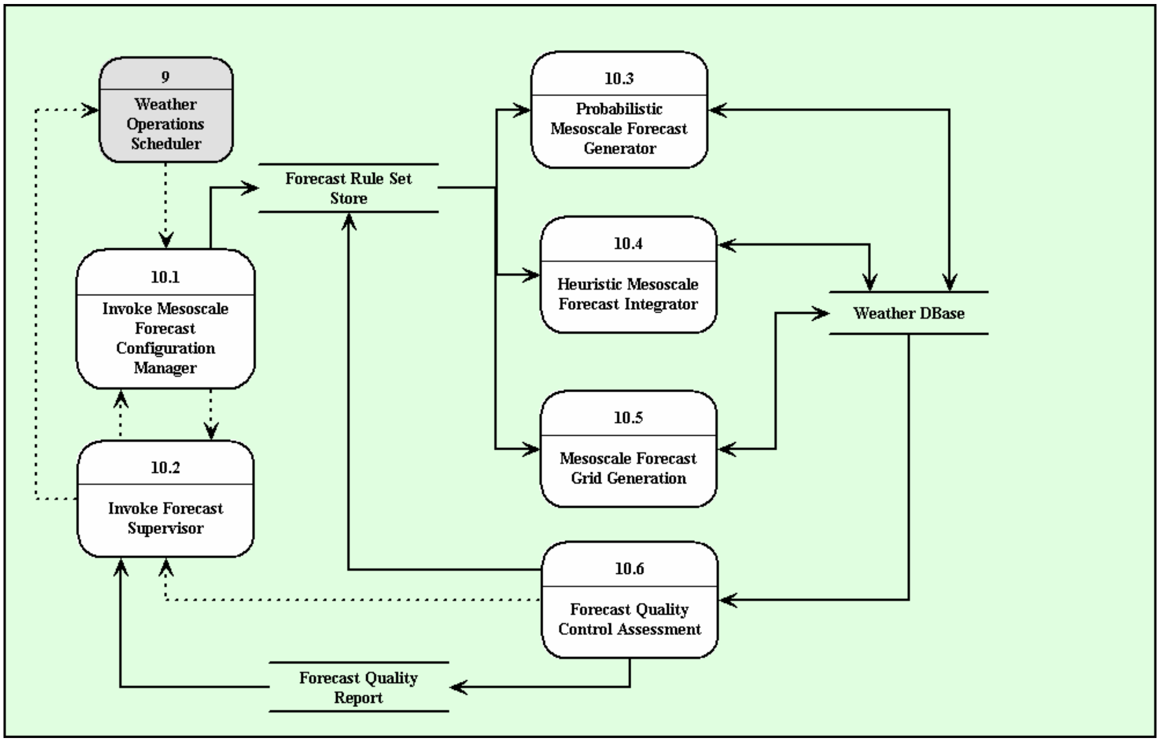

Figure B-23 Pooled Fund MDSS STWx Level 2 Data Flow Diagram for the Mesoscale Forecast Generator Process

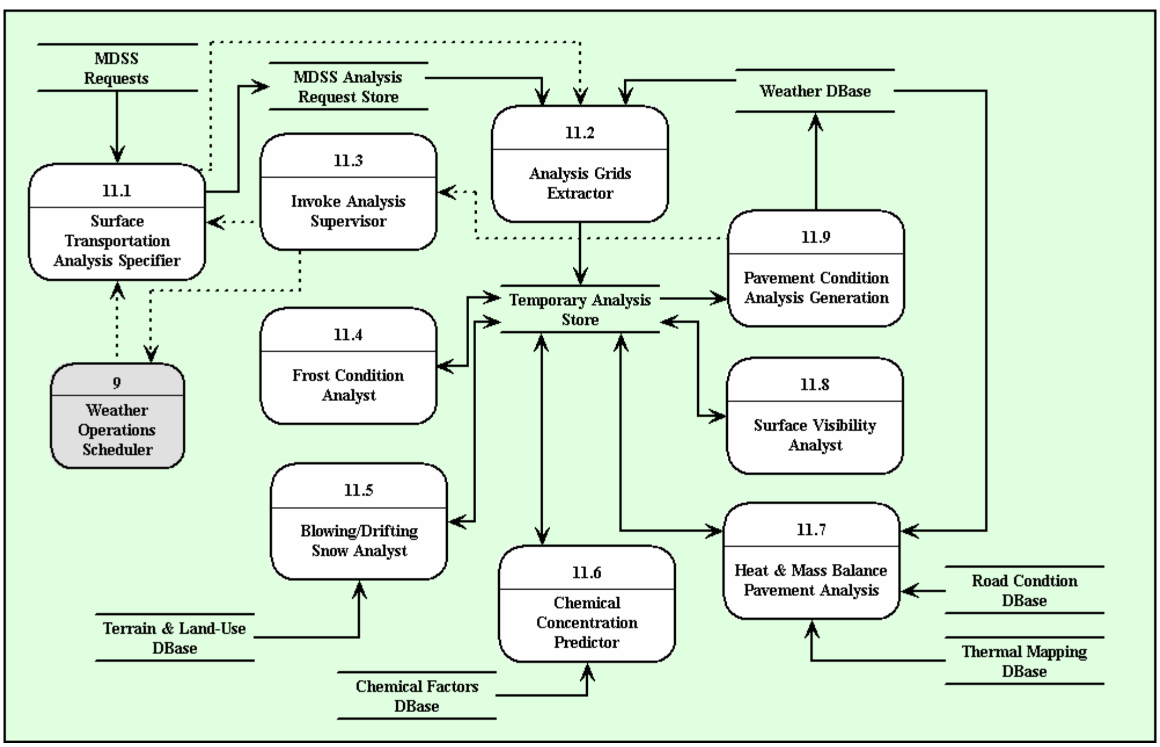

Figure B-24 Pooled Fund MDSS STWx Level 2 Data Flow Diagram for the Surface Transportation Analysis Generator Process

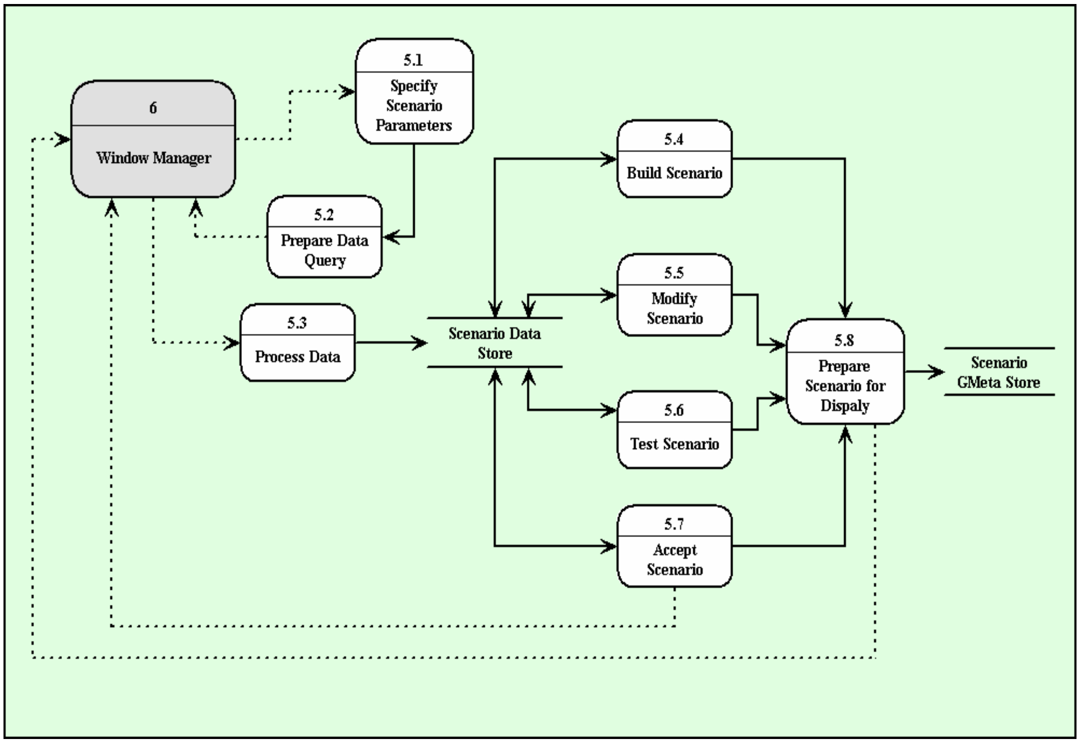

Figure B-25 Pooled Fund MDSS Level 2 Scenario Generator Data Flow Diagram

APPENDIX C: GUIDELINES FOR GRAPHICAL USER INTERFACES

The construction of a highly functional graphical user interface will be a critical part of a successful MDSS system. While the graphical user interface (GUI) by itself will have little functional role other than directing information to and from the decision support elements in the MDSS, it is the interface that the maintenance user will encounter and will likely be assumed to "be the MDSS". Therefore, developing this functional interface carefully is important to meet the expectations of the MDSS outcomes. As the interface will involve numerous individuals in the development and design level, both at Meridian and at the respective state DOTs, it is important that all parties involved have an understanding of expectations and limitations of GUIs. This guideline document is meant to serve both as an overview of graphical user interfaces and as a design guideline to be used throughout the development process of all MDSS GUIs. Following this guideline will help to ensure that consistency in purpose and construction is attained.

C.1 Overview of Graphical User Interfaces and Their Design

Graphical user interfaces (GUIs) have become the user interface of choice found on desktop computers. Yet despite the GUI's popularity, surprisingly few programs exhibit good interface design. Moreover, finding information explaining what constitutes a good and intuitive interface is exceedingly difficult. The guideline documents that follow results from reviews of existing literature on GUI design, discussions with computer scientists in academia and industry who focus on GUI design methods, insight from cognitive psychology literature on methods in decision making and from personal experiences by Meridian staff in effective GUI applications. This summary document identifies the basic rules for good interface design that are recommended for adoption by the MDSS Technical Panel.

Before beginning a discussion of elements constituting a good design of graphical user interfaces, it is important to first describe various causes a bad design. In this way, the personnel involved in designing and evaluating the MDSS GUI design will understand better that beginning down wrong paths can lead to poor design and poor user effectiveness.

A cardinal sin in GUI design is attributable to developers often designing for what they know, not what the users know. This age-old problem occurs in many other areas of software development, such as testing, documentation, and the like. It is even more pernicious in the interface because it immediately makes the user feel incapable of using the MDSS client software. Because of this it is important that the development of effective GUIs focus on the user and their desires for the end product and not a perception by the developers as to what they believe the user should see. Furthermore, with the premise that naturalistic decision-making (Zsambok and Klein, 1997) (the way people use their experience to make decisions in the context of a job or task) embodies the principle elements of the present MDSS project, it is important to understand the methods of cognition as part of the decision making and to impart as much of this effort to the GUI as possible.

This topic is central to the field of human-computer interaction (HCI), which is concerned with interface design and its highly interdisciplinary nature. Complete understanding of the processes involved requires the use of research findings and methods from psychology, computer science, information science, engineering, education, and communications. A central concern of HCI research is to determine the effects of human physical, cognitive, and affective characteristics on the interactions between users and computers for specific tasks. Thus, HCI researchers develop models of human activity and use these models in designing new interfaces (Dix, et. al., 1998).

The information-processing model of cognition prevalent in cognitive psychology provides a foundation for interface design. This model establishes that: (1) humans have a working memory limited to five to seven "chunks" of information; (2) humans must have their attention refreshed frequently; and (3) recalling information requires more cognitive effort than recognizing information. Computer interface styles consistent with this model include menus, query-by-example, and direct manipulation. Novices and casual users prefer menus to command languages because recognizing an appropriate option is easier than remembering a command. Direct manipulation interfaces (such as touch panels in information kiosks, in-maintenance vehicle input devices and graphic displays in of complex weather images) overcome many psychological limitations because they share the "load" between physical and cognitive activity. In addition, their immediate feedback and ease in reversibility invite user application.

GUI designers' predilection for control is evident in applications that continually attempt to control user navigation by graying and blackening menu items or controls within an application or limiting their ability to adjust the level of detail afforded the user in the interface. Controlling the user is completely contradictory to the event driven design in which the user rather than the software dictates what events will occur (Reisner, 1981). As GUI development occurs, if a lot of time is being spent dynamically graying and blackening controls, then the design approach must be re-examined as to whether too much is being blocked from the user or being made too complex to obtain. With the plug-and-play design concept being promoted for the MDSS client, there will no doubt be numerous new elements added to the maintenance decision support system over time. As these changes occur at a faster pace, flexibility in user interfaces will become a key enabler for providing these changes without the ongoing need to 're-invent' the GUI. Allowing the maintenance personnel to access the client-side applications in ways not initially anticipated is indeed intimidating for the MDSS developers, but will ultimately be satisfying to both the developers and users as the development evolves into a greater overall acceptance and empowerment for the maintenance user.

Likewise the GUI design should ensure that features used frequently are readily available. The design must avoid the temptation to put everything on the first screen or load the toolbar(s) with rarely used buttons. It will be important to do the extra analysis with maintenance personnel to find out what features can go behind the panel instead of on the faceplate.

C.2 Elements in Successful GUI Design

Successful GUIs share many common characteristics. Most importantly, good GUIs are more intuitive than their character base counterparts. One way to achieve this is to use real-world metaphors found either within maintenance operations or common to the maintenance personnel's frequently used computer desktop environment whenever possible. Another important characteristic of good GUIs is speed or more specifically, responsiveness. Many speed issues are handled via the design of the GUI, not the hardware. Depending on the type of application, speed can be the make-or-break factor in determining MDSS projects acceptability by the maintenance community. Experience has shown that slow performance will quickly result in users of any computer-based application wanting to abandon the system.

However, it is important to understand that most applications in the MDSS software system will involve sophisticated calculations, access to distant data sources and/or the generation of complex graphics. Thus, it will often be necessary to develop a perception of speed when periods of slow response are unavoidable. Fortunately, there are a number of ways to proceed. Avoid repainting the screen unless it is absolutely necessary. Another method is to have all field validation's occur on a whole screen bases, instead of a field-by-field bases. Also, depending upon the skills of the user, it may be possible to design features into a GUI that give the "power user" the capability to enter more complex commands that reduce the mining downward through multiple menus. Such features include mnemonics accelerator keys and toolbar buttons with meaningful icons, all of which allow the speed user to control the GUI and rate/type of display generation.

The ultimate goal is to develop the best possible MDSS GUI that provides a long-term framework and consistency for maintenance personnel. The following sections list specific design principles to be used in the MDSS GUI design and development.

- *Understand Maintenance Personnel*—Above all, the GUI applications must reflect the perspectives and behaviors of maintenance personnel and their manner of computer usage. To understand these characteristics fully, Meridian must first understand what commonalities in characteristics exist between all maintenance personnel beyond their computer experience i.e., understand them as people. Cognitive psychology stresses that people learn more easily by recognition than by recall (O'Neil, T, 2003). By breaking down the complex decision making process into smaller communication pieces between the system and the user provides the modularity that will enable the construction of recognition paths that permit the user to make more informed inputs to the decision making process. The expression of these smaller communication pieces as visual event grammars permits the algorithm construction of the GUI modules (Reisner, P., 1981; Berstel et.al, 2001). Therefore, it is important to always attempt to provide a list of data values to select from rather than have the users key in values from memory. The average person can recall about 2000 to 3000 words, yet can recognize more than 50,000 words.

- *Be Careful Of Different Perspectives*—Many GUI designers unwittingly fall into the perspective trap when it comes to icon/symbol design or the overall behavior of the application (Mandel, 1997). Often these designers will apply too much artistic creativity to the development of icons where simplicity would serve an equal purpose. Further, designers may apply a faulty perception to the meaning of an icon for a given application that often leads to confusion and misperception by the user. To eliminate these problems, it is important to have a reserved set of icons or symbols containing standard approved icons and symbols used within the maintenance community. In addition, depending upon the computer experience of the maintenance personnel selected icons found within standard computer-based word processing environments and desktop applications should be used in a non-ambiguous manner within the display environment.

- *Design for Clarity*—GUI applications often are not clear to end-users. One effective way to increase the clarity of MDSS applications is to develop and use a list of reserved words. A common complaint among by application software users is that certain terms are not clear or consistent. This lack of clarity can be found in semantic differences between what the developer believes are the appropriate term for a button or menu and what the maintenance personnel believe is appropriate. There may also be debates among maintenance personnel, either between states or within a single state, as to what the appropriate meaning should be. An example of this might be the meaning of "item" versus the meaning of "product". Neither may be the most appropriate and the use of either could lead to confusion. This lack of consistency, ultimately leads to confusion and frustration for users. Table C-1 gives an example of a list of reserved words, and application development group might completely expanded table with additional reserved words.

Text	Meaning & Behavior	On Button?	On Menu?	Mnemonic Keystrokes	Shortcut Keystrokes
OK	Accept data entered or acknowledge information presented and remove the window	Yes	No	None	<Return> or <Enter>
Cancel	Do not accept data entered and remove the window	Yes	No	None	Esc
Close	Close the current task and continue working with the application; close view of data	Yes	Yes	Alt+C	None
Exit	Quit the application	No	Yes	Alt+X	Alt+F4
Help	Invoke the application's Help facility	Yes	Yes	Alt+H	F1
File	Invoke drop down menu presenting base program operations	No	Yes	None	None
Open	Invoke file selection dialog	No	Yes	Alt+O	Ctl+O
Save	Save data or configuration entered and stay in current window	Yes	Yes	Alt+S	Shift+F12
Save As	Save the data or configuration entered with a new name	No	Yes	Alt+A	F12
View	Invoke drop down menu presenting viewport options	No	Yes	Alt+V	None
Tools	Invoke drop down menu presenting optional data/window applications	No	Yes	Alt+T	None
Properties	Display and modify general GUI configuration preferences	No	Yes	Alt+I	None

Table C-1 Standard Reserved Words Common in Most Graphical User Interface Systems

- *Design for Consistency*—Good GUIs apply consistent behavior throughout the application and build upon the user's prior knowledge of other successful applications (Smith and Mosier, 1986). When writing software GUI interfaces for MDSS applications it is important to provide as many consistent behaviors for each level of maintenance personnel and/or maintenance personnel between state DOTs as possible.

For example, each of the participating state DOTs has or will have road condition reporting systems available for MDSS activities. However, the database structures and possible content will vary for each state and will result in differing ability to display certain information. Defining a GUI that hides the dissimilarity in these databases will be important to provide a similar look-and-feel across all states. Further, this uniformity in design will provide for more stability in GUI software maintenance for the future.

- *Provide Visual Feedback*—As mentioned earlier, the calculations involved in completing a maintenance decision support activity will be lengthy at times. Furthermore, the inconsistency in processor speeds within the participating MDSS DOT maintenance community, even within a given state or within a maintenance unit, may lead to significant variation in desktop performance. This will result in a great variation in time needed to complete a given application transaction. When delays occur, unless there are visual cues provided to indicate the status of the activity occurring, user frustration will likely develop that will potentially reduce user acceptance of the MDSS application. Users greatly appreciate knowing how much longer a given operation will take. As a general rule, most users like to have a message dialog box with a progress indicator displayed when operations are going to take longer than seven to 10 seconds. This number is highly variable based on the type of user in overall characteristics of the application. Capabilities must be designed in the MDSS GUI to inform the maintenance user of the status of pending operations and special notices when certain activities are to take extended time to complete.

- *Provide Audible Feedback Judiciously*—Audible feedback, on systems capable of supporting this feature, can be useful in cases where the client's application needs to warn the user of an impending serious problem. Such a problem might be one in which further activity by the user could cause loss of data or software or an application may abort. It will be important to allow users to enable/disable audio feedback, except in cases where a significant error must be addressed. The GUI must avoid excessive use of audio feedback as it can sensitized the users to the effective use of audio and it can become a source of annoyance not only to the user, but to those in the workspace around the user.

- *Keep Text Clear*—Developers often try to make textual feedback clear by adding a lot of words. However, they ultimately make the message less clear. The MDSS GUI must use concise wording of text labels, user error messages, and online help messages, which is often challenging to accomplish. Textual feedback will be most effectively accomplished after conducting user feedback surveys and working with the Technical Panel to assure that wording meets the approval of experienced maintenance personnel.

- *Provide Traceable Paths*—It will be critical to prevent maintenance user comments such as "I don't know how I got to this window, and now that I'm here, I don't know how to get out." To prevent this, it is important to provide traceable (or retraceable) paths

(Preece, et.al., 2002). Providing a traceable path is harder than it sounds. It starts with an intuitive menu structure from which to launch specific features.

To assist in minimizing the path lengths to perform an activity, the GUI design must identify areas where menu structure can be flattened. It is necessary to avoid more than two levels of cascading menus. For each menu and/or dialog box there must be a descriptive title bar provided to remind the user what menu items or buttons were pressed to bring them to the window now in focus.

- *Provide Keyboard Support*—Keyboards are a common fixture on computer desktops and provide efficient means to enter text and data. With the introduction of GUI applications, it is often assumed that computer users will embrace a mouse as the primary interactive device. However, mouse inputs are serial and do not provide convenient methods to circumvent a chain of serial inputs. This can become time-consuming and inefficient when too many mouse clicks are required to enter a request. As the maintenance user becomes more accustomed to the GUI interface and the applications desired, the use of a mouse may actually detract from the efficiency and effectiveness of the GUI.

  Where practical, keyboard accelerators can provide efficient ways for users to access specific menu items and/or control application execution within the client window. The accelerators used should be easy to access and limited to one or two keys (such as F3 or Ctrl-P). However, keyboards have limitations in the GUI world, such as when trying to implement a direct manipulation task like drag-and-drop, pointing, and resizing.

  In contrast, some users find difficulty with typing on keyboards and prefer an exclusive use of a mouse for all operations. The result is that it is necessary to provide complete, and equal, keyboard and mouse support for all menu and window operations.

- *Watch the Presentation Model*—A critical aspect that ties all facets of the interface together is the interface's look and feel. The look and feel must be from one screen to the next. On the basis of the maintenance user's experiences with one screen or one dialog box, they should have some sense of how to interact with the next screen or control.

  Searching the interface model for good design continuity is most important. The model should involve careful decisions, such as whether the application will have a single (such as found with the MDSS Functional Prototype) or a multiple document interface (such as commonly found with word processing software applications). The model also will validate how users perform their main task within the application.

  Identifying the appropriate presentation for the application early in the design development phase of the GUI will greatly facilitate the subsequent windows being developed, since they will have a common framework in which to reside. On the other hand, if the presentation model is not defined early in the design of the MDSS GUI, late changes to the look and feel of the application will be much more costly and time-consuming because nearly every window may be affected.

- *Modal vs. Modeless Dialogs*—When input is needed from the user the information is often entered through the use of a modal dialog box. GUI developers have largely shunned using modal dialogs asserting they are too constraining on the user. However modal dialogs do have many uses in complex applications, since most people only work on one window at a time. Hence, when a finite task exists, the use of modal dialogs is encouraged. For tasks with no fixed duration, modeless dialogs will normally be the preferable choice with a major caveat: try to keep the user working in no more than three modeless windows at any one time. Go beyond this magical number and the level of window confusion increases rapidly and the availability of computer resources may become critically short. Table C-2 provides guidelines to determine the appropriate use of dialog boxes and windows.

Type	Description	Use	Example
Modal	Dialog Box	Presentation of a finite task.	File Open dialog box
Modeless	Dialog Box	Presentation of an ongoing task.	Search dialog box
Task List Dialog Box	Modal dialog box	Presentation of static or dynamic list of actions or selection items	Word Processor font selection dialog box
Application Window	Window frame with document (child) windows contained within	Presentation of multiple instances of an object. Presentation of data within two or more windows.	Word Processor
Spreadsheet	Application Window	Ordered entry of and operation on data	Accounting records Tabulated data from experiments
Document Window	Modeless dialog box or document window contained within and managed by the application window	Presentation of multiple parts of an application	Multiple views of data (sheets) i.e., view of displays from multiple weather radars.
Secondary Window	Primary window of a secondary application.	Presentation of another application called from parent	Invoke Help within an application. Display of treatment scenarios.

Table C-2 Guidelines for Appropriate Use of Dialog Boxes and Windows

- *Control Design*—Controls are the visual elements that let the user interact with the application. GUI designs are faced with an unending array of controls to choose from. Each new control brings with it expected behaviors and characteristics. Hence, choosing the appropriate control for each user task will result in higher productivity, lower error rates, and higher overall user satisfaction. Figure four includes a guideline for control usage in screens. It is important to try to keep the basic behavior and placement of these controls consistent throughout the MDSS GUI application. If attention is not placed on consistency, the maintenance user will possibly become confused when the behavior of the controls change. Table C-3 provides some standard guidelines on using controls.

Control	Number of Choices in Domain Shown	Types of Controls
Menu Bar	Maximum 10 items	Static action
Pull-Down Menu	Maximum 12 items	Static action
Cascading Menu	Maximum 5 items, 1 cascade deep	Static action
Pop-up Menu	Maximum 10 items	Static action
Push button	1 for each button, maximum of 6 per dialog box	Static action
Check Box	1 for each box, maximum of 10 to 12 per group	Static set/select value
Radio Button	1 for each button, maximum of 6 per group box	Static set/select value
List Box	50 in list, display 8 to 10 rows	Dynamic set/select value
Drop-down List Box	Display 1 selection in control at a time, up to 20 in a drop-down box	Dynamic set/select value
Combination List Box	Display 1 selection in control at a time in standard format up to 20 in a drop-down box	Dynamic set/select single value; add value to list
Spin Button	Maximum 10 values	Static set/select value
Slider	Dependent on data displayed	State set/select value in range

Table C-3 Guidelines on Window Control Standards

C.3 Applying Design Principles

Understanding the principles behind good GUI design and correctly applying them to the MDSS GUI will be a challenge requiring considerable time and effort by not only the Meridian developers, but also a commitment to review by maintenance personnel and the Technical Panel. Attention to the checklist of items (Table C-4) will result in improved interface acceptance.

C.4 The Limits of GUI design

Constructing the perfect GUI is impossible; albeit it is the goal to which to strive in the current project. Understanding that there are limits to be found in GUI design are important concepts to be understood by Meridian developers and the maintenance personnel it is attempting to serve. An early awareness and acceptance of this premise will go far to balance the design development process into achieving the best possible functionality without becoming a sinkhole for time and effort. However, having a good initial design built upon a framework that permits routine design maintenance and adaptation to new modularity and functionality will be important.

The following items should be kept in mind as something akin to Murphy's Law of GUI design:

- Do not rely solely on GUI standards and general style guides. Most users do not know the standards; they have their own way of operation. (Customization)
- Do not expect the users to follow the specifications. Most users do not know your way of thinking. Remember, you are not the user. (User Focus)
- Do not expect usability practitioners to guarantee the product usability. Common usability practices target only a subset of the usability needs. (Uniqueness)
- Good design does not guarantee usability. Users are always unpredictable!! Even the best GUI designers cannot think the way many different users do. And, some of the user unexpected actions are really costly. (The Unknown)

Category	Guidelines
Workflow Guidelines	Be consistent.
	The user should always know where they are.
	It should take a very small number of clicks to get anywhere.
	The high frequency windows take the smallest number of clicks to get too.
	GUI applications involving an extended series of workflow steps are expressed by a logical series of windows. As many as possible of these windows are also used in other applications (often referred to in the literature as use cases).
	Provide useful defaults.
	Always validate all user input. Do this as close to the time of entry as possible. This smoothes out the user's habitual workflow.
	Use Wizards when the workflow needs active guidance.
Window Guidelines	Be consistent.
	The window must be easily understood at the first glance.
	Use a small collection of standard widgets. Follow industry standards.
	Use a standard window layout. For example, put the most important data at the upper left, the buttons at the bottom, and a close button at the lower right. Follow industry standards.
	Clearly label everything.
	Don't put too much on a window unless it's for a highly skilled user. Avoid too many buttons or menus on a window.
	Avoid inventing cool new widgets, clever layout and snazzy effects.
	Put the user in a "look and choose" mindset, not "remember to enter". Strive for symmetry in window layouts.
	Right click context menus are a form of "hidden choices". The simplest GUIs don't use them. If you do start to use them, you must uniformly provide them everywhere.
	Everything should be able to be done without the mouse.
	Allow expert users to sail through a window fast, such as without the mouse.
	Always follow the principle of "Least user astonishment".
Complexity Guidelines	Be consistent.
	A huge problem for products with complex requirements is how to make the product appear simple to the user. Address this large risk early.
	Hide complex areas from the casual user, such as with an Advanced button, lower window expansion (show detail button) or user types. Different user types cause the system to reveal different types of behavior.
	Organize the workflow so complex areas are not accidentally encountered.
	Provide online "how to do it assistance" in a variety of levels, such as tool tips, F1 use, and a User's Guide. Each level has progressively more assistance.
	Have a sophisticated workflow for all complex applications. Make the hard stuff easy.
	In some cases offer alternate paths to accomplish something. For example, for the average user offer a Wizard, but for the expert offer raw data and application commands. The first is easy but slow, the second requires more skill, but is fast.

Table C-4 Graphical User Interface Application Checklist

C.5 GUI Design and Implementation

Following the guidelines and standards discussed above will enable an orderly development of the MDSS graphical user interface. To achieve the final design and GUI implementation will require strong teamwork between Meridian and the state DOT maintenance personnel. The following steps are general industry accepted standards to follow for development and implementation of a new GUI design (Rubin, 1994):

- Determine the top objectives of the product from the maintenance user's viewpoint.
- Organize these objectives into a single top-level window.
- List the window GUI applications, data input/output and displays. Rank by frequency of use (collectively referred to as the use cases).
- Organize these use cases into a logical, easy-to-use window workflow model.
- Do a mockup of each window with a design tool (Meridian uses Smart Draw).

- Validate the mockup model with user exercises and expert reviews.
- Fine-tune the models.
- Get final feedback and approval.

It may be necessary to repeat this process several times at various stages of this list.

C.6 Conclusion

Designing a good graphical user interface is a challenging task requiring insight, vision and expertise; they don't happen by accident. Good GUIs require the development team to learn and apply basic principles, including making the design something the end user will accept and work with everyday. For this to occur the maintenance personnel using the MDSS GUI must find value in efficiency and effectiveness towards completing their job tasks.

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