An Overview of the Pooled Fund Study Maintenance Decision Support System

J. Mewes, R. Hart, & L. Osborne
Meridian Environmental Technology, Inc., Grand Forks, ND, United States
jmewes@meridian-enviro.com, bobhart@meridian-enviro.com, leono@meridian-enviro.com

D. Huft
South Dakota Department of Transportation, Pierre, SD, United States
Dave.Huft@state.sd.us

ABSTRACT

The goal of the multi-state Pooled Fund Study (PFS) Maintenance Decision Support System (MDSS) program has been to develop a comprehensive system for real-time winter maintenance decision support. A sophisticated road condition model is used to combine information on weather conditions, roadway observations, and the maintenance activities being performed to arrive at an ongoing assessment of the condition of maintenance routes. The system permits automated reporting of maintenance activities via third-party Mobile Data Collection (MDC) / Automated Vehicle Location (AVL) technologies. Given this ongoing assessment of the condition of each maintenance route and a detailed weather forecast, the system is able to predict the evolution of the road condition and suggest subsequent treatments. Information is delivered back to system users via graphical user interfaces designed for both workstation environments and on-board third-party computing devices in maintenance vehicles. The PFS MDSS system presently operates on nearly 1,000 maintenance routes in fourteen states, and interprets data from thousands of environmental sensing stations and MDC/AVL equipped snowplows. This paper will provide an overview of the system and how it is being applied with the PFS states, as well as an assessment of the benefits being realized as a result of MDSS deployment.

KEYWORDS

MDSS / MDC / AVL / RWIS / WINTER MAINTENANCE

1. INTRODUCTION

The Pooled Fund Study (PFS) Maintenance Decision Support System (MDSS) [1] is the first public / private venture into the operational application of winter maintenance decision support technologies following the Federal Highway Administration's (FHWA) MDSS Functional Prototype [2] demonstration. The PFS MDSS research program combines the efforts of 15 states and a research and development contractor, Meridian Environmental Technology, Inc (Meridian). The PFS MDSS integrates in-situ, remotely sensed, and forecast weather information with data gathered from Road Weather Information Systems (RWIS), road condition reporting systems, and winter road maintenance activities data collection platforms to provide maintenance personnel with a suite of decision support tools. This MDSS was developed under a Federal Highway Administration (FHWA) Transportation Pooled Fund (TPF) research program.

As of early 2009 the PFS MDSS has matured into its early deployment phase. The system encompasses nearly 1,000 maintenance routes in fourteen states and interprets data from thousands of environmental sensing stations as well as over 650 snowplows equipped with MDC/AVL technologies. Version 6.0 of the Pooled Fund Study (PFS) Maintenance Decision Support System (MDSS) will be released to the participating agencies during the fall of 2009. This paper will 1) provide an overview of the system from a scientific standpoint and the users' perspective, 2) present initial findings on the benefits of MDSS deployments, and 3) highlight continuing research needs and anticipated future applications.

2. MDSS DESIGN

The PFS MDSS approach focuses on simulation of a 'dynamic layer' consisting of freeze point depressants, abrasives, and various forms of moisture (snow, ice, frost, water) residing atop the roadway. Analyses of past and present weather conditions (including precipitation amounts and radiation budgets) are integrated with Road Weather Information System (RWIS) observations, as well as road condition and maintenance activities reports, to provide an ongoing assessment of the past and present states of the roadway. This ongoing assessment of the initial state of the dynamic layer is used in concert with weather forecast and available maintenance resources information to simulate the expected evolution of the dynamic layer, identify problematic conditions, and identify treatment options. Minimization techniques are used to find candidate maintenance actions that will maintain the required level of service in the most economical manner for the available human, equipment, and material resources. Resources and service level information are preconfigured for each maintenance route, but can be adjusted by the user as resource availability and practical maintenance limitations change during a storm situation. The system also supports dynamic layer simulation for user-defined maintenance actions in a "What-If" virtual scenario mode.

2.1. Road Condition Modeling

The aforementioned information integration occurs within the HiCAPS^{TM} model and supporting MDSS software libraries. A key premise of the PFS MDSS system is that the roadway dynamic layer behavior is predictable. Predicting its characteristics and evolution require a great deal of sophistication. A key enabling technology for the PFS MDSS was the incorporation of Meridian's proprietary HiCAPS^{TM} pavement condition prediction model, a sophisticated mass and energy balance model with a proven ability to simulate the characteristics of the dynamic layer. The HiCAPS^{TM} model has tapped additional modules developed during the PFS MDSS project to enhance its ability to support the MDSS system. Functions for modeling traffic and the effects of freeze-point depressing chemicals placed atop the roadway are newly developed during the Pooled Fund Study, and are held in a library of MDSS-related functions accessible by the HiCAPS^{TM} model.

HiCAPS^{TM} uses the unsteady heat flow equation to forecast pavement and bridge deck temperatures. It utilizes sophisticated parameterizations for representing heat and moisture exchanges between the road, the atmosphere, and pavement substrate. A key capability of HiCAPS^{TM} for serving the needs of the MDSS system is the coupling between the mass and energy balances in the model. In simpler terms, when moisture (such as snow, rain, frost, dew, etc.) is deposited onto the road it transfers energy to or from the road, and evaporation or sublimation of moisture from the road requires an adequate amount of available energy to support those processes. Similar restrictions apply to phase changes of moisture atop the road. This coupling is a key to the model's ability to support MDSS in a scientifically sound manner.

HiCAPS^{TM} has a sophisticated scheme for handling latent heat fluxes (heat exchanges related to changes in the state of water). This scheme includes modeling of heat exchanges associated with evaporation, sublimation, condensation, deposition (frost formation), and phase changes (e.g., water freezing on the road surface) whether naturally or chemically induced. HiCAPS^{TM} also makes actual predictions of the depth of water, ice, frost, snow, and compacted snow upon the roadway. For example, HiCAPS^{TM} may project a layer of snow on the pavement based upon a forecast of snow falling at a certain rate. HiCAPS^{TM} can then determine what effect plowing and an application of chemical at a given rate will have on the snow layer (using the phase diagram for the applied chemical). Chemical applications change the relative amounts of snow, ice, and liquid water in the model to reflect their impact on the dynamic layer as it existed before treatment. The result may be a projected slush composition based on the chemical action, traffic, and any additional precipitation.

A new chemical solution module was developed within the PFS to support the need for modeling the effects of freeze point depressants on the condition of the roadway. The PFS MDSS supports the application of commonly used freeze point depressant materials. In the simulation process, a configurable amount of the applied material is assumed lost from the dynamic layer immediately upon application. The amount of material lost depends on the form of the material (e.g., dry, prewet, or brine) and application technique. For simulated plowing operations, the system estimates the depth of snow and ice remaining behind the plow based on plow type and the road surface roughness. Previously applied soluble / insoluble chemicals and abrasives are removed at the same fractional rate as the liquid / total moisture mass in the dynamic layer. Due to density considerations, liquid is assumed to preferentially reside near the bottom of the dynamic layer and is therefore generally removed at a lesser rate than frozen materials within the mixture. Runoff and the effects of traffic also remove liquids and dissolved maintenance materials.

Due to the lack of reliable and consistent research data on the cumulative effects of hundreds or thousands of vehicles upon the dynamic layer, the PFS MDSS models the effects of traffic on a more tractable vehicle-by-vehicle basis. Based upon average daily auto and truck traffic counts, the MDSS distributes vehicles across the dynamic layer at a rate that varies according to a configurable pattern throughout the day. Each vehicle is assigned a lane as well as random track, vehicle, and tire widths. Moisture within the tire tracks is splattered, sprayed, spread, or compacted depending on the composition of the dynamic layer. Moisture and materials are moved laterally atop the roadway, and may also be removed from the roadway depending on the relative distance of the tire track locations from the edge of the roadway.

HiCAPS^{TM} uses a continuous data assimilation system that adds to the pavement condition model's robustness. It is able to continue to make reliable forecasts in the complete absence of RWIS observations (typically with less than a 1° C loss of forecast accuracy). Since the goal of MDSS is to provide guidance on entire road networks, this is a key capability.

2.2. Winter Maintenance Decision Support

Direct decision support in the form of maintenance recommendations in the PFS MDSS is provided on a maintenance route and segment basis. A maintenance route is comprised of one or more discrete segments of highway that are to be treated contiguously by a given maintenance vehicle. Each segment within a maintenance route reflects unique weather, construction, traffic, and environmental factors. Since a maintenance route may be composed of multiple segments, maintenance needs within a single route can vary considerably. However, the MDSS will only present maintenance action recommendations on the different segments of a given route that can be practiced with a single vehicle configuration, and that can be performed at contiguous times where traversal, cycle, and dead times are physically realistic. Note that although the materials recommended will be the same on all segments of a route, the recommended rates can vary substantially between segments based upon the modeled needs.

Maintenance recommendations in the PFS MDSS software can be made by one of two available modules. ‘Standard Practices,’ or ‘Best Practices,’ for an agency historically have been the predominant means of providing guidance to operators on how to approach maintenance in various situations. This type of guidance may be referred to as an ‘analogue’ approach in that guidance is made by drawing analogies to what has been proven to work in similar situations in the past. One approach to generating recommendations in MDSS is the computerization of these policy documents using what will be referred to herein as the ‘Standard Practice’ recommendation module. Since these documents have been generated based on proven experiences over time they generally provide a safe, but not necessarily optimal, approach to maintenance. When using this module to make recommendations, MDSS is not provided the authority to stray from Standard Practice in such a situation; and as such, MDSS makes no guarantee the recommended activity will work effectively. It simply identifies the need for a particular maintenance action and models the impact of the maintenance recommendation on the dynamic layer. The same process is used to make additional later recommendations as necessary.

While field-proven and typically a safe response, Standard Practice recommendations also have drawbacks. One of the most significant is an oversimplification of situations. While road conditions may vary substantially due to traffic, environmental, or other subtle considerations, these types of variances are not typically accommodated by Standard Practice recommendations. Standard Practice guidance also typically leaves the ongoing response to a storm after the completion of the first maintenance action rather vague. Also problematic is the fact that many agencies are exploring the use of new chemicals and there is little or no existing basis on which the agency can draw to prescribe how these new chemicals should be used. Because of these and other considerations, the PFS MDSS has pursued a parallel approach it refers to as a ‘dynamic’ approach using what will herein be referred to as the ‘Dynamic’ recommendation module. In this approach, the characteristics of the dynamic layer, as compared to a configurable goal for its condition, are used as the basis for prescribing maintenance actions. When a condition requiring maintenance is detected, the MDSS can examine crew schedules, available materials, and forthcoming weather and traffic conditions to identify the maintenance approach and timing most likely to yield favorable results. The system accomplishes this by identifying one or more candidate maintenance actions that will adequately maintain the road from a safety / mobility standpoint, then selecting the optimal recommendation that most effectively maintains that condition based upon cost, environmental impact, or other considerations.

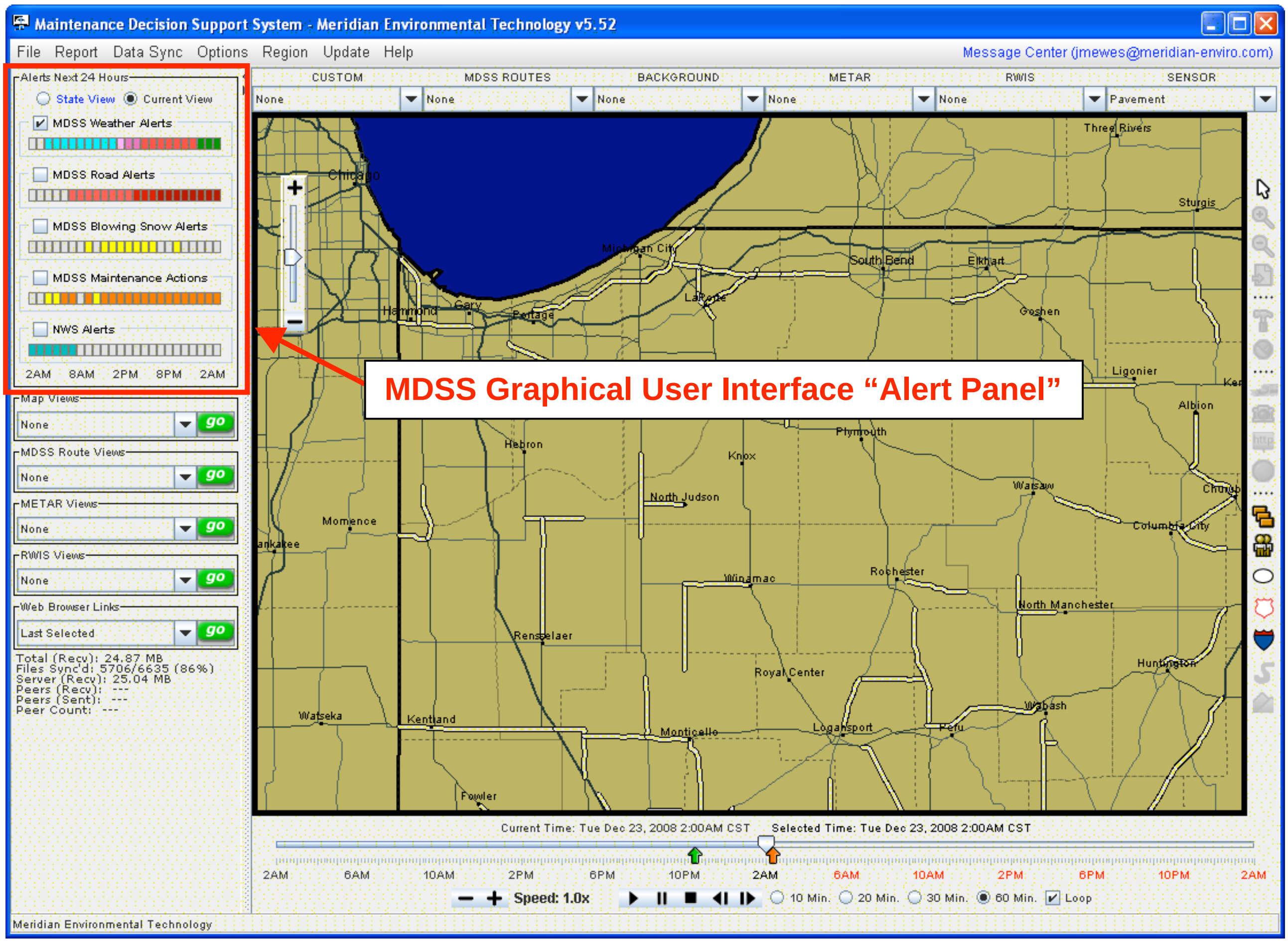
A third option for providing direct winter maintenance decision support is available via the “What-If” tool of the MDSS graphical user interface (GUI). This tool permits the user to define an alternative maintenance plan and simulate the expected impact of that maintenance plan on road conditions. The user is permitted to specify the timing and nature of three successive maintenance actions, to include specification of freeze point depressant or abrasive applications, and compare the resulting road conditions against those expected to arise from the maintenance plans recommended by the Standard Practice and/or Dynamic recommendation modules.

2.3. Graphical User Interface

The primary mode of interaction with the MDSS system is through a graphical user interface (GUI) that is installed either on the client computer or on a central agency server. An alternative capability for conveying MDSS information is delivery to user-provided onboard computing systems within the snowplow (although these onboard computing systems are not part of the MDSS system). This onboard information provision capability will be discussed in a later section.

The GUI design is based upon a 3-panel layout. The upper-left panel is called the “Alert Panel,” and the lower-left panel is called the “Support Panel.” The third “Primary Panel” of the display carries most of the functionality of the MDSS and occupies 80% of the right side of the GUI. In order to function well in all environments, the PFS MDSS GUI has been designed to work at 600x800 screen resolution, but can easily be maximized to take advantage of additional screen dimensions when available.

The Alert Panel is present at all times, conveying information about weather, road, and blowing snow conditions meeting specified alert criteria, as well as the need for maintenance activities (see Figure 1). The corresponding panel of the FHWA’s Functional Prototype was well received by test users; thus, the fundamental format was used in the PFS MDSS. The alerts for the various conditions are presented using time-series based color bars, where the period in time over which the alert is valid is color-coded based on the perceived severity of the alert. A road weather service provider generates alerts for road conditions and blowing snow, while either the road weather service provider or a government weather service may provide weather-related alerts. The Alert Panel can be customized by the user to monitor information for all agency maintenance routes, routes contained within the Map View (not yet discussed), or specific routes chosen by the user.



Map Views: None
MDSS Route Views: None
METAR Views: None
RWIS Views: None
Web Browser Links: Last Selected
CUSTOM: None
MDSS ROUTES: None
BACKGROUND: None
METAR: None
RWIS: None
SENSOR: Pavement

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Peers (Sent): ---
Peer Count: ---
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Current Time: Tue Dec 23, 2008 2:00AM CST

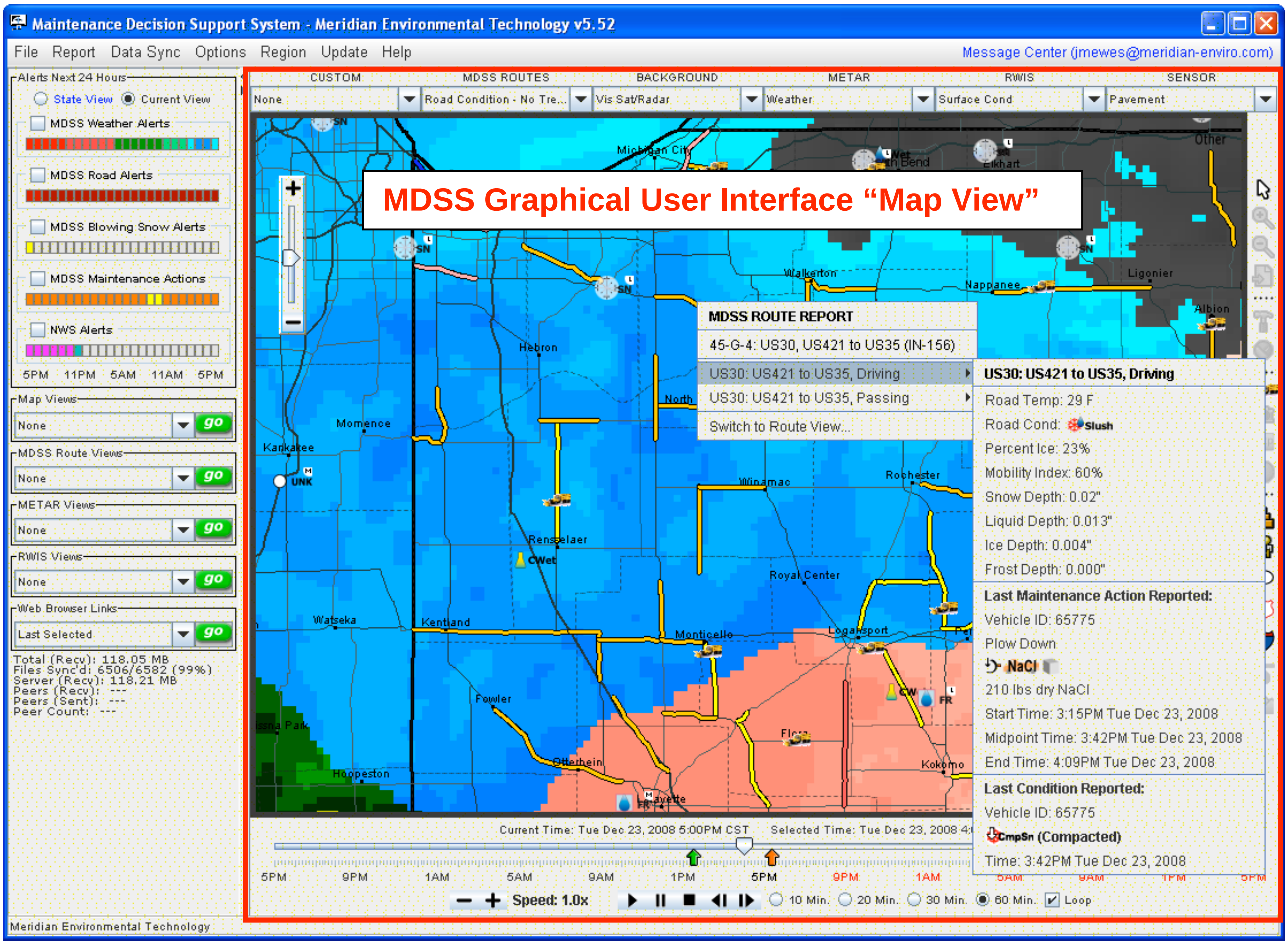
Selected Time: Tue Dec 23, 2008 2:00AM CST

MDSS Graphical User Interface "Alert Panel"

Figure 1 - The Alert Panel of the MDSS GUI monitors for weather, road, and blowing snow alerts from the meteorological service provider and / or the government weather service.

The Primary Panel of the GUI holds most of the functionality of the PFS MDSS from the user's perspective. The Primary Panel can host one of four different "views." These views are the "Route View," the "Map View," the "RWIS" view, and the "METAR View." The user selects which view is active in the Primary Panel using selection tools in the Support Panel. Alternatively, when in the Map View the user can quickly switch to any of the other three views by clicking on objects located on the map.

The Map View is the geospatial display component of the GUI (see Figure 2). Users are provided a base map with pan and zoom capabilities as well as selectable reference overlays (e.g., counties, cities, roads, etc.). In addition, the GUI presently supports six other overlay types: Route, Background, RWIS, METAR, MDC/AVL, and Cameras. These overlays are dynamic in the sense that they change over time. The user is provided a time slider that can be move forward or backward in time to view past, present, or future data (where applicable) in a geospatial format.



CUSTOM: None
MDSS ROUTES: Road Condition - No Tre...
BACKGROUND: Vis Sat/Radar
METAR: Weather
RWIS: Surface Cond
SENSOR: Pavement

Map Views: None
MDSS Route Views: None
METAR Views: None
RWIS Views: None
Web Browser Links: Last Selected

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Files Sync'd: 6506/6582 (99%)
Server (Recv): 118.21 MB
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Peer Count: ---
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MDSS ROUTE REPORT

45-G-4: US30, US421 to US35 (IN-156)

US30: US421 to US35, Driving

US30: US421 to US35, Passing

Switch to Route View...

US30: US421 to US35, Driving

Road Temp: 29 F
Road Cond: Slush
Percent Ice: 23%
Mobility Index: 60%
Snow Depth: 0.02"
Liquid Depth: 0.013"
Ice Depth: 0.004"
Frost Depth: 0.000"

Last Maintenance Action Reported:

Vehicle ID: 65775
Plow Down
NaCl
210 lbs dry NaCl
Start Time: 3:15PM Tue Dec 23, 2008
Midpoint Time: 3:42PM Tue Dec 23, 2008
End Time: 4:09PM Tue Dec 23, 2008

Last Condition Reported:

Vehicle ID: 65775
CmpSn (Compacted)
Time: 3:42PM Tue Dec 23, 2008

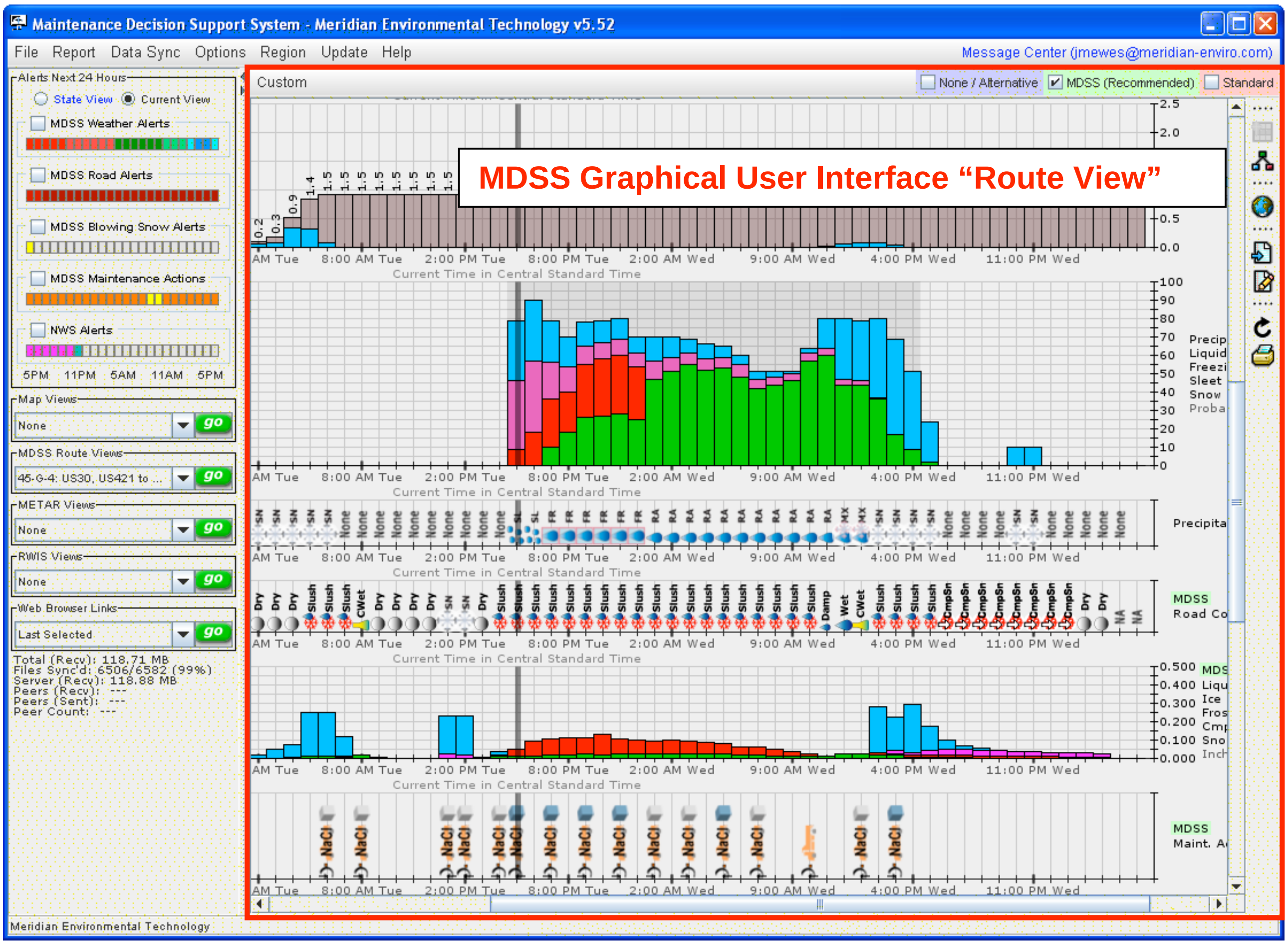
Current Time: Tue Dec 23, 2008 5:00PM CST   Selected Time: Tue Dec 23, 2008 4:

Figure 2 - The “Map View” of the PFS MDSS GUI shown in the Primary Panel. In this particular example an MDSS Route on the Map View is being probed for more detailed information on a specific route.

The Route overlays are displayed in the form of selectable and color-coded segments in the Map View. They convey information about the MDSS’ analyzed and forecast state of the dynamic layer for each maintenance route. Since the forecast state is dependent upon maintenance actions, the user is provided the option to visualize outcomes with “No Treatment” or by following either the “Standard Practice” or “Dynamic” treatment options. The Background overlays are comprised primarily of raster graphics (e.g., radar, satellite, etc.). The RWIS overlays are presented as point data (text or icons) at the locations of the various RWIS sites and convey information about road and / or weather observations. The METAR overlays are presented in a similar fashion, but display METAR weather observations instead. If an agency employs Mobile Data Collection / Automated Vehicle Location (MDC/AVL) technologies and have equipped their maintenance vehicles with appropriate in-vehicle computing/display systems, real-time data being communicated back from the vehicles is also available in a similar fashion. Traffic, RWIS, or web-based camera information can also be collected and displayed within the GUI. Regardless of which data layers are being displayed, all layers are coupled to the same time slider to permit time-synchronized visualization and looping of all displayed layers.

Features displayed in most of the aforementioned overlays are selectable with a single mouse click. This selection brings up an information box giving summary information about the selected item (see Figure 2). Within these information boxes there are options by which the user can swap the Route, RWIS, or METAR Views into the Primary Panel of the GUI. As mentioned previously, the user can also switch the contents of the Primary Panel using selection tools that are always present in the Support Panel. It is therefore not necessary for the user to return to the Map View to switch between locations for a particular type of data (or even to switch types of data).

The Route View presents a time-series portrayal of maintenance, weather, and road information for a maintenance route (see Figure 3). These time-series span from the past into the future, showing what has already occurred as well as what is expected to occur in the future. Since the state of the dynamic layer atop the roadway and the maintenance actions affecting that state are dependent on the chosen treatment strategy, the user is allowed to compare expected results given no maintenance actions, either of the two types of recommended maintenance actions, or an alternative 'What-If' action specified by the user as previously discussed. The user via a simple interface edits the specifics of the 'What-If' actions. This functionality is intended to allow the user to attempt virtual maintenance actions and gain an understanding of the expected outcomes without the risk of carrying those actions out in reality. Information in the Route View is presented via either tables or graphs that permit drag-and-drop reordering of information as well as customizable information types.



○ State View ● Current View

☐ None / Alternative ☑ MDSS (Recommended) ☐ Standard

Map Views: None

MDSS Route Views: 45-G-4: US30, US421 to ...

METAR Views: None

RWIS Views: None

Web Browser Links: Last Selected

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Peers (Recv): ---
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Peer Count: ---
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Figure 3 - The PFS MDSS "Route View" displays time series of maintenance, road, and weather information to the user. Information to the left of the dark gray vertical bar represents recent activity, while information to the right represents forecast / recommended activity. A "What-If" interface allows the user to view the expected results from candidate maintenance actions in a virtual setting.

The RWIS and METAR Views function in substantially similar manners, but without the maintenance-oriented interactivity. They present the user with a time-series view of RWIS or METAR observations over the past 24 hours. The table and graph display formats used in the Route View are also utilized in the RWIS and METAR Views.

2.4. Interfacing with Data Collection and Provision Systems

The PFS MDSS requires only one external information provider: a meteorological service provider (MSP). The system requires the MSP to provide specific georeferenced raster weather maps, METAR information, government weather service advisories, as well as detailed past, present, and future weather information for each maintenance route.

The PFS MDSS also accepts data from other information resources, although they are not required in order for the MDSS system to function as a basic level. These include RWIS and third-party MDC/AVL systems, as well as sources of real-time camera imagery.

RWIS data is utilized by the MDSS as an additional guide in generating its ongoing assessment of the condition of the agency's road network. The MDSS system contains modules to aid in and configure the interpretation and application of the data being received from the RWIS. The RWIS data provided to the system is also passed through to MDSS users via the GUI, as discussed above.

MDC/AVL systems employed by the agency can optionally interface with the PFS MDSS in a two-way communications mode. MDSS modules for interpreting and applying maintenance data (as well as road condition and weather observations) collected with these systems have been developed. Many lessons have been learned during the study about the practical operational considerations associated with MDC/AVL systems intended to support maintenance decision support. Further information regarding these considerations in the interaction of MDC/AVL and MDSS has recently been published separately [3]. Further, if the third-party MDC/AVL systems are equipped with on-board computing and display capabilities capable of displaying basic HTML and graphics, the MDSS system possesses the ability to provide vehicle-tailored maintenance recommendations, weather forecasts, weather imagery, and/or maintenance fleet vehicle locations back to the driver via standard web protocols.

2.5. Playback Capabilities

Many early adopters of MDSS expressed a desire for the ability to use MDSS for post-storm debriefings as well as off-season training. To maximize the effectiveness of this application, MDSS possesses a playback capability permitting users to effectively change the clock and put themselves back into the situations they would have encountered in the MDSS GUI at previous points in time. Thus, the decisions that were made during a storm can be reevaluated after the fact considering only the information available at the time those decisions were made. Further, the MDSS GUI permits replaying specified periods of time at a user-selectable pace that might be faster than real-time. Particular storms deemed important to the agency may be packaged and saved for later analysis or off-season training using the MDSS GUI playback capability.

3. BENEFITS OF EARLY MDSS DEPLOYMENTS

The PFS MDSS Technical Panel commissioned a benefit/cost study to gain a better understanding of the potential costs and benefits of deploying MDSS. Although the PFS MDSS has been under development and in test-level deployment for a number of years, the small-scale nature of the early deployments, a general lack of detailed historical maintenance and road condition data, legal concerns associated with strict adherence to MDSS' recommendations, and wide variations amongst users in how MDSS is applied, have all acted to make establishment of the benefits of deploying MDSS difficult. The Western Transportation Institute (WTI) at Montana State University, in partnership with Iteris, Inc., was selected by the Technical Panel to conduct the study [4]. Due to the aforementioned obstacles, the WTI team opted to pursue a simulation-based approach to the problem. This involved using the MDSS to simulate multi-year periods of winter maintenance operations on representative maintenance routes using historical weather information and the MDSS Standard Practice recommendation module. The agreement between the simulated operations and resulting road conditions were established using the more limited datasets the associated agencies were able to provide. When good agreement was found, this "Standard Practice simulation" was established as the control case representative of current maintenance operations. This control case was then compared against simulations using MDSS' Dynamic recommendation module. Two comparison cases were sought: one in which the Standard Practice and Dynamic simulations used the same amount of salt (or other deicer), and a second in which the two simulations achieved approximately the same road conditions over time. These two comparisons can be taken to represent the cases where all of the benefits of MDSS are realized as user benefits (improved road conditions with no increase in salt usage) and agency benefits (decreased salt usage with no degradation in road conditions), respectively. The simulation process was repeated on routes in widely dispersed geographical areas and in agencies with substantially different maintenance practices to provide a range of potential benefit/cost ratios. The study concluded that the likely benefit/cost ratios of deploying MDSS would range between 1.3 and 8.7, with an average ratio of 4.75, depending upon numerous factors.

Since completion of the benefit/cost study, the Indiana Department of Transportation (INDOT) has undertaken an agency-wide deployment of MDSS (during the 2008-2009 winter season). While tracking the efficiency of winter maintenance operations is notoriously difficult due to the varying severities of winter weather from one year to the next, INDOT's conclusion after attempted normalization for winter severity was that MDSS saved the agency approximately $10,000,000 (approximately 36%) in terms of salt usage in its initial year of deployment, with additional benefits realized in fuel and labor savings [5]. The manner by which these savings were incurred is difficult to assess, but is generally perceived to have occurred through the improved management of winter maintenance operations that MDSS deployment enabled rather than through strict adherence to MDSS' recommendations.

4. FUTURE RESEARCH AND APPLICATIONS OF THE MDSS SYSTEM

Current efforts within the MDSS Pooled Fund Study are focusing on the development of more capabilities tailored toward high-level management, as well as on the continued refinement of all aspects of the system. Specifically regarding management capabilities, focus is being placed on the potential for using the MDSS system to generate a maintenance-centric approach to gauging winter severity (and ultimately changes in the efficiency of winter maintenance operations within the agency) [6]. Focus is also being placed on developing capabilities for interfacing MDSS with other agency information systems.

From a scientific research perspective, the Pooled Fund Study continues to prioritize and address research identified as potentially valuable in developing pathways for improvement to the system. An overview of some of the areas where additional research is needed, either within the PFS or within the larger road weather community, has recently been presented at the annual meeting of the American Meteorological Society [7].

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