The U.S. Federal Highway Administration winter road Maintenance Decision Support System (MDSS): Recent enhancements & refinements

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ABSTRACT

In an effort to mitigate the challenges associated with winter maintenance decisions, the United States Federal Highway Administration initiated a project aimed at developing a winter road Maintenance Decision Support System (MDSS). The goals of the MDSS project are to construct a functional prototype MDSS that can provide objective guidance to winter road maintenance decision makers concerning the appropriate treatment strategies (treatment types, timing, rates, and locations) to use to control roadway snow and ice during adverse winter weather events, and develop a prototype that will also serve as a catalyst for additional research and development by the private sector. To date, five versions of the MDSS prototype code have been made freely available to the surface transportation stakeholder community.

The demonstration prototype uses current weather observations and numerical model predictions from the United States National Weather Service to create route-specific analyses and forecasts (out to 48 hours) of atmospheric conditions. The current version of the system uses METRo, an energy and mass balance model developed by Environment Canada, to generate predictions of pavement conditions along each route of interest. Treatment recommendations, which are based on standard rules of practice for effective deicing and anti-icing operations, are constructed using current and forecasted atmospheric and road condition information. Forecast data, along with treatment recommendations, are presented to end users via an interactive Java-based display. Through this interface, users can examine and select recommended treatment strategies produced by the system, as well as investigate alternative courses of action and ascertain the anticipated consequences of action or inaction.

Over the last three years, the FHWA MDSS prototype has been demonstrated in Colorado. During this period, the system was accessible to maintenance managers in the Denver Metropolitan area. As a result of the demonstration activities, the MDSS has undergone a number of recent improvements and refinements, which have been based primarily on end user feedback and lessons learned. This paper provides a comprehensive overview of the FHWA MDSS Release 5.0 prototype, including the latest system enhancements and changes.

Keywords: weather, winter maintenance, Maintenance Decision Support System, MDSS, road weather.

1. INTRODUCTION

Over the years, winter maintenance managers and crews have had to make critical decisions regarding what strategies to employ to maintain the highest level of service possible within their sectors of responsibility or along roadways of interest. Advancements in the equipment used to service roadways, along with new chemicals and treatment strategies (e.g., anti-icing, pre-wetting, etc.), has helped winter maintenance practitioners mitigate the impacts of adverse winter weather conditions. However, the decision making process, as it relates to winter maintenance, is grounded in knowing the evolution of road weather conditions during adverse winter weather events and effectively using this knowledge to select the most appropriate treatment strategies, taking into account best practices for anti-icing and deicing and available resources.

In 2002, the United States Federal Highway Administration (FHWA) introduced the first version of the Maintenance Decision Support System functional prototype (MDSS FP), a system designed to support the winter maintenance decision process by providing winter maintenance personnel with objective guidance about how to treat roadways prior to, during, and after winter weather events. This guidance is based on weather and road condition analyses and forecasts, as well as best practices for winter maintenance operations. The system alleviates the need to acquire, synthesize, and apply road weather data and information in support of the treatment decision process. In some instances, conventional methods of gathering, distilling, and using road weather data has resulted in less than favorable results, as this can be overwhelming for some winter maintenance practitioners. The MDSS automates many of the steps that maintenance managers and crews typically follow (e.g., gathering and interpreting data), and it disseminates objective products and information in an easily understood format.

Since its initial release in 2002, the MDSS has undergone several iterations. The latest version of the system, which is freely available to the public, was released in late 2007. This version (Release 5.0) represents a considerable amount of end-to-end research and development aimed at constructing a prototype system that could be used as leverage to implement a fully operational, tailored version for end users (e.g., state departments of transportation, local municipalities, etc.). An ancillary goal of the FHWA is to promote the use and advancement of the MDSS and related technologies in an effort to improve winter maintenance operations throughout the United States and abroad [5].

During the course of the MDSS project, the National Center for Atmospheric Research (NCAR) has played a lead role in the development of the prototype system, but several U.S. national laboratories have made substantial contributions including the Army's Cold Regions Research and Engineering Laboratory (CRREL), Massachusetts Institute of Technology/Lincoln Laboratory (MIT/LL), National Oceanic and Atmospheric Administration (NOAA) Earth System Research Laboratory (ESRL), and NOAA National Severe Storms Laboratory (NSSL).

In recent years, NCAR has demonstrated the MDSS over the state of Colorado in support of winter operations for the City and County of Denver and the E-470 Public Highway Authority. These demonstrations have allowed researchers and engineers to monitor and track system performance, identify and target areas for improvement, and validate system enhancements. This paper describes the MDSS, with an emphasis on the latest version, Release 5.0. The paper also documents several of the more principal changes and enhancements that have taken place in recent years.

2. MDSS STRUCTURE

An illustration of the MDSS prototype framework, as it relates to Colorado demonstrations, is contained in Fig. 1. Key components of the system include: 1) an observation and numerical model data ingest module; 2) a road weather forecast and data fusion system; 3) a road condition and treatment module; and 4) a Java-based display system. The components currently being distributed by NCAR on behalf of the FHWA include the road condition and treatment module and the display software. As described later, the road condition and treatment module is the focal point of the MDSS.

During Colorado demonstrations, numerical model forecasts are acquired from the National Center for Environmental Prediction (NCEP), which runs several numerical weather prediction models. These models include the North American Mesoscale (NAM) and Global Forecast System (GFS). Additional forecast information is gleaned from the Rapid Update Cycle (RUC) model, which is routinely obtained from NOAA ESRL. In addition to numerical model data, real-time observations of weather and road conditions from Road Weather Information System (RWIS) Environmental Sensor Stations (ESSs) are utilized in the MDSS (Fig. 1). These observations are supplemented with data from automated observing platforms located at airports throughout the state. Together, numerical model data and real-time observations are fed into the Road Weather Forecast System (RWFS) module. The RWFS is a proprietary system run by NCAR to generate consensus forecasts based on observations and model data. It should be noted that this particular module is not necessary for MDSS setup and operation. Any data series forecast in the correct format can be used to drive the system; the forecast could be produced by automated means or be manually generated.

As illustrated in Fig. 1, the consensus forecasts from the RWFS are passed to the Road Condition and Treatment Module (RCTM) where they are used to force a one-dimensional energy and mass-balance model to predict the evolution of road and bridge temperatures, as well as the state of roadways (e.g., dry, wet, snow depth, etc.). The combination of diagnostic and prognostic weather and road condition information is used in conjunction with best practice rules for anti- and deicing to formulate treatment recommendations [2]. This module is also responsible for tracking information regarding the type of actions that are taken by users. By maintaining a history of selected treatment actions, the system is better able to make more appropriate treatment recommendations during subsequent forecast update cycles. This module also enables end users to investigate and gauge the impact that the system recommended treatment, alternative treatment or inaction will have on the state of user-defined roadways.

Data and information are supplied to users through a Java-based graphical user interface (Fig. 1). Through this interface, maintenance practitioners can examine hourly predictions of road weather conditions out to 48 hours at user-specified locations, with updates provided every three hours. Fundamental atmospheric variables forecast by the MDSS include ambient air temperature, dew point temperature, wind speed and direction, and precipitation occurrence, type and rate. As part of the process of determining precipitation type, the system computes the conditional probability for rain, snow and ice. This information is provided to the user via the graphical display, along with the total probability of precipitation. Decision makers are also presented with route-specific forecasts of key roadway-related elements such as road and bridge temperatures, roadway snow accumulation, bridge frost potential, and chemical concentration.

Along with strategic information, the current version of the MDSS has the capacity to deliver tactical environmental and road condition information. The system can display several different data elements from multiple sources and platforms including ESS, maintenance vehicles (via Automated Vehicle Location [AVL]), radars and satellites, with the ability to animate select data. Such data and capabilities not only allow users to track weather systems that will potentially affect their area of responsibility, but they also enable users to observe real-time, local conditions once the storm has commenced, and determine which roadways are being most heavily impacted. In addition, the system is capable of generating tactical alerts, which are based on a combination of observed and forecast data. These alerts notify winter maintenance personnel about current and near-term (0 – 3 hours) conditions that may require action, such as the occurrence of frozen precipitation and forecasts of subfreezing pavement temperatures during precipitation events.

One of the most important facets of the MDSS is the system's ability to supply decision makers with guidance regarding the road conditions should one of three scenarios be followed: 1) no treatment is performed during the entire forecast period; 2) the recommended treatment is followed; or 3) a user-defined treatment plan is selected. Together, weather and road condition data and treatment guidance allow winter maintenance practitioners to make more informed decisions regarding the best approaches to use to address adverse road weather conditions.

3. MDSS IMPROVEMENTS AND ENHANCEMENTS

Considerable resources have been invested in recent years in an effort to optimize the guidance provided by the MDSS and deliver data and information in an easily understood, accessible format. In this section of the document, some of the more significant system enhancements that have taken place in recent years are highlighted. The technical transfer (distribution of MDSS software to external organizations) of the MDSS is a fundamental goal of the project; thus, several of the modifications discussed herein were carried out in an effort to simplify this process and ensure that the code could be more easily adapted to the needs of disparate users.

3.1. Road Condition and Treatment Module

As previously noted, the central component of the MDSS is the Road Condition and Treatment Module, as this module is responsible for road condition forecasts and treatment recommendations. The RCTM is comprised of several discrete sub-modules that help facilitate the generation of treatment recommendations and provide ancillary information regarding the current and future state of the roadway. Fig. 2 shows the flow of data within the RCTM.

Roadway configuration information, along with weather forecasts and roadway observations, is needed by the Road Temperature and Snow Depth sub-module. This module is used to produce forecasts of pavement temperatures and conditions. The primary element of this module is a one-dimensional energy and mass balance numerical model capable of predicting pavement temperature and condition. This model is discussed in further detail in section 3.2. Information from the Road Temperature and Snow Depth module is used in the derivation of a net mobility index, which is a very rudimentary index designed to provide system users with a sense of how current and anticipated road conditions will impact their operations.

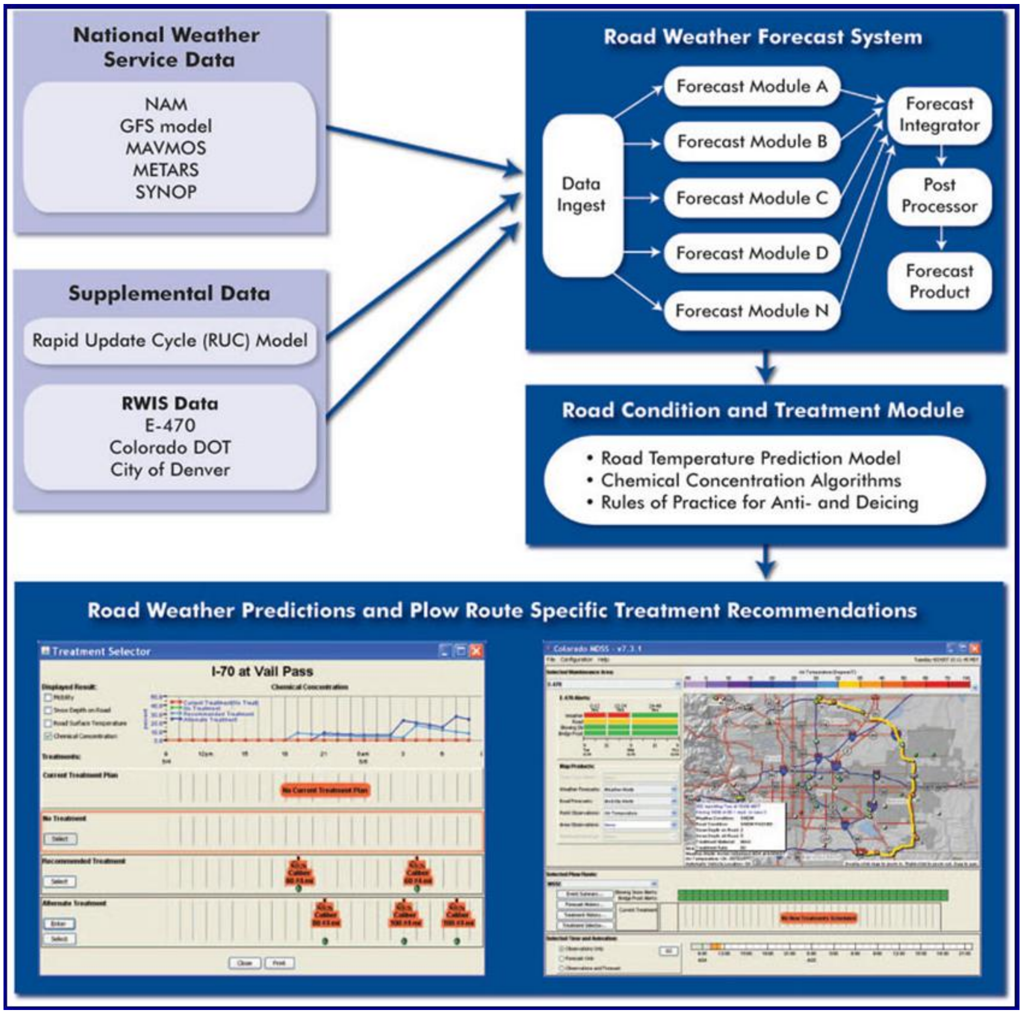

Fig. 1. Illustration of the MDSS framework during Colorado demonstrations.

Data from the Road Temperature and Snow Depth module is also utilized by the Rules of Practice (RoP) component of the RCTM. The RoP ingests road weather condition forecast data to make recommendations regarding the appropriate road treatment strategies for various conditions. The RCTM has been designed to determine road conditions and recommend treatment actions in three different modes: 1) no treatment; 2) recommended treatments; and 3) user-defined treatments. The "no treatment" mode assumes that no action (i.e., treatment) is taken, and information is provided to the user concerning the state of the roads if no maintenance action takes place. The second mode, the recommended treatment mode, determines the most appropriate course of action based on anticipated road weather conditions and best practices for anti- and deicing [2]. In the user-defined treatment mode, users can specify alternate treatment plans (what-if's) in an effort to examine what happens to the state of the road under different scenarios. When a user selects a treatment plan, whether it is the system recommended plan or a user-specified treatment plan, the system stores this information and uses it to calculate the road conditions and subsequent treatment actions.

Upon selection of a user-defined treatment plan or a system recommended plan, the Chemical Concentration module tracks and estimates the concentration of anti-icing and deicing chemicals on the roadway. In order to effectively estimate the chemical concentration along a stretch of roadway, it is essential to have knowledge regarding the actual chemical application (e.g., quantity, type, and timing) and precipitation characteristics (e.g., occurrence, type, liquid water equivalent). The effectiveness of a chemical application is degraded as the chemical concentration decreases, which is a result of the chemical mixing with precipitation. Additionally, other factors such as evaporation and solution drainage will also have an impact on chemical concentration. The Chemical Concentration module attempts to capture the essential aspects of the chemical application/dilution process. Note that chemical concentration is used to derive subsequent treatment recommendations, as illustrated by the link from the Chemical Concentration module to the Road Temperature and Snow Depth module.

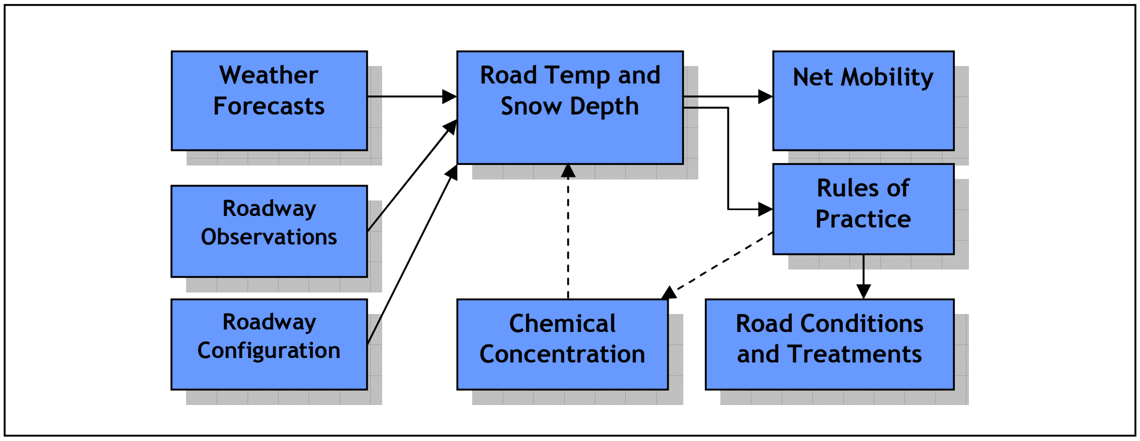

Fig. 2. Diagram of the Road Condition and Treatment Module illustrating the data flow. Dashed lines indicate flow if treatment recommendations are generated by the Rules of Practice module.

3.2. Road Temperature and Condition Model

Last year, a new road temperature and condition model was incorporated into the MDSS. The Model of the Environment and Temperature of Roads (METRo), which was developed by the Enviornment Canada, is now used to provide the MDSS with forecasts of pavement temperatures and conditions. The model is a physically-based one-dimensional energy and mass balance model [1]. It has been integrated into the MDSS as part of the Road Temperature and Snow Depth sub-module of the RCTM. Several criteria were examined in an effort to select a model that would provide the most benefit to the MDSS with the least amount of overhead. These criteria included forecast performance, code stability, support, efficiency, and ease of use.

In the case of performance, METRo has exhibited good performance during several disparate weather events. A basic study was conducted by NCAR to examine the performance of METRo, along with two other models, the Fast All-season Soil Strength (FASST) model and SNTHERM, both of which were developed at CRREL [4]. Select results from this study are provided herein.

The model assessment entailed exploring model performance at a site-specific location along the E-470 toll road, which is west of downtown Denver, Colorado. The investigation used weather and road condition data from an ESS located at 6th Parkway. Although the ESS is capable of supplying atmosphere and pavement data, it does not have the capacity to report precipitation or cloud cover. The precipitation and cloud cover observations were taken from a GEONOR gage and an Automated Surface Observing System (ASOS), respectively. These devices are located on the grounds of Denver International Airport (DIA), approximately 16 km northeast of the forecast site. Thus, the precipitation and cloud cover information used in the investigation may not always be fully representative of the conditions at the forecast site. A perfect prognosis approach was used to investigate forecast performance. In this approach, road temperature forecasts from each model were generated using actual observations [4].

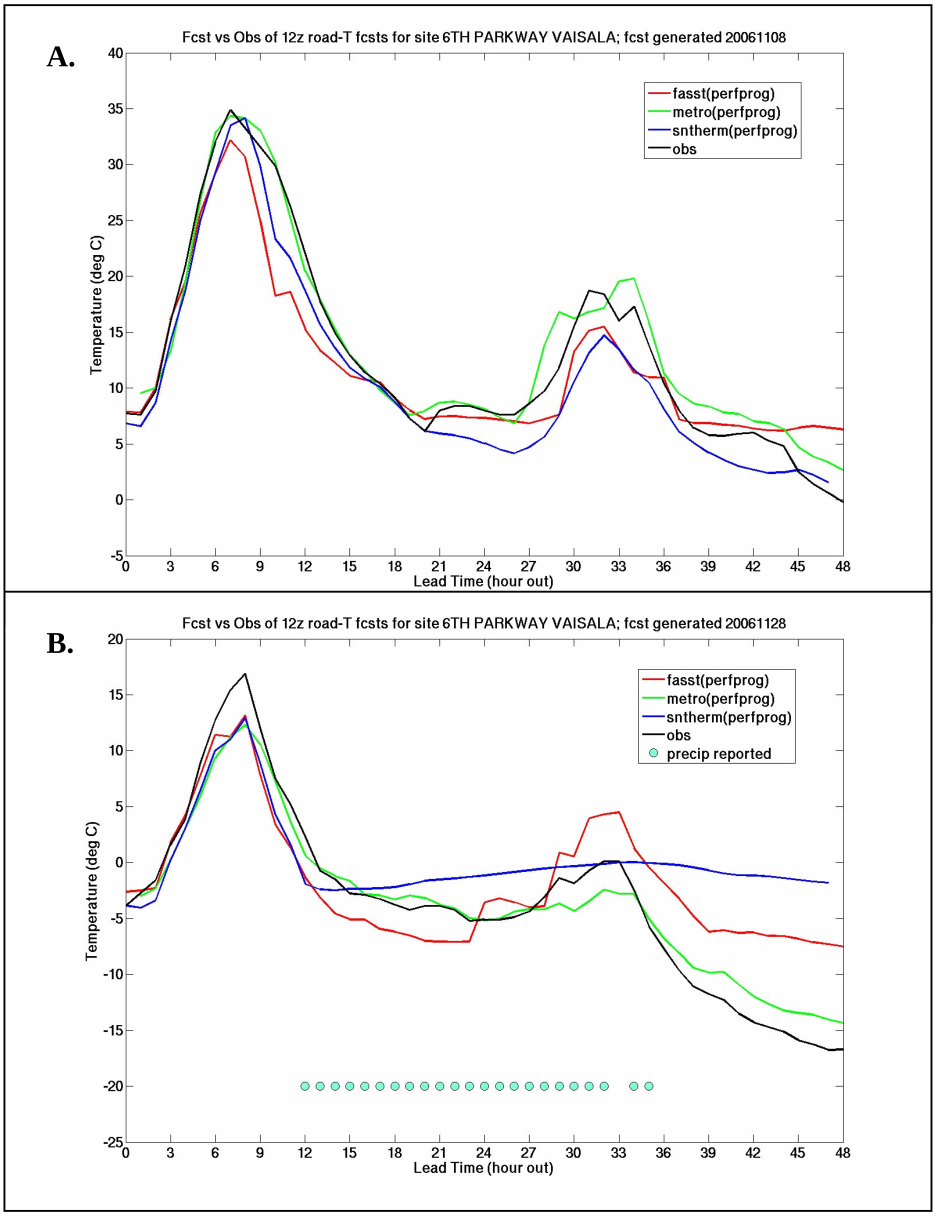

Fig. 3. Perfect prognosis generated road temperature forecasts from FASST, METRo and SNTHERM for 12Z on 08 November (A.) and 28 November 2006 (B.) [4].

Fig. 3 displays forecasts for two events that occurred in November 2006. The first was a case in which a record high temperature (ambient air) of 26.7^{o}C was set on 8 November, followed shortly thereafter by a weak cold front, which acted to suppress temperatures on the following day (Fig. 3A). In the second case, the Denver, Colorado region experienced an extended moderate snow event (28 November) on the first day. This was followed by much colder temperatures on day two (29 November). In both cases, METRo exhibited better overall performance when compared to FASST and SNTHERM. In the second case, which is more representative of the kinds of conditions that impact winter maintenance operations, METRo's performance was clearly superior to the other models tested. Unlike SNTHERM, METRo's temperature forecast did not become dampened by the presence of snow, and it was able to pick up on the steep decline in pavement temperatures that occurred on the evening and night of the second day, while FASST and SNTHERM continued to show a considerable warm bias. Although these two cases do not constitute a statistically significant sample size, objective and subjective investigations of forecasts from supplementary events support the notion that METRo performs quite well across a wide range of environmental conditions.

To date, there have been two noteworthy issues with utilizing the METRo model: the need for an observational history at the forecast site, and the time required to run the model. While models such as SNTHERM and FASST take approximately 0.2 seconds to generate a 48-hour forecast, METRo takes roughly 2 seconds. This can be attributed, in part, to the fact that METRo uses the industry standard XML format, and the parsing of XML input files and/or writing the XML output files takes a significant amount of the processing time. METRo also requires an observational history of the surface and, if available, subsurface observations. Using this history, METRo develops its own estimate of the current subsurface temperature profile. At least a 3 hour history is required and 12 hours is preferred, and this can present challenges at non-observing sites.

Regardless of the previously described issues, METRo exhibits several other traits that make it an attractive option for use in the MDSS. A fundamental goal of the MDSS project is technology transfer; there is a strong emphasis placed on distributing the MDSS software to the private sector to stimulate further research and development. The METRo model is easy to obtain, install, and use. Moreover, the model is freely available to the public and comes with adequate documentation that describes the setup process. A METRo wiki has also been established to help facilitate the distribution of the software and provide users with information regarding METRo updates. As METRo's user base expands, the wiki will serve as a means to exchange information and experience.

3.3. Rules of Practice

The RoP sub-module is also an important part of the RCTM and is instrumental in the generation of treatment recommendations. Feedback collected during MDSS field demonstrations has resulted in a number of RoP changes and enhancements, leading to more robust software capable of meeting the needs and requirements of the end user community. Some of the more relevant RoP changes are discussed in this section.

During multiple field demonstrations, more than one agency was utilizing the MDSS system. It became evident that the MDSS needed more flexibility in terms of setting select parameters related to the treatment recommendation process (e.g., chemical type, pre-treatment strategy, maximum and minimum application rates, etc.), since each agency traditionally has very prescribed treatment methods and limitations. The system and the RoP were updated to not only allow these parameters to be set for each agency, but for individual routes as well. This change enables the system to provide treatment plans based on a wide variety of strategies, even within a single agency.

Earlier versions of the RoP used simplified curves to essentially automate the treatment look-up from the FHWA tables. This latest version of the RoP, however, utilizes both the eutectic curves directly and the dilution information from the Chemical Concentration module to more accurately estimate the amount of chemicals needed on the road surface to keep snow and ice from bonding. Treatment recommendations are now driven by dynamically calculating chemicals needed based on expected chemical dilution and hourly forecasted weather and road conditions. This process benefits from the development and implementation of a storm characterization module, which was added to better categorize pre-, in-, and post-storm weather and road conditions. To further improve the treatment recommendation process, the RCTM tracks the expected amount of available water on the road surface and the phase of the water (e.g., snow, ice, wet, etc.), improving the RoP logic and enabling the system to protect against critical situations such as surface water refreezing post-storm.

The reconfiguration of the MDSS for operation over Colorado sheds light on the need for the system to support additional chemical types, since some maintenance agencies in Colorado use newer products such as Caliber and Ice Slicer in treating roads. As a result, additional eutectic curves were added to the RoP to handle these chemical types. Currently, the system supports five different chemical types: 1) Sodium Chloride; 2) Calcium Chloride; 3) Magnesium Chloride; 4) Caliber; and 5) Ice Slicer. Furthermore, the form of the treatment chemical (dry, pre-wet, and liquid treatments) can be entered explicitly by the user (either as the preferred treatment type or in the user and what-if treatment strategies). Chemical splatter off the road and dilution rates are modified by the chemical form entered (liquids splatter less, but dilute faster).

Support for the application of multiple chemicals was added allowing users to select user-defined treatments that apply more than one chemical during a storm. System-recommended treatments, however, are still only capable of single chemical recommendations (except for pre-treatment). An option was also added to allow users to configure the treatment strategy that their operation employs: *continuous* or *triggered* operations. *Continuous* operations occur when trucks are deployed continuously during the precipitation phase of a storm regardless of current treatment effectiveness. *Triggered* treatment strategy refers to operations that deploy treatments only when either the chemicals are ineffective or the snow is at a plowable depth.

Finally, blowing snow potential is now considered in the development of treatment plans (higher blowing snow potential yields higher treatment recommendations). The RoP also provides textual output that describes the reasoning behind the development of the recommended treatment plan.

3.4. Alerts

The occurrence of pavement frost can have an impact on roadway level of service, with bridge surfaces being particularly susceptible to these conditions. Work has been carried out to implement and refine a frost potential product; this product is based on research conducted at Iowa State University [3]. Pavement temperature forecasts from METRo and predicted environmental conditions (e.g., air temperature, dew point temperature, wind speed, etc.) are used as input in the Iowa State algorithm to compute frost deposition. A Monte-Carlo statistical technique is applied to the input variables in an attempt to calculate the uncertainty in forecasts. The variations used are based on appropriate standard deviations for each variable. An interest function is applied to the frost depth returned from the Iowa State algorithm and a weighted average of these interest values is calculated. The weight given to each frost occurrence estimate emulates the statistical probability of that combination of events happening. The likelihood of frost is calculated and mapped to the MDSS alert categories (none, low, medium, and high).

In an effort to supply users with additional tactical information regarding the state of the atmosphere and roads, a module was added to the MDSS to generate short-term weather and road condition alerts. The alerts are designed to provide system users with simple notifications of adverse weather or pavement states that are either occurring at the present time or will be occurring in the next few hours. Weather alerts are based on precipitation reports from observation data such as METARs and provide real-time indication of potentially hazardous weather. A Weather Alert is generated when snow or freezing precipitation is reported at or near a specific route. Weather alerts are updated as new observation data are received. Road alerts are more predictive in nature and use the most recent road condition forecasts to determine if an alert is warranted. A Road Alert is generated for a route if the road temperature is anticipated to go below freezing and precipitation is expected, or if the road is currently wet and the road temperature is expected to go below freezing. Road Alerts are updated each time a new forecast is available and are valid until the next forecast update.

3.5. Display System

The MDSS display application supplies an interactive display of data generated by core system components (e.g., RCTM). The display is a Java-based application that resides on an end user's computer and is invoked through Java WebStart from Sun Microsystems. This allows the display to be run on a variety of platforms. The display system enables the user to:

- Determine whether adverse weather or road conditions are predicted to occur in the future (current forecast period is 48 hours).
- Examine forecasted and observed weather information at user-defined forecast sites.
- Examine forecasted and observed road condition information at each user-defined maintenance route or zone.
- Be alerted to potential real-time and near-term road weather hazards.
- Verify forecast performance (air and pavement temperature, relative humidity, and wind speed).
- Examine archived events, including weather and road condition forecasts, observations, treatment recommendations and selected treatment actions.
- Generate winter maintenance treatment plans for each route or zone.
- Assess the predicted impact of system-recommended treatment plans.
- Perform *what if* scenarios to assess the impact of user-defined treatment plans.
- Examine recommended and selected treatment history (previous 6 hours).

In the initial state maintenance area view displayed in Fig. 4, the state alert zones on the map are color coded for the worst weather forecasted for the next 48 hours. This is the view presented to the user upon display startup. The display system also provides other high-level alerts of forecasts for inclement weather, impaired road conditions, blowing snow, and bridge frost. From this display level, the user can determine whether the alert information warrants further investigation. If so, the user can choose to select one of the preconfigured maintenance area views. The combo box located in the upper-left corner of the display is used to select the maintenance district of interest. When a maintenance area is selected, the map is zoomed to that area and the alerts are updated to reflect only the roads and forecast points within that maintenance area.

Fig. 5 displays the E-470 Public Highway Authority maintenance district. At this level, current and anticipated road weather conditions that are valid for the district can be inspected. All of the datasets listed in the Map Products panel to the left of the map may be independently enabled and disabled. The display of weather variables such as air temperature, relative humidity and snow accumulation, are controlled via the Weather Forecast combo box, while the Road Forecasts combo box controls the visibility of the road variables, including road and bridge temperature and snow depth. The Point Observations combo box controls the visibility of the real-time variables (e.g., ESS data), and the Area Observations combo box controls the visibility of the radar and satellite datasets.

Weather and road forecast charts and tables can be accessed by clicking on a user-defined forecast point or road segment, respectively. As an alternative, for each route in the system, a summary of predicted weather and road conditions is provided in the Event Summary dialog. This summary provides an overview of key forecast parameters, including but not limited to road temperatures, total snow accumulation on the road, conditional probabilities of rain, snow, and ice, as well as the total probability of precipitation and the declared precipitation type.

The Treatment History dialog for each route displays the recommended and last-selected treatments for the current 3-hour run and the two previous 3-hour runs. The information is presented in graphical or textual format, as desired, and as with many of the dialogs, the contents may be printed.

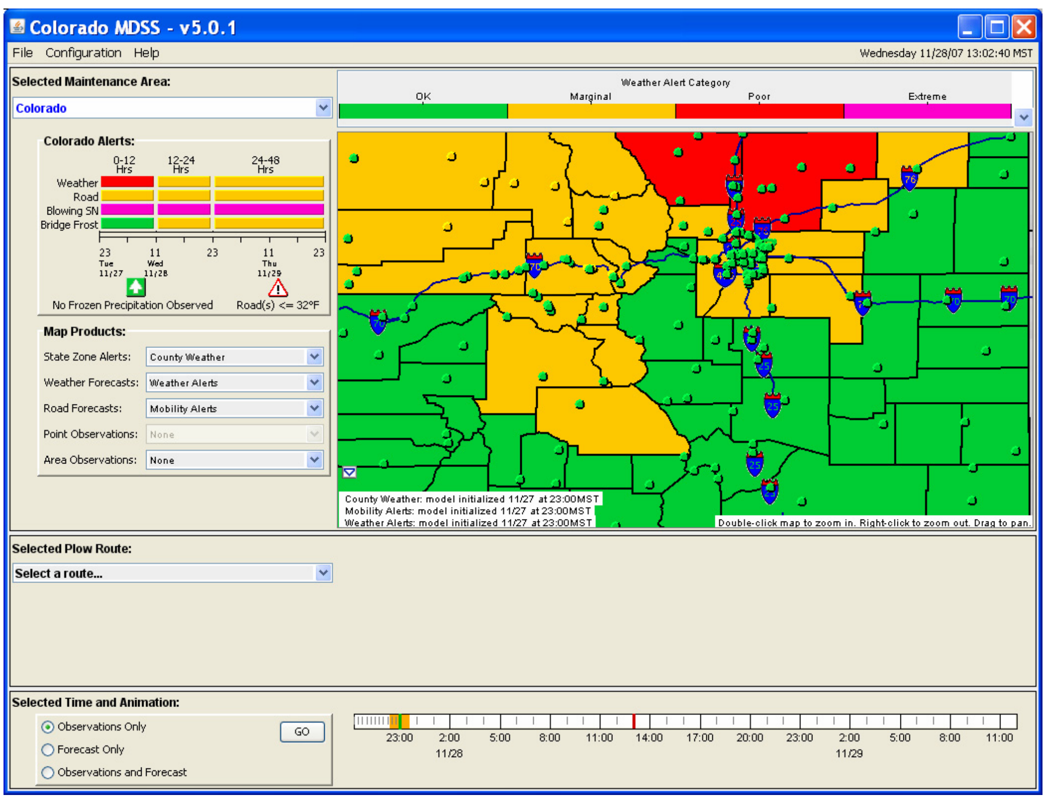

Fig. 4. Example MDSS state view for Colorado.

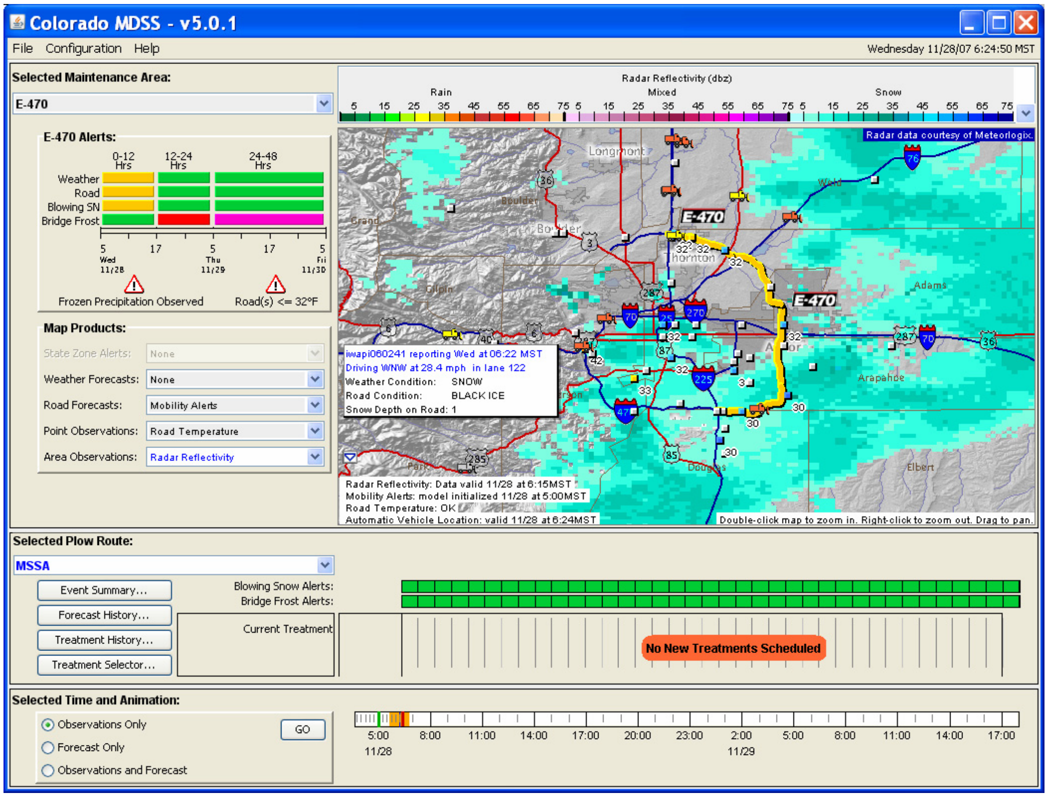

Fig. 5. Example district view (E-470 Public Highway Authority). Displayed data include pavement temperatures, mobility alerts, radar data, and AVL information.

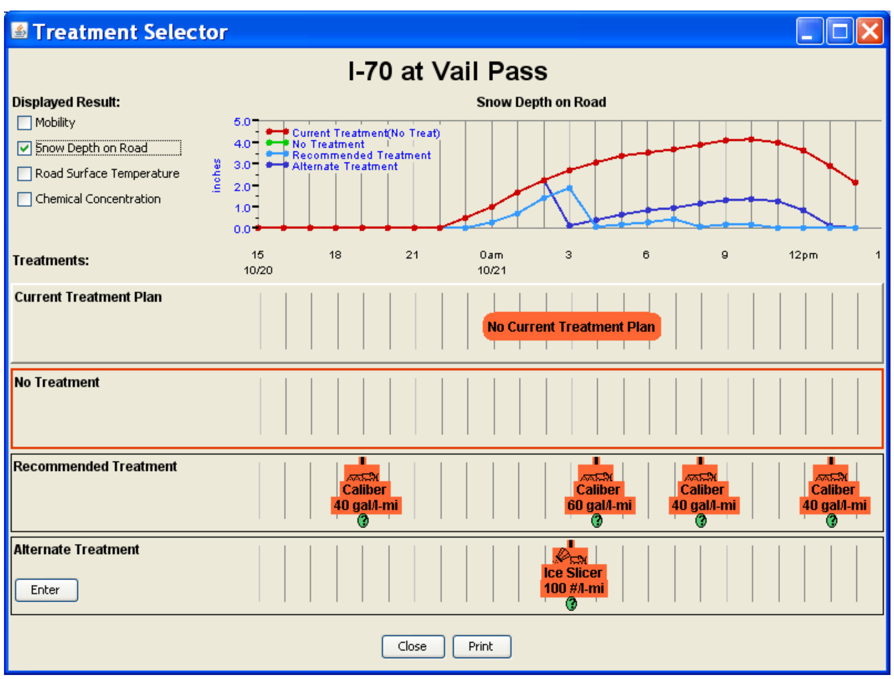

Fig. 6. Example treatment selector dialogue.

Road treatment selection and functionality are provided in the Treatment Selector dialog. This dialog allows users to get a recommended treatment for each of the road segments modeled in the MDSS system. It also allows users to test user-specified treatments for each segment. If the user is satisfied with the results of a treatment scenario, the user can select it for use in operations. The user may also opt to select one of the other scenarios for use in operations. In either case, the display adjusts the road condition alerts to reflect the predicted road conditions based on the selected treatment (Fig. 6).

One of the major extensions to the MDSS is the ability to display gridded products such as radar and satellite data (Fig. 5); these products can be used to support tactical maintenance operations. These data are distributed by a Thematic Real-time Environmental Distributed Data Service (THREDDS) server and are loaded in one of the emerging standard meteorological data formats, network Common Data Form (netCDF). In the example contained in Fig. 5, radar data indicating the location and intensity of snow are displayed.

The support for dynamic basemaps has also been added. These maps show the appropriate resolution of roads, political boundaries, and topographic detail for the current pan and zoom. Users now have the ability to arbitrarily zoom and pan using a double-click to zoom in, a right-click to zoom out, and a click-drag to pan.

The Configuration menu provides access to several useful features. This menu enables users to select historical forecasts produced by the MDSS. This historical information includes the treatments recommended by the MDSS, as well as an account of what treatments were selected. Maintenance practitioners have the capacity to review past events and investigate whether appropriate actions were taken based on the forecasted information. Moreover, MDSS's ability to display archived events allows it to be used as a training tool for less experienced maintenance managers and crews. The Configuration menu also has a selection that enables the display of AVL data for all trucks which have reported within the desired time range: the last 12 hours; the last 24 hours; or any time, allowing managers to view vehicle location, speed and direction, treatment, and observed weather and road conditions. Only the latest report from each truck is shown. Tooltip (i.e., mouse over) inspection of trucks yields a table containing all available details from the truck report (Fig. 5). Finally, the speed at which animations of gridded data are displayed can be controlled through the use of a slider controller. This too is found in the Configuration menu.

Overall, the new display is far more localizable than its predecessors and provides considerably more functionality.

4. SUMMARY

The U.S. Federal Highway Administration funded and directed the development of a prototype system capable of providing guidance to winter maintenance personnel regarding what treatment actions to take based on the anticipated road weather conditions. Since its inception, the MDSS FP has been augmented and enhanced significantly. The latest MDSS release (version 5.0), which will likely be the last public release, contains a number of upgrades and improvements that have resulted in a very comprehensive winter maintenance support system capable of being used as a foundation for operational MDSS capabilities. The success of the MDSS project can be measured by the fact that several private sector companies have begun developing operational versions of the MDSS. Nonetheless, it should be noted that more research and development is needed in order to develop end-to-end MDSS capabilities that are able to meet all of the demands of the winter maintenance community. Specifically, improvements in road weather forecasting, mobile data integration, and assessments of current and emerging treatment chemical effectiveness are needed. As more commercial vendors work with the winter maintenance community to develop and implement MDSS-related technologies, MDSS capabilities will be improved, leading to a high level of performance and ultimately, widespread adoption of the technology by winter maintenance practitioners.

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