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THE WINTER ROAD MAINTENANCE DECISION SUPPORT SYSTEM (MDSS) PROJECT UPDATE AND FUTURE PLANS

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1 INTRODUCTION

Winter road maintenance operators have the difficult job of planning deicing, anti-icing and snow removal operations with limited information about current and predicted weather and road conditions. This inefficient process can often result in frustration, misinterpretation of environmental conditions, and poor decisions. In FY2000, the Federal Highway Administration (FHWA) Road Weather Management Program began a project to develop a prototype winter road Maintenance Decision Support System (MDSS). The MDSS is designed to provide guidance on winter maintenance decisions (treatment times, types, rates, and locations) specific to winter road maintenance routes.

The requirements gathering phase of the MDSS project began in fiscal year 2000. In 2001 the goal was to develop a conceptual prototype MDSS and in FY2002 a functional prototype was developed. The functional prototype software was released on a non-exclusive basis to the surface transportation community in September 2002. An MDSS field demonstration and verification project will occur during the winter months of 2003 in Iowa for plow routes near Des Moines and Ames. System refinements will be made based on the results of the field demonstration and they will become part of the second system release.

The MDSS project goal is to develop a prototype capability that capitalizes on existing road and weather data sources, fuses data to make an open, integrated and understandable presentation of current environmental and road conditions, processes data to generate diagnostic and prognostic maps of road conditions, provides a display capability on the state of the roadway, provides a decision support tool which provides recommendations on road maintenance courses of action together with anticipated consequences of action or inaction.

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2 BACKGROUND

In fiscal year 2000, the U.S. FHWA Road Maintenance Management Program began an initiative to gather surface transportation weather decision support requirements from State Department of Transportation (DOT) personnel. In addition, the Office of Federal Coordinator for Meteorology (OFCM) together with the FHWA, co-sponsored symposiums on Weather Information for Surface Transportation (WIST).

Five national research centers have participated in the development of the functional prototype MDSS. The participating national labs include the Army's Cold Regions Research and Engineering Laboratory (CRREL), National Science Foundation's National Center for Atmospheric Research (NCAR), Massachusetts Institute of Technology - Lincoln Laboratory (MIT/LL), National Oceanic and Atmospheric Administration (NOAA) National Severe Storms Laboratory (NSSL), and NOAA Forecast Systems Laboratory (FSL).

During FHWA reviews of candidate technologies, it became clear that many candidate technologies currently exist, but the new technologies needed to be integrated, refined, and tailored to address winter road maintenance concerns. It also became clear that new and focused research must be conducted to address specific winter maintenance decision support needs that are not addressed adequately by current technologies.

3 NEEDS ASSESSMENT

Based on an extensive user needs assessment performed by the FHWA in 2000, it became clear that substantial benefits can be realized if weather forecasts are improved, are more specific, more timely, and tailored for surface transportation decision makers who are not meteorologists. The most important environmental factors that have been identified to date that are necessary for supporting maintenance decisions include: event definition with respect to start and stop times; precipitation characteristics (type, amount, rate); road condition (temperature, chemical concentration, friction, contamination); and risk (confidence and/or probabilities associated with data elements). The decision support components of the prototype MDSS have been designed to address decisions frequently made by users prior to, during, and after events occur. User decisions are generally based on having answers to the following questions specific to each maintenance route:

- When will the event start and stop?
- How is the road temperature changing?
- When will the roads freeze?
- What type of precipitation will fall?
- How much precipitation and at what rate will it fall?
- What type of mitigation (treatment) should be performed (salt, sand, anti-icing chemicals)?
- When and where should the treatment(s) be performed?
- How long will the treatment(s) last?
- What resources are available to conduct the operation?

4 TECHNOLOGY TRANSFER – PUBLIC RELEASE

The MDSS functional prototype software (version-1) was developed between October 2001 and September 2002. The overarching goal of the MDSS project is to accelerate the time to market for MDSS capabilities; therefore the MDSS and its components were made available to the public on a non-exclusive basis. Another objective of the MDSS project is to create a surface transportation weather capability in the national labs and with surface transportation stakeholders. The stakeholders who are public-sector transportation operators and private-sector weather information service providers will be the beneficiaries of applying that capability.

The MDSS FP is designed to be a template for future operational capabilities. It is envisioned that the private sector together with local DOTs will review the FP and jointly develop operational versions of the system whether standalone or integrated with broader decision support systems.

A live demonstration of the MDSS FP is planned for the winter of 2003. The objective of the 2003 demonstration is to test the system in a real-time environment, verify its performance, and tune the system where necessary. Enhancements made to the system based on the demonstration will be included as part of a second software release which is planned for September 2003.

5 FUNCTIONAL PROTOTYPE STRUCTURE

The MDSS functional prototype was designed as a modular system so that individual components can be extracted, replaced, improved and implemented efficiently by organizations responsible for implementing an operational version of the system for a DOT. Primary components to the system include: a) a numerical weather prediction system, b) road weather forecast and data fusion system, c) road temperature model, d) road chemical concentration algorithms, e) road mobility index algorithm and f) display system.

The MDSS provides decision makers with explicit information on current and predicted weather and road conditions for user defined locations along winter road maintenance routes. Road specific products include information on road temperature, road chemical concentration, contamination (snow, ice, etc.), and road mobility. Environmental information includes but is not limited to air temperature, precipitation type, precipitation rate, wind, insolation (percent cloud cover), and dew point. The system also provides decision guidance for each route based on standard practices for effective winter road maintenance (e.g., anti-icing, deicing, plowing, etc.). The MDSS provides road condition information for three primary conditions. The information provided is based on:

a) Performing no treatment during the entire event
b) Performing the recommended treatment based on standard rules of practice
c) Performing a user-defined treatment

Users have the ability to select treatment constraints (chemicals used, route times, application rates, etc.) for each route. In addition, the system is designed to allow users to tailor the rules of practice for each route.

5.1 Data Flow

The MDSS FP utilizes data from external sources including the National Center for Environmental Prediction (NCEP) and individual State DOTs (e.g., weather and road surface observations). Supplemental numerical weather prediction models (e.g., mesoscale models) are also utilized. These data are ingested and processed for use by downstream algorithms and modules. Downstream modules include the Road Weather Forecast System (RWFS), Road Condition and Treatment Module (RCTM), and display system.

Data flows from NCEP, State DOT(s), and the supplemental external model forecast providers, which in the case for the prototype is numerical model output from NOAA FSL and NSSL. The Local Data Manager (LDM) software acquires and forwards these data to other processes. A data assimilation step extracts data at the forecast sites (along or near routes) and performs straightforward derivations to obtain further data fields, which are used by downstream algorithms.

5.2 Road Weather Forecast System

The RWFS (Myers et al. 2001) process is tasked with ingesting meteorological data (observations, models, statistical data, climate data, etc.) and producing meteorological forecasts at user defined forecast sites and forecast lead times. The forecast variables output by the RWFS are used by the RCTM to calculate the road surface temperature and to determine a suggested treatment plan. In order to achieve this goal, the RWFS generates independent forecasts from each of the data sources using a variety of forecasting techniques. A single consensus forecast from the set of individual forecasts is generated at each user defined forecast site based on a processing method that takes into account the recent skill of each forecast module. Because the RWFS utilizes local observations to optimize its forecasts, having real-time access to weather observations and road condition measurements along or near the maintenance routes is very important.

The RWFS generates point forecasts for locations along the highway system (and elsewhere as configured). However, very few of these sites are observational sites that regularly make automatic reports. At observational sites, forecast parameter tuning based on past performance helps improve the forecasts. This class of sites is called core forecast sites. Forecasts at non-core sites are derived from forecasts at core sites.

The numerical weather model data used by the RWFS has three-hourly resolution. Since the system is primarily model data driven, forecasts are initially generated at three-hour intervals. These times are called the core forecast lead times.

The variables output by the RWFS are used by the RCTM and the display. The observational data ingested only contains a subset of the variables required by these downstream processes. The RWFS output variables contained in the observational data sets are called the core forecast variables.

The RWFS creates several independent forecast estimates. Each forecast module attempts to create the best forecast it can by applying a specific forecast technique to its input data set. Each RWFS forecast module uses one of three basic techniques to generate forecasts. They are:

- Dynamic Model Output Statistics (DMOS),
- Interpolation of NWS MOS site forecasts, and
- Semi-static techniques.

Each forecast module produces an identically formatted output file. No forecast module is dependent on another forecast module. That is, no forecast module's output is used as input to another forecast module.

The DMOS forecast modules are a dynamic variation of the traditional National Weather Service MOS procedures. DMOS, like traditional MOS, finds relationships between model output data and observations using linear regression methods. However, while MOS equations are calculated using many years of data, DMOS uses only the last 100 days (configurable) of data. New regression equations are re-calculated once per week.

The DMOS technique has several advantages over traditional MOS. The reliance on only a short history allows DMOS equations to be calculated and DMOS forecasts generated for newly ingested models or models that are changing due to enhancements. Traditional MOS equation generation would require the model to be stable (no changes) for several years. Also, the MOS equations are calculated painstakingly with a large human quality control effort. This makes it difficult to add MOS equations for a new set of forecast sites. DMOS forecasts can be made at these sites immediately provided they have a short observational history.

The RWFS forecast modules each generate as complete a forecast as possible. This includes a forecast for every forecast variable at every forecast site for every forecast lead-time. These independent forecast estimates are combined by the integrator process to generate one final consensus forecast. Numerous combination techniques have been developed. Investigation has led to a decision to use an enhanced Widrow-Hoff learning method. This method creates its final forecast using a weighted average of the individual module forecasts. The weights are modified daily by nudging the weights in the gradient direction of the error in weight space. The effect of this is that forecast modules that have been performing well for a particular forecast (variable, site, and lead time) get more weight and the poorly performing modules get less weight.

An illustration of the RWFS data flow is provided in Figure 1. The RWFS generates point forecasts for locations along the highway system (and elsewhere as configured). However, very few of these sites are observational sites that regularly make automatic reports. At observational sites, forecast parameter tuning based on past performance helps improve the forecasts. This class of sites is called core forecast sites. Forecasts at non-core sites are derived from forecasts at core sites.

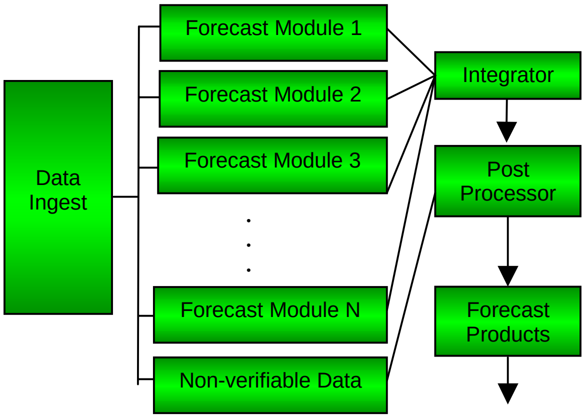

Figure 1. RWFS real-time processing data flow.

5.3 *Road Condition and Treatment Module*

A diagram of the RCTM is provided in Figure 2. The RCTM ingests and processes weather forecast data to predict the road surface temperature at all forecast sites and lead times. Using the meteorological forecast data and the pavement temperature data, a predicted mobility index is calculated along with a treatment plan. For prototyping purposes, a small number of forecast sites have been selected per highway route and weather and road condition data have only been processed for those sites.

The road temperature module called SNTHERM-RT is a land-surface model enhanced by CRREL that generates a temperature profile of the road surface and subsurface. This snow/road/soil temperature model is a one-dimensional mass and energy balanced model constrained by meteorological boundary conditions. The model considers the transport of liquid water and water vapor, and phase changes of water (except in the road layer) as components of the heat balance equation. The impact of snow accumulation, ablation, densification, and metamorphosis on the snow thermal optical properties are modeled. The infiltration of water in the snow/soil is modeled assuming gravity flow. The chemical concentration module ($NaCl$, $MgCl_2$, and $CaCl_2$) predicts the dilution of chemicals existing on the road.

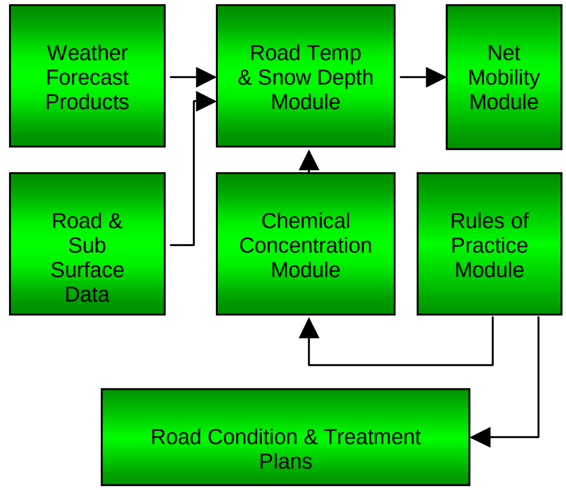

Figure 2. RCTM module data flow diagram. The dashed lines indicate the data flow if the Rules of Practice Module determines that a treatment is required.

Given an initial concentration applied as part of the treatment process and the weather forecast (e.g., temperature, precipitation type and rate), the module generates an hourly time series of expected chemical concentrations. The concentration is dependent on the road surface temperature and liquid precipitation amount, and secondary factors including traffic volume, chemical scatter and spray. A complicating factor is that road temperature and the chemical concentration are interrelated. To simplify the calculation, an approximation of the road temperature is made using the initial road surface temperature and the forecast air temperature (at $t = 0$). Given the predicted precipitation, it can be determined when the chemicals applied on the road will become ineffective.

A treatment plan is calculated (on demand) for highway forecast points that represent the conditions along particular maintenance routes. The treatment plans can vary spatially and no approach is currently in place to resolve the potential discrepancies between nearby points. Discrepancies may be partially due to differing subsurface structures of the roadways at adjacent points. For example, road conditions on a bridge can be very different from conditions a few hundred meters away. The output of the RCTM is passed to the display system.

If the treatment module recommends a chemical treatment, the suggested chemical amount as determined by the rules of practice module is applied. The chemical algorithm then calculates the dissipation and effectiveness of the chemical based on time, traffic, and precipitation.

The treatment impacts the road state and a new road temperature time series is calculated starting from the treatment time. This iterative process continues until no treatment is required in the remaining time to the end of the forecast period.

The DOT users indicated a desire to have a single (non-dimensional) metric to identify the predicted state of the roadway relative to winter road conditions. A mobility metric has been developed that takes into account pavement condition (wet, dry, snow, snow depth, ice, etc.). The net mobility module reads in the meteorological and road surface conditions and outputs an index describing the amount of 'mobility' a vehicle could experience on the road. This index ranges from 0 (no mobility) to 1 (optimal road conditions). A number of tables exist which describe the mobility in certain conditions. A decision tree leads to finding the proper value. The mobility index is determined by finding the proper cell in the table that fits the existing weather, road and traffic conditions.

The rules of practice module ingests weather and road condition time series data to determine a treatment plan. As the RCTM is currently designed, only information about the first treatment needs to be determined. Once that treatment is implemented, the calculated road temperature and snow cover time series become invalid, as they have been affected by the plowing or chemical application specified in the first treatment. The system inputs are adjusted and the module re-invoked to determine if another plowing run and/or chemical application is needed. The rules module consults what is best described as an electronic version of the *FHWA Manual of Practice for Effective Anti-Icing Program* (FHWA, 1996) to determine the recommended treatment.

5.4 Display System

Data from the RWFS and RCTM subsystems are disseminated to a single interactive display application that allows both high-level and detailed views of weather and road condition over time. Prediction information sent to the display updates every three hours. That is, a new forecast of weather and road condition is available to the user every three hours. The display system allows the user to:

a) View weather information for each user defined forecast point
b) Be notified when weather or road conditions are predicted to deteriorate in the future (current forecast period is 48 hrs)
c) View road condition information at each user defined maintenance route
d) Calculate winter maintenance treatment plans (e.g., chemical use, plowing, timing of treatment, and location) for each route
e) Review the predicted impact of the recommended treatment plans
f) Perform *what if* scenarios to assess the impact of various user defined treatment plans
g) Compare treatment plans and shift schedules
h) Review the depletion of stock supplies for various treatment plans

The MDSS FP display has been coded as a Java application. Data necessary to populate the display can be obtained over the Internet or through local networks. This configuration provides an efficient mechanism for processing and will result in a responsive interactive capability.

Users access the display system to determine where, at the state level, the weather is forecast to be poor during the next 48 hours. They can also use the display to determine poor weather and road conditions at the sub-district (route) level. The display system is map-based, and provides alerts where the weather and road conditions are predicted to require road treatment. The state view (see Figure 3) shows the worst weather conditions for districts or sub-districts within the state during the 48-hour prediction period. Areas that are forecast to have weather that may affect road condition are colored to indicate the severity of the forecast. Areas that are forecast to have severe weather flash in this view.

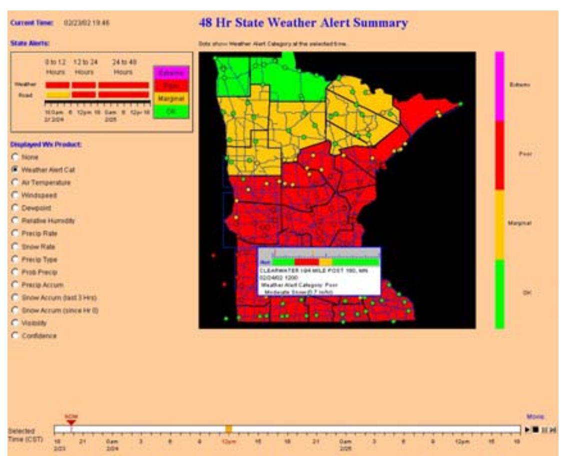

Figure 3. An example of the MDSS *State View* page. This page allows the DOT user to get a quick assessment of the potential risk for bad weather during the next 48 hrs.

The user can click on any district or sub-district to view the forecast for that area. Forecast data can be viewed, if desired, as a set of time-series graphs. Variables graphed include, but are not limited to air temperature, relative humidity, wind speed, wind direction, probability of precipitation, precipitation rate, precipitation type, road temperature, chemical concentration, mobility, and confidence. A representative forecast station point within each selectable area is used as the source of this information.

The sub-district (route) view (see Figure 4) provides users a way to look at a forecast of weather and road conditions for a set of plow routes associated with a single shed or maintenance garage. This view provides alerts for points where the road condition is forecast to drop below the acceptable level during the forecast period. Detailed information for all the weather forecast points within the area are available to the user for closer inspection – clicking on these points brings up time series plots similar to those described for the state view. In addition, the forecast road condition is available as a series of graphs for each plow segment. Variables from the road condition forecast such as mobility, snow depth on road, and chemical concentration are available on these plots. The initial road condition forecast assumes no treatment, so users will be quickly alerted to areas where road treatment is necessary to counteract the effects of weather. In the example shown in Fig. 6, the Morris, Minnesota region was selected. From this page, treatment plans can be generated by clicking on the “Select Treatments” button.

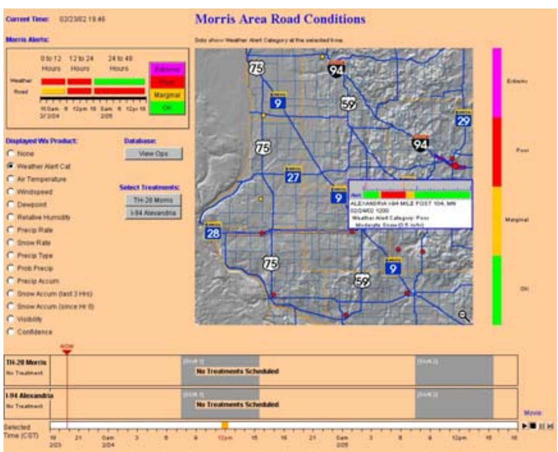

Figure 4. An example of the MDSS *Route View* page. The *Route View* page allows the user to see weather and road condition prediction information.

From the sub-district view, users can request road treatment recommendations for a maintenance route that has an unfavorable weather forecast. The system describes a recommended treatment and shows graphically how that treatment is forecast to affect road conditions (see Figure 5). The user can make modifications to the recommended treatment plan and view the predicted road conditions based on the customized treatment.

The user may want to customize treatments due to staffing or stock constraints. The user can then compare the treatment options (no treatment, recommended treatment, and customized treatments), and choose the one most suitable for the given scenario. After the user has completed this process of choosing a treatment plan, the alert map for that plow route is colored based on the predicted road condition after the selected treatment has been applied.

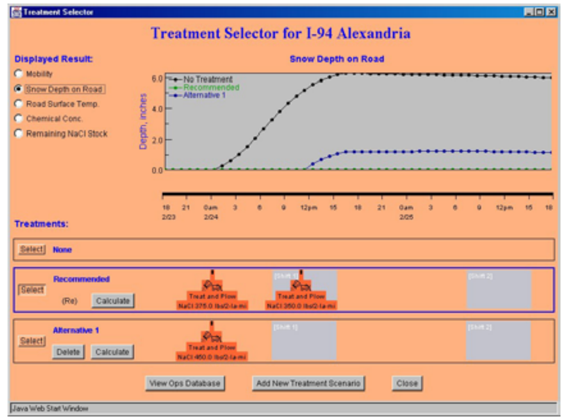

Figure 5. An example of the MDSS *Treatment Selector* page. This page allows the user to select and edit treatment plans, and see weather and road condition prediction information for specific routes.

The display system also provides some basic functionality to allow users to display and print reports of scheduled treatments for each plow route. These reports will be designed in conjunction with DOT personnel so that they are appropriate for the truck drivers to carry with them on their routes. The simple text-based treatment plans could also be sent to users via e-mail or cell phone messages although this application has not been developed in the prototype.

6 DEVELOPMENT STATUS

All of the primary components of the MDSS FP have been coded and integrated. In its current state, the MDSS FP is able to automatically generate weather forecasts at specific points, calculate road conditions (road temperature and chemical concentration) for road maintenance routes, provide recommended treatment guidance, and allow users to perform *what if* calculations for multiple treatment options. It also provides decision support for monitoring stocks (chemicals and abrasives) and crew shifts. In addition, the user is able to delve into the data and view time series information for weather and road condition parameters.

General project information, technical documents, and specific information related to

MDSS Release-1 are available at the MDSS web site, which can be found at:

http://www.rap.ucar.edu/projects/rdwx_mdss/

Only quick-look reviews of the system output have been achieved at this time with results reported in these proceedings. Cases from late winter and early spring 2002 have been analyzed to determine system skill and areas for improvement. This activity will lead to system improvements based on verification results and tuning activities

7 CONCLUSIONS

The overall success of the MDSS will be measured by its ability to predict weather and road conditions with enough accuracy that decision makers will feel comfortable with its treatment recommendations. It is still too early to determine its skill over a large range of conditions, but initial results are promising. The field demonstration that is scheduled for the winter of 2003 will provide an opportunity to assess its potential over a larger range of environmental conditions.

A major objective of the MDSS program was to raise the awareness of the surface transportation community that weather has a significant impact on the transportation system and any serious attempt to improve its efficiency has to address weather and its overall impact on the system. The MDSS project is rooted in the FHWA and OFCM efforts that captured surface transportation weather requirements and unmet user needs. Bringing the users and providers together as part of the Surface Transportation Weather Decision Support Requirements (STWDSR) effort provided a unique opportunity to discuss needs and assess the nation's ability to address unmet needs. A clear message from the STWDSR process emerged and that message was that the users are generally unsatisfied with today's surface transportation weather capabilities and that a lot more could be done to address their needs. The FHWA Road Weather Management Program chose to address some of the unmet weather needs for winter road maintenance by launching the MDSS project.

When the MDSS development team came together to design the system, they essentially began with a clean slate. It was clear that the system had to integrate advanced weather forecasting technologies, road condition models, and anti- and deicing rules of practice. This had never been attempted before. Both time and funding were limited so it was imperative that the MDSS incorporate, to the greatest extent possible, existing technologies that could be reapplied for this project. A big challenge was identifying technical components that could be integrated rapidly.

The resulting prototype architecture is unique, and based on user feedback to date, has the potential to significantly change the paradigm of how winter road maintenance planning is performed. State department of transportation personnel have already indicated that the core components (e.g., Road Weather Forecast System, and road condition modules) could be used to drive other decision logic that could support traffic, incident, and emergency management as well as information systems including 511 services.

Another important aspect of the MDSS program is how the users (DOT personnel), prototype developers (national labs) and future providers (private sector meteorological service providers) have worked together from the early stages of development to ensure that the solution meets the needs of the users and can be transitioned to the market and implemented quickly. This public/private partnership approach to development is beneficial because the stakeholders have been given several opportunities to provide feedback. This feedback process should improve the likelihood that user needs are met and should also help the providers position themselves to adopt the resulting technology, which will save time and resources. Another major benefit of the open development effort is that the resulting solution, in this case the MDSS prototype, is available to the public on a non-exclusive basis.

There are a lot of opportunities for improving surface transportation weather capabilities; however, to do so will require a significant investment in directed atmospheric and road condition research. Research efforts will require a multidisciplinary approach and the ongoing involvement of stakeholders. Thus far, the MDSS project appears to be on the right track and could be used as a template for future surface transportation weather research and development programs.

8 ACKNOWLEDGEMENTS

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9 REFERENCES

Myers, B., M. Petty and J. Cowie. An Automated Road Weather Prediction System for Road Maintenance Decision Support, *Preprints to the 18th International Conference on Interactive Information and Processing Systems for Meteorology, Oceanography, and Hydrology*, Orlando, FL, 13-17 January 2002, American Meteorological Society, Boston, MA.

Federal Highway Administration. Manual of Practice for an Effective Anti-icing Program: A Guide for Highway Winter Maintenance Personnel. Publication No. FHWA-RD-95-202. FHWA, Department of Transportation, June 1996.