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Clarus Multi-State Regional Demonstrations

Evaluation of Use Case #3: Non-Winter Maintenance Decision Support System

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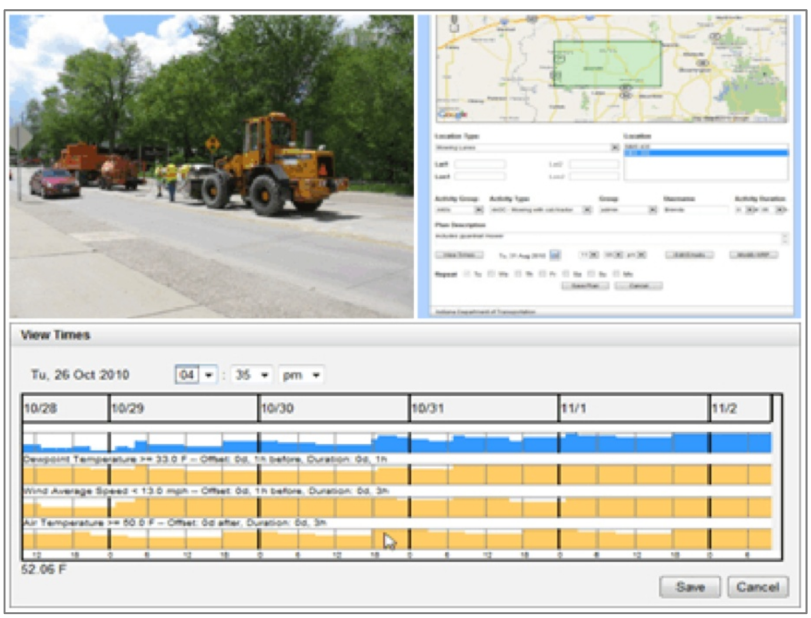

U.S. Department of Transportation
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16. Abstract

This evaluation report documents benefits, challenges and the lessons learned from the demonstration of a new tool that offers state DOTs the ability to expand decision support beyond snow and ice control to incorporate *Clarus* data to assist maintenance, operations, and construction-related scheduling decisions. The tool has been developed by Mixon Hill, Inc. and was demonstrated in selected northern tier states as part of the *Clarus* Multi-State Regional Demonstration Program under the auspices of the Road Weather Management Program (RWMP) of the Federal Highway Administration (FHWA).

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Preface/ Acknowledgements

The Road Weather Management Program (RWMP) within the Federal Highway Administration (FHWA), under the auspices of the *Clarus* Initiative, has sponsored a multi-state demonstration of *Clarus*-enhanced experimental tools that offer state Departments of Transportation (DOTs) new ways to mitigate the effects of adverse weather events on the operation of their transportation systems. The RWMP sponsored independent evaluations of each of these “use case” demonstrations, and this report focuses on the results of one of those demonstrations; namely, non-winter maintenance decision support system. Findings from this evaluation, as presented in this report, are encouraging regarding the potential benefits of a tool that offers DOTs enhanced capabilities for non-winter maintenance activity scheduling and decision support.

The authors of this report would like to acknowledge and thank the members of the demonstration teams, the state representatives, who collaborated in support of this evaluation and generously gave of their time and expertise. While many individuals deserve recognition, we want to particularly acknowledge a few individuals for supporting the demonstration and our evaluation. Principal members of the Battelle evaluation team included Kevin Balke and Dan Middleton of the Texas Transportation Institute, and although authorship for the individual use case evaluation reports was split across the team members, everyone on the team contributed to the evaluation across all the four use cases. Leon Osborne of Meridian Environmental Technology, Inc., and Brenda Boyce of Mixon Hill led the two demonstration teams and worked closely with the evaluation team. Representatives of each of the states in which the demonstrations and evaluations took place generously offered their time and support, including Dean Kernan, Dwren Boston, Steve Sellon, John Peed and John Seei from Illinois DOT, Tina Greenfield, Roger Vigdal from Iowa DOT. Finally, Paul Pisano of the RWMP has provided on-going support of this effort with a guiding vision of how *Clarus*-enhanced weather information can improve traffic operations and contribute to the safety and mobility of all travelers.

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List of Acronyms

ASOS……………..... ………………Automated Surface Observing System
AWOS…………..……………..Automated Weather Observation System
DOT .... Department of Transportation
ESS ....Environmental Sensor Station
FHWA ....Federal Highway Administration
MDSS ....Maintenance Decision Support System
METRo ....Model of the Environment and Temperature of Roads
NDFD .... National Digital Forecast Database
O&M……………........... ……………………Operations and Maintenance
NWS ....National Weather Service
RWFS ....Road Weather Forecast System
RWMP ....Road Weather Management Program
WRF………………………………..Weather Reseach and Forecasting
WRP……… .... …………………………..Weather Related Practice

Executive Summary

The *Clarus* Multi-State Regional Demonstration Program leverages the quality-checked data available through the national network of Environmental Sensing Stations (ESS) called the *Clarus* System to test and provide road weather management applications for state and local agencies. This document describes the approach and findings from an independent evaluation of the use and benefits of Use Case #3 – Non Winter Maintenance Decision Support System.

The objective of the tool is to expand decision support beyond snow and ice control to incorporate *Clarus* data to assist maintenance, operations, and construction-related scheduling decisions. The role of decision-support is becoming mainstreamed for winter operations. Maintenance crews are increasingly becoming comfortable relying on the weather information to proactively perform snow and ice removal. Using decision-support tools has helped maintenance agencies strategically and tactically adjust their operations to save time and money, as well maintain a high-level of service.

However, maintenance operations do not stop after the winter season, and in many ways, maintenance crews are conducting a larger set of activities during spring, summer and fall seasons. Weather remains a major factor in the non-winter operations, and unlike during winter, the use of advanced weather forecasting tools and decision-support systems are not as prevalent. Most maintenance crews rely on their existing weather service providers and adjust schedules on a reactive, ad-hoc manner to account for weather.

This use case demonstrates a decision-support system for non-winter operations that translates location-specific weather forecasts into favorable or unfavorable conditions for non-winter maintenance and construction activities.

There are two major capabilities offered by this tool. First, the tool integrates a wide variety of observations, forecasts, and alerts that may be of interest to a maintenance supervisor for planning the current day's and future activities. The tool provides the following data in a map-based interface:

- A range of surface weather station observations from *Clarus* and other available sources (i.e., Automated Surface Observing System (ASOS), Automated Weather Observation System (AWOS))
- NOAA Satellite and NWS radar observations
- NWS Advisories, watches, and warnings
- USGS earthquake alerts
- Forecast model provided by NOAA: National Digital Forecast Database (NDFD)
- Forecast models provided by NCAR: Weather Research and Forecasting (WRF), Road Weather Forecasting System (RWFS), and Model of the Environment and Temperature of Roads (METRo)

The multi-state observations available through the *Clarus* System were also used in the NCAR's forecast models that are available as part of the system.

The second capability aims to assist agencies in making better scheduling decisions based on observations, targeted *Clarus*-enhanced weather forecasts, and agency rules of practice.

The tool was developed by Mixon Hill, Inc. and demonstrated in Illinois and Iowa as part of the *Clarus* Multi-State Regional Demonstration Program under the auspices of the Road Weather Management Program (RWMP) of the Federal Highway Administration (FHWA). The independent evaluation of this use case tool examined how maintenance personnel of the Iowa DOT and Illinois DOT could use the tool and the availability of new information and capabilities for their operations.

Evaluation Approach

The evaluation of the tool was conducted in two maintenance districts in Illinois and Iowa. The evaluation in Illinois was carried out under the jurisdiction of the Maintenance Yards in Henry County located in northwest central Illinois. The evaluation included three crews working within the county. One crew (Geneseo) that consisted of 15 maintenance persons continued to schedule operations in their usual way, without using this tool. This crew served as the control group for the evaluation. Two other crews (Lynn Center and Galva) that consisted of seven individuals each used the tool to schedule activities and served as the experimental group. In Iowa, the tool was tested and evaluated in the northwest part of District 3, namely the Spirit Lake, Spencer, and Emmetsburg garages. The entire district constituted an experimental group.

The evaluation was conducted from April 1st to October 1st, 2010 for Illinois and April 1st to August 30th, 2010 for Iowa DOT. Both groups recorded detailed logs of their activities performed and the weather conditions encountered in the field. The evaluation also included interviews with the maintenance crew chiefs and supervisors to understand qualitatively the potential of the tool for use in non-winter operations.

Evaluation Findings

The hypotheses for the evaluation were tested to the extent that the available data would allow. The data from crew records, emails and interviews, along with comments received from the participating DOTs, were assessed in terms of the support they offered for each of the hypotheses. Results of the tests of the hypotheses are shown in Table ES-1.

Lessons Learned and Conclusions

Overall, both Iowa DOT and Illinois DOT noted that the tool and the concept are relatively easy to adopt and integrate within their operational philosophy but some of the technical software issues need to be resolved. Lessons learned from the evaluation include the following:

- **Integration of weather forecasts and observations in the tool is appreciated by users.** The tool integrated a wide variety of weather forecasts and observations into a single interface. This integration was appreciated by the users but a few interviewees also noted that they had a private sector weather provider who provided them hour-by hour forecasts daily. The text forecasts provided the hourly probability of precipitation, anticipated timing and duration of precipitation and type of precipitation. Users did not apparently perceive that the forecasts offered by the tool were inherently any more actionable than the weather forecasts that they already have available to them. The tool is set up to include integration of any weather service provider applications so potentially an agency could use their existing weather information service with which they are comfortable as input to the activity scheduling capability. It is the integration of weather forecasts with an alerting capability and thoughtfully scheduled weather-related practices that provides a system capable of more effectively guiding activities that are potentially impacted by weather.

- **Communications between the tool and field personnel are critical for success.** The utility of the tool is greatest when maintenance personnel in the field are alerted to changes in weather conditions. Interviews with the supervisors noted that once the day's plan has been communicated to the crew and they have been dispatched, the supervisors often leave the office and are out in the field monitoring their crew's actions. As a result, they noted that the greatest benefit of the tool is experienced when they are out in the field and not in front of a computer. The tool can alert them of changing weather conditions that may require modification of the set plans and reassignment of crew activities while out in the field. This necessitates a robust alerting system be included as part of the tool. Currently the demonstration was hampered by a complicated and evolving alert system in the tool that was viewed as cumbersome by some of the interviewees. Adding to the challenge of communicating with the field, as well as for future deployments, was that a lot of field personnel were not provided with state-owned communication devices. The demonstration tool would send alerts either as text messages or as emails. Several of the maintenance personnel either did not have communication data plans that would allow for the receipt of such information on their personal devices or were unwilling to receive text and emails on their personal devices.
- **Content of the alerts has to be better tailored for the supervisor.** Related to the above lesson, interviewees noted that the alerts needed to be not only location-specific but also clearly linked to the activity that triggered the alert.
- **Routine maintenance actions are conducted with a high degree of flexibility.** Crew supervisors consider a variety of factors in scheduling daily activities. While weather is an important factor, crew capabilities and availabilities, equipment availability, and daily priority needs often result in a flexible approach to scheduling routine maintenance activities. What this implies for the tool is that crew supervisors have enough "slack" and easily adapt their schedules to accomplish routine maintenance activities. Long-term scheduling of these activities is often unnecessary and not fruitful. As such, the alert capabilities and near-term (overnight or current day) weather information is most important to the supervisors.

Table ES-1. Identified Level of Support for the Hypotheses

Hypotheses	Evidence	Level of Support
1. Use of tool will result in fewer occasions where crews are dispatched and find hazardous conditions at their field site due to weather.	▪ No evidence to support or disprove the hypotheses. Experienced supervisors and flexibility in crew scheduling resulted in no instances in which crews were exposed to unsafe conditions.	Inconclusive
2. Use of the tool will result in improved scheduling efficiency and productivity of maintenance crews over the season.	▪ No differences in scheduling approaches were observed between the control and experimental groups. Interviews with the maintenance chiefs revealed that the supervisors were very experienced and had an excellent understanding of crews, activities and weather. In addition, both control and experimental groups have access to a daily private sector weather service provider that currently satisfies their strategic needs. However, the interviewees noted that in 2012, both experimental and control garages will have less experienced supervisors (due to staff turnover) and having the rules of practice documented in the tool would be of great benefit.	Inconclusive
3. Notifications and alerts from the tool will result in greater agency responsiveness and flexibility in adjusting maintenance and operations schedules on a day to day basis.	▪ In Iowa, the maintenance chief was able to effectively use the alert function of the tool to dynamically adjust his schedules several times during the evaluation period. In the summer of 2010, 11 schedule changes were made based on the use of the tool in about 37 days. ▪ In Illinois, the tool was not as useful primarily due to implementation and software problems. Over the 64 day evaluation period, 15 days were impacted by weather. Of these, the tool was able to provide notification only 3 times. ▪ Overall, alert features were valued but concerns regarding their timeliness were expressed during the evaluation.	High level of support in Iowa Low level of support in Illinois
4. Maintenance personnel view the use case as a useful and beneficial aspect of non-winter maintenance decision-making	▪ Interviews reveal acceptance of the potential of the tool but also indicate a need for further refinement of the software tool to be useful in daily operations. Overall, the interviewees thought the concept was sound and effective if software difficulties were overcome. ▪ Setting up the weather-related practices was a challenge to both the state DOTs. They reported that identifying the criteria for their non-winter activities was a complex task. ▪ Maintenance personnel rated the concept positively and indicated moderate agreement (~ 6/10) for the potential for the concept to improve operations.	Moderate level of support

- **For certain non-routine activities, this tool may provide a valuable long-term planning capability.** A few activities conducted by maintenance crews do allow for long-term scheduling. They are highly dependent on weather and can be planned several days or weeks in advance. Concrete and asphalt patching work were mentioned as two promising applications for the tool. Another promising activity pertains to specialized maintenance that requires equipment from another part of the state or would need to be contracted out. In these situations, better understanding of long-term weather forecasts would be very useful.
- **Weather-related practices are critical to new and inexperienced staff.** One of the benefits of the demonstration was the opportunity to create weather-related practices. Traditionally, these rules were ad-hoc and not formalized anywhere. Experienced supervisors knew what activities could be scheduled based on weather conditions but this demonstration helped create clear rules of practice. Over the course of the demonstration, both Iowa and Illinois adjusted their weather parameters but viewed the process of clearly defining the criteria as helpful. Interviewees noted that having these practices is invaluable for a new supervisor brought on board due to staff turnover.
- **Agencies need guidance in creating weather-related practices.** From the start of the demonstration, it became quickly clear that there were no standard weather-related practices for maintenance actions. Both Iowa and Illinois used their expertise to translate some of the loose rules of practice into specific criteria. Participants thought this might be an area worth investigating further. The interviewees noted that AASHTO or NCHRP could develop suggested practices and criteria that states could adopt with minimal effort.
- **Agencies need to be flexible to work around weather-related practices.** Supervisors noted that while the weather related practices are useful, there needs to be flexibility provided to the supervisors to conduct the activity, especially when the weather criteria are close to the boundary condition. For example, they wanted the flexibility to schedule an activity requiring a temperature greater than 50º F, even if the weather condition was only 48º F.
- **Potential users of the tool extend beyond State DOTs.** The use of the tool in the construction and maintenance contracting industry should be explored. Interviewees noted that they, as a DOT with a wide range of job responsibilities, can move crews from activity to activity without losing much time; whereas, a general contractor who does crack sealing exclusively can benefit greatly from knowing when weather might interrupt their operations.

While technical issues regarding the software were challenging during the demonstration phase of the tool, the primary users of the tool (maintenance supervisors) provided continuous feedback that already has led to various software enhancements. In many ways, the supervisors were unsure of what technology or system they would need at the outset of this project, and this demonstration has helped clarify their needs and expectations similar to a prototype approach. A more clear expectation of the needs of a non-winter maintenance decision-support system should lead to better system development henceforth. Overall, both Iowa DOT and Illinois DOT noted that the tool and the concept should be easy to adopt if some of the technical issues were resolved with respect to the software. They noted that once some of the demonstration issues have been worked out, this system would be helpful to use regularly and could be easily integrated into their operations philosophy.

1 Introduction and Background

The *Clarus* Multi-State Regional Demonstration Program leverages the quality-checked data available through the national network of Environmental Sensor Stations (ESS) called the *Clarus* System to test and provide road weather management applications for state and local agencies. Five use cases were developed as part of the demonstration:

- Use Case #1 – Enhanced Road Weather Forecasting
- Use Case #2 – Seasonal Weight Restriction Decision Support
- Use Case #3 – Non-Winter Maintenance Decision Support System
- Use Case #4 – Multi-State Control Strategy Tool
- Use Case #5 – Enhanced Road Weather Traveler Advisories

The use case development was led by two deployment teams. Each team was comprised of a private-sector system developer and several state agencies where the use case was tested. Two independent evaluations were conducted. The first evaluation assessed the improvements in road weather forecasting in Use Case #1 from a meteorological perspective. The second set of four evaluations assessed the value of the remaining four use cases to the state Departments of Transportation (DOTs) during 2010 and early 2011. The evaluation of the four use cases (#2 to #5) sought to understand the systems' impacts and benefits experienced by the state agencies and end users, including transportation managers, related agencies, and travelers.

This document describes the approach and findings from an independent evaluation of the use and benefits of *Use Case #3 - Non-Winter Maintenance Decision Support System*, a tool developed and tested under the *Clarus* Multi-State Regional Demonstration Program.

2 Description of the Use Case

State DOTs have a diverse set of activities that need to be performed during non-winter months to ensure the continued maintenance of their facilities. From vegetation management (mowing, weed control) to pavement striping, DOT maintenance districts around the country strive to schedule crews and equipment effectively throughout the spring, summer and fall. A major determinant in activity scheduling is the weather that a maintenance crew may encounter in the field. Many maintenance activities are very sensitive to weather conditions, and they are guided by rules of practice involving precipitation, temperature, wind speeds, visibility and other related factors governing whether, when, and how an activity may be performed.

Traditionally, the use of weather-related decision-support systems has been for winter maintenance activities. Decision-support systems during winter are designed to help maintenance crews with strategic and tactical planning during weather events. These systems can provide localized weather forecasts, pavement condition information, customized treatment recommendations, and “what-if” capabilities enabling a maintenance crew to decide how to manage their activities during a winter storm, including deciding the crew shift deployment strategy (such as when to call-up crews, and how many to call up), and the treatment approach (such as the materials to use, amounts, and when to apply).

The objective of the non-winter Maintenance and Operation Decision Support System (MODSS) tool is to expand decision support beyond snow and ice control to incorporate *Clarus* data to assist maintenance, operations, and construction-related scheduling decisions. This expansion will provide the capability to bridge the current gap between year-round road weather information and a proactive decision-making process that is properly informed by current and forecast weather condition information.[1]

There are two major capabilities offered by this tool. First, the tool integrates a wide variety of observations, forecasts, and alerts that may be of interest to a maintenance supervisor for planning the current day’s and future activities. The tool provides the following data in a map-based interface:

- A range of surface weather station observations from *Clarus* and other available sources (i.e., Automated Surface Observing System (ASOS), Automated Weather Observation System (AWOS))
- NOAA satellite and NWS radar observations
- NWS advisories, watches, and warnings
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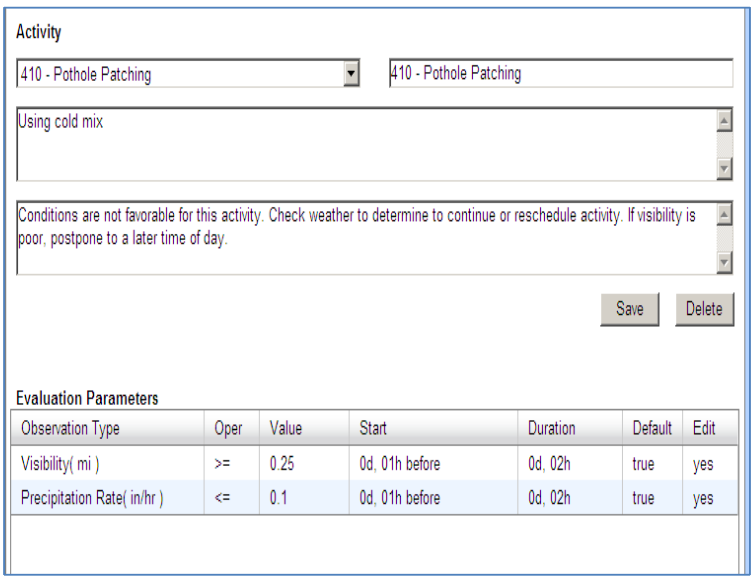
- Forecast models provided by NCAR: Weather Research and Forecasting (WRF), Road Weather Forecasting System (RWFS), and Model of the Environment and Temperature of Roads (METRo)

[1] Mixon Hill, Inc. 2009. *Development and Deployment of Clarus-enabled Services, Use Case #3: Non-Winter Maintenance and Operations Decision Support Tool, USE CASE SCENARIO.* (February).

The multi-state observations available through the *Clarus* System were also used in the NCAR's forecast models that are available as part of the system.

The second capability aims to assist agencies in making better scheduling decisions based on observations, targeted *Clarus*-enhanced weather forecasts, and agency rules of practice. The tool allows a maintenance supervisor to define the weather-related rules of practice for a variety of activities using a menu-driven interface.

Figure 1 is an example of a weather-related practice (WRP) for a "Pothole Patching" activity supported by the tool. The pull-down box in top-left corner lists a selection of activities that have been predetermined by the DOT. The box below that provides a description of the activity, and the third box from the top indicates the message that needs to be sent to the supervisors if the evaluation parameters are not met. For this activity, the evaluation parameters are "visibility is less than or equal to 0.25 miles" and "precipitation rate is less than or equal to 0.1 inches" an hour before, during, and an hour after the activity.



Source: Mixon Hill, Inc.

Figure 1. Example WRP for Pothole Patching

Essentially, the evaluation parameters define a set of weather conditions under which an activity can be successfully performed. A weather-related rule of practice is defined in terms of the weather conditions that need to be satisfied before, during, and after the activity for that activity to be successfully performed. Figure 2 shows a schematic for a weather-related practice. In the following figure for a fictional activity, the evaluation parameters are:

1. Dew Point Temperature greater than or equal to 30º F an hour before the activity

2. Wind Average Speed less than 13 mph an hour before, during and after the activity

3. Air Temperature greater than or equal to 50º F two hours after an activity

The one hour duration of the activity is represented by the thickness of the box in the figure.

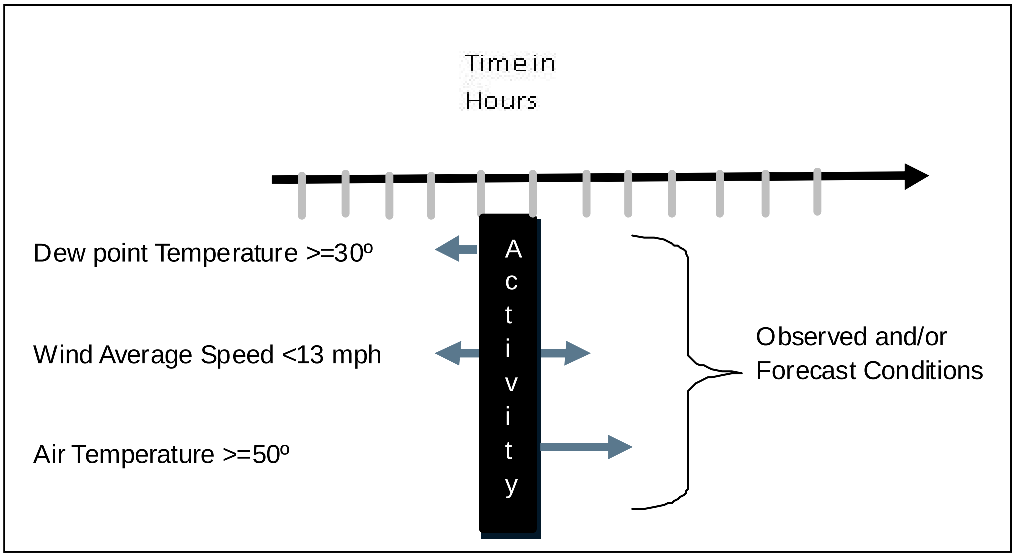
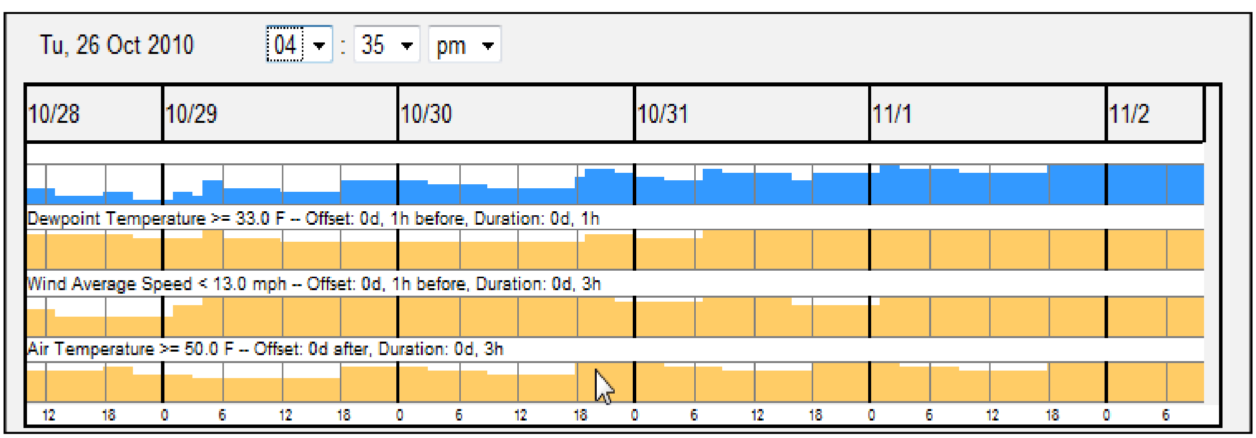


Figure 2. Weather Related Practice Schematic

Once the activities and the rules of practice are defined for the agency, the maintenance supervisor or other decision maker can use the tool to pre-schedule activities based on system-generated "windows of opportunity" or schedule periods during which the weather conditions meet the criteria and are favorable for conducting the desired activity.

Figure 3 show the windows of opportunity during the week of October 28th for a particular activity with the criteria in Figure 3 as determined on Tuesday, October the 26th. The times when conditions are favorable for the activity are represented by the solid colored areas in first, blue-shaded histogram in the figure which is a summation of the times when the evaluation criteria are met in the histograms below (colored orange). An activity can be performed when all three conditions in the figure (dew point, wind average speed, and air temperature) are met with 100 percent probability (i.e., each bar fills its space completely).



Source: Mixon Hill, Inc.

Figure 3. System Generated Schedule Forecast for WRP

Once an activity is scheduled, the tool continues to monitor the weather conditions, and if conditions are not expected to be met for the activity, an alert is sent to the user indicating that the activity can no longer be performed according to the rules of practice. The tool sends the alert via an e-mail or a text message with the pre-specified message to users who have been identified for each activity. The user has the option to reschedule, cancel, or relax the rules of practice if desired to identify new possible times based on experience and judgment. This rescheduling can be done in the office or potentially from the field by responding to the alerts. However, while the functionality of the communication to the field was demonstrated, technical difficulties resulted in this functionality not being tested during the evaluation period.

3 Evaluation Approach

The focus of each of the four use case evaluations was on how end users might actually use the new tools and the benefits they would expect to derive from that usage. The approach to evaluating each use case began with the development of an overall Evaluation Strategy. The strategy sought to identify the expected benefits of the tool use and develop a set of testable hypotheses that would guide the data collection and analysis. The strategies were prepared based on documentation from the demonstration teams and discussions with the states about how they thought they might use and benefit from the new tools. As the tools were refined and presented to the states through initial training sessions, both the states' and the evaluator's understanding of the tools evolved further, and in several cases the attributes and capabilities of the tool were modified. As a result of this dynamic process, the evaluation approach as projected in the Evaluation Strategy was refined accordingly in the development of the Evaluation Plan.

3.1 Evaluation Setting

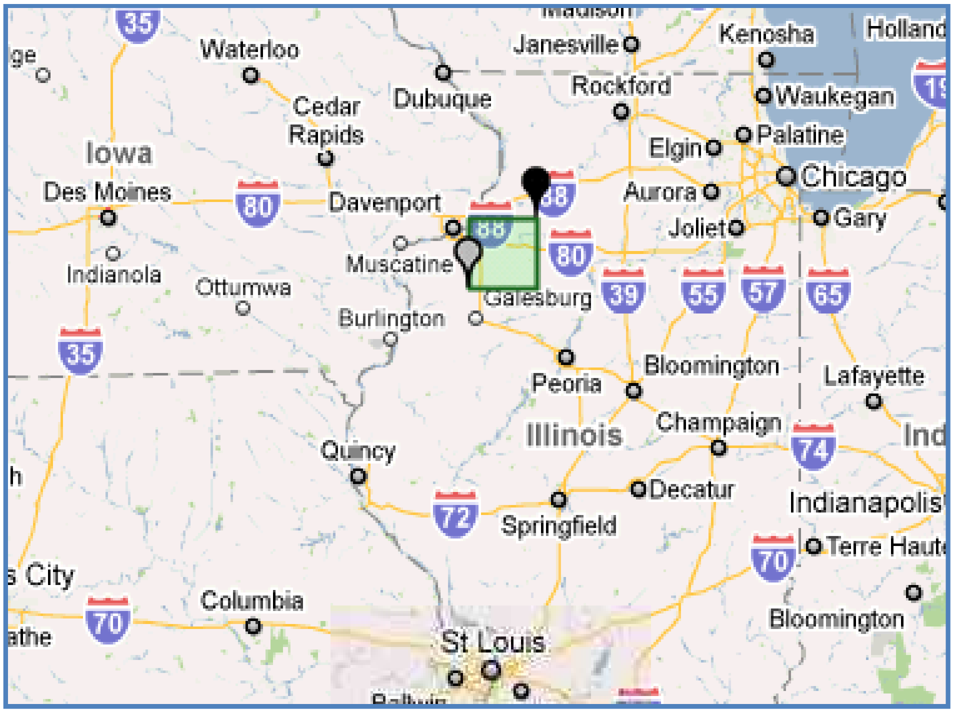
The evaluation of the tool was conducted in two maintenance districts in Illinois and Iowa between May and October 2010. The evaluation in Illinois was carried out under the jurisdiction of the Maintenance Yards in Henry County located in northwest central Illinois. The evaluation included three crews working within the county. One crew (Geneseo) that consisted of 15 maintenance persons continued to schedule operations in their usual way, without using this tool. This crew served as the control group for the evaluation. Two other crews (Lynn Center and Galva) that consisted of seven individuals each used the tool to schedule activities and served as the experimental group. Figure 4 shows the evaluation area for Illinois.

All crews conduct a wide variety of maintenance work activities during the non-winter season that, according to their rules of practice, can be affected by weather. Typical activities include:

- Pavement – Pothole Patching – Cold Mix
- Pavement – Partial Depth Patching
- Pavement – Full Depth Patching
- Shoulders – Patch and Repair
- Shoulders – Blading and Dragging
- Roadside – Mowing
- Roadside – Right of Way Herbicide Application/Spraying

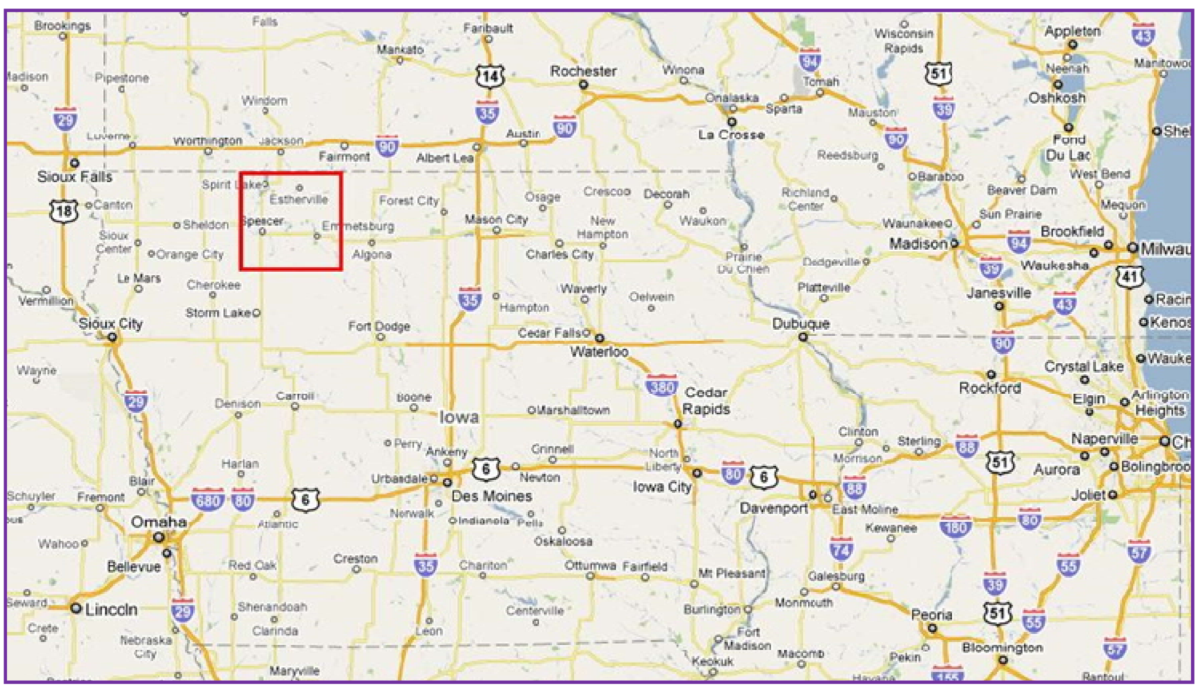
In Iowa, the tool was tested and evaluated in the northwest part of District 3, namely the Spirit Lake, Spencer, and Emmetsburg garages. The entire district was considered as experimental. The garage in Iowa performs similar activities to the activities identified in Illinois.

Figure 5 shows the evaluation area of interest in Iowa.



Source: Mixon Hill, Inc.

Figure 4. Illinois Evaluation Area



Source: Google Maps

Figure 5. Iowa Evaluation Area

3.2 Evaluation Design

The evaluation is designed as a "with-without" study with a control and experimental group. The evaluation was conducted from April 1st to October 1st, 2010 for Illinois DOT and April 1st to August 30th, 2010 for Iowa DOT. Rain was the predominant weather activity during the evaluation period. The control group scheduled and conducted activities following their customary manner. The control group would schedule their daily activities one day in advance using a private sector weather service and other information about staffing, equipment, and maintenance needs. The experimental group used the demonstration tool to set-up activities using the templates provided by the non-winter MODSS, and conducted activities with assistance from the tool. Both groups kept detailed logs of their activities and the weather conditions encountered in the field. The evaluation also included interviews with the maintenance crew chiefs and supervisors to understand qualitatively the potential of the tool in non-winter operations.

3.2.1 Objectives and Hypotheses

The primary objective of the evaluation was to document how the use case tool was used and the benefits derived from using it to schedule crews and maintenance activities. The secondary objectives were to document lessons learned and help guide development and deployment past the demonstration phase. Specifically, the evaluation sought to answer the following questions:

1. Are road maintenance resources (labor, equipment, material) assigned more effectively and efficiently by using the tool?
2. Are weather forecasts provided by the tool more actionable than previously used services/products?

The use of the tool was expected to have benefits in the areas of safety, efficiency, productivity and customer satisfaction. The evaluation hypotheses associated with each of these goal areas are shown in Table 1.

Table 1. Evaluation Hypotheses

Goal Area	Hypotheses
Safety	1. Use of the tool will result in fewer occasions where crews are dispatched and find hazardous conditions at their field site due to weather
Efficiency / Productivity	2. Use of the tool will result in improved scheduling efficiency and productivity of maintenance crews over the season
	3. Notifications and alerts from the tool will result in greater agency responsiveness and flexibility in adjusting maintenance and operations schedules on a day to day basis
Customer Satisfaction: State DOT	4. Maintenance personnel view the use case as a useful and beneficial aspect of non-winter maintenance decision-making

The following sections describe the hypotheses in detail including describing the pathway by which benefits are accrued, the measures of effectiveness, and the test approach.

Hypothesis 1. Use of the tool will result in fewer occasions where crews are dispatched and find hazardous conditions at their field site due to weather

Pathway

Some obvious weather hazards such as high-winds, lightning, and heavy precipitation rates uniformly cause unsafe conditions for crews to be out in the field carrying out a maintenance activity in which they are exposed. Safety considerations include the actual exposure to hazardous conditions (lightning for example) as well as increased risk of injury due to difficult driving conditions (loss of traction by drivers on roadways due to rain or limited visibility leading to maintenance workers being struck by traffic). By using the weather alerts and advisory capabilities of this tool, maintenance chiefs can reschedule, caution crews in advance, or even cancel the planned activity before the hazardous conditions are encountered in the field.

Measures of Effectiveness

- Number of occasions for which crews find hazardous weather conditions once they report to the site
- Number of occasions for which alerts from the use case tool were used to reschedule, caution crews, or cancel planned activities

Test Approach

The test of this hypothesis was for the entire district without a control or experimental distinction since any notification related to crew-safety will be shared quickly and widely with all crews out in the field. The test relied on two sources of data:

- Crew logs indicating situations where hazardous weather conditions were encountered
- Debriefing interviews with the maintenance chief regarding events in which the use case tool was able to alert them in advance of a potentially unsafe situation.

The test isolated instances where crew safety was a factor in decision-making and assessed the role the use case tool played in that instance.

Hypothesis 2. Use of the tool will result in improved scheduling efficiency and productivity of maintenance crews over the season.

Pathway

A key hypothesis for this use case was that the impacts of weather on maintenance activities could be minimized through more effective scheduling. By using the tool to incorporate rules of practice with the scheduling of activities based on weather forecasts, the maintenance district, over a season, can:

- Lose fewer hours due to unacceptable weather conditions for operations and maintenance (O&M) actions in the field
- Reduce the number of O&M actions that have to be redone
- Achieve more efficient utilization of crews over a season

- Be better prepared for weather at the site (more appropriate clothing or tools)
- Realize material savings and fuel savings

Measures of Effectiveness

- Hours lost due to having to react to unanticipated adverse weather conditions impacting O&M actions
- Number of unsatisfactory maintenance actions
- Crew down-time
- Materials and fuel spent on O&M actions that had to be redone due to weather-related conditions

Test Approach

The test approach used control and experimental groups to assess the impact of the use case on activity scheduling and possible resulting efficiencies. Both experimental and control groups filled out their usual daily work assignments that indicated the crew number, work code and description, location, and the impact of weather on the activity performed. In addition, during the evaluation period, every instance in which weather was a factor was recorded by both experimental and control groups along with the corresponding action taken to mitigate the impact (e.g., rescheduling the activity resulting in down-time, conducting a different activity in the scheduled time). Alerts from the tool or the lack of alerts were recorded by the supervisor in the work assignment sheets also.

Hypothesis 3. Notifications and alerts from the tool will result in greater agency responsiveness and flexibility in adjusting maintenance and operations schedules on a day to day basis.

Pathway

The ability of the use case to “push” alerts to a mobile device and inform the crews of changing conditions before they occur is expected to allow for greater flexibility in making same-day schedule changes to take advantage of changing weather conditions.

Measures of Effectiveness

- Increase in the number of instances of same day or previous day adjustments to O&M activity schedule based on tool information.

Test Approach

Changes in crew assignment records were tabulated over the course of the season to identify whether the experimental group was able to be more responsive to day to day situations.

Hypothesis 4. Maintenance personnel view the use case as a useful and beneficial aspect of non-winter maintenance decision-making.

Pathway

By using the tool, maintenance personnel are able to have more flexibility in their decision-making, thereby allowing them to make more informed decisions and improve their planning capabilities.

Measures of Effectiveness

- Agency level of satisfaction

Test Approach

Interviews with the maintenance chiefs and supervisors were conducted to assess changes in strategic and tactical decision-making that were possible with the tool. This hypothesis also tests their overall satisfaction with the tool, the readiness of the tool to be deployed in routine operations, the challenges and the lessons learned.

3.2.2 Data Collection

The following section discusses the sources of data required for the evaluation and the approaches to collecting the data:

Crew Work Assignments

Both Illinois and Iowa DOT maintained daily field work reports that had to be submitted by crew chiefs and entered into their electronic tracking system. These work reports contained information on the hours worked per activity, the equipment used, and the materials consumed. Each day, the crew chief had a desired list of activities that he/she wanted their crews to perform. As the day progressed, the planned list was updated with actual work activities. In addition to the information contained in the report, specifically for this evaluation, the crews noted the following in their reports:

- Adverse weather conditions on site, if encountered
  - Unable to perform activity due to current or forecast weather conditions
- Weather that presented a hazard to crew operation
- Response to the weather conditions
  - Relocated and conducted activity in another area
  - Waited at the site until weather improved
  - Rescheduled and returned to base
  - Conducted another activity at this location and rescheduled planned activity
  - Conducted the activity in spite of the weather conditions

When suggested by an alert from the tool that rescheduling was necessary, the experimental group made a note on their work sheets on the nature of the alert received, whether or not it was useful/timely and if a response was required and the nature of the response. These modified crew reports were collected for both control and experimental groups.

Work Related Practices and Activity Plans

A key part of the evaluation was to track the development of weather-related practices that had been set up in Illinois and Iowa. The experimental group created activity plans and strove to follow them as part of the work plan. Iowa DOT and Illinois DOT created thirty-eight (38) and thirty (30) individual weather-related practices respectively for the demonstration. Appendix A provides weather related practices created by Iowa DOT and Illinois DOT respectively. It is important to note that these practices were not formalized before this demonstration, and the documentation of these practices was a significant achievement for the evaluation. Table 2 is an example of the tables provided in Appendix A.

Table 2. Example of Weather-related Practice Used in the Demonstration

ID	Plan Name	Observation	Units	Operator	Value	Qualitative	Duration (minutes)	Offset (Before/After) (minutes)	Message Sent When Conditions Not Met
1	Maintain Pavements: Full Depth Concrete Replacement	Air Temperature	ºF	>=	50	NULL	120	-60	Temperature is going to be too low during the activity or relative humidity after the replacement is too low. Plan another activity.
		Relative Humidity	%	>=	60	NULL	300	0	
		Precipitation Rate	in/hr	<=	0.01	NULL	0	0	
		Prob of Precip 3hr	%	<=	40	NULL	0	0	

In the table, the offset refers to the time before or after the activity has begun. This allows the monitoring of conditions which are important to be satisfied either before an activity is conducted or once an activity has been done. The qualitative field relates to those observations where a numerical value is not applicable (for example, wet/dry, etc.).

Agency Interviews

The users of the system (the maintenance chief and the supervisors) were interviewed to assess their level of satisfaction with the tool. The interviews were conducted to understand the level of usage, the benefits provided by the tool, the lessons learned, areas for improvement, and challenges associated with the use of the tool. The interviews were conducted towards the end of the evaluation period to ensure the supervisors had enough time with the use case tool. Appendix B lists the questions that were asked in the agency interviews with the experimental and control supervisors and crews.

4 Evaluation Findings

The following sections present the results of the evaluation of the demonstration.

The hypotheses presented at the outset were tested to the extent that the available data would allow. The data from crew records, emails and interviews, along with comments received from the participating DOTs, were assessed in terms of the support they offered for each of the hypotheses. Results of these tests and the degree of support for each hypothesis are discussed below and summarized in Table 3.

4.1 Hypothesis 1

Use of the tool will result in fewer occasions where crews are dispatched and find hazardous conditions at their field site due to weather.

1. Number of occasions for which crews find hazardous weather conditions once they report to the site

In both experimental and control garages, no instances of crews being placed in unsafe weather conditions were reported. Data recorded on the crew sheets do not indicate any situations where crews encountered unsafe conditions in the field. Interviews indicated that the maintenance supervisors are very vigilant about worker safety and tend to be conservative in activity scheduling. Interviewees reported the flexibility to move the crews around the morning of the activity based on observed conditions to an activity that could be conducted safely. They also noted that the alert function, especially if pushed to the maintenance crews themselves can provide some safety benefits by giving them advance notification about impending weather conditions. The challenge is that many of the maintenance crews do not have state-issued cell phones or web-enabled devices they can use in the field. The demonstration tool would send alerts either as text messages or as emails. Several of the maintenance personnel either did not have communication data plans that would allow for the receipt of such information on their personal devices or were unwilling to receive text and emails on their personal devices. Overall, this hypothesis could not be conclusively supported for this evaluation.

2. Number of occasions for which alerts from the use case tool were used to reschedule, caution crews, or cancel planned activities

Alerts from the use case tool were used to change plans several times over the season. For example, in Iowa DOT, close to 30% of the days during the evaluation period had changes due to weather with alerts being provided by the tool. Most of these changes were due to rain where planned activities could not be performed. While safety was a factor in these changes, other factors were also considered in changing plans.

Table 3. Identified Level of Support for the Hypotheses

Hypotheses	Evidence	Level of Support
1. Use of tool will result in fewer occasions where crews are dispatched and find hazardous conditions at their field site due to weather.	▪ No evidence to support or disprove the hypotheses. Experienced supervisors and flexibility in crew scheduling resulted in no instances in which crews were exposed to unsafe conditions.	Inconclusive
2. Use of the tool will result in improved scheduling efficiency and productivity of maintenance crews over the season.	▪ No differences in scheduling approaches were observed between the control and experimental groups. Interviews with the maintenance chiefs revealed that the supervisors were very experienced and had an excellent understanding of crews, activities and weather. In addition, both control and experimental groups have access to a daily private sector weather service provider that currently satisfies their strategic needs. However, the interviewees noted that in 2012, both experimental and control garages will have less experienced supervisors (due to staff turnover) and having the rules of practice documented in the tool would be of great benefit.	Inconclusive
3. Notifications and alerts from the tool will result in greater agency responsiveness and flexibility in adjusting maintenance and operations schedules on a day to day basis.	▪ In Iowa, the maintenance chief was able to effectively use the alert function of the tool to dynamically adjust his schedules several times during the evaluation period. In the summer of 2010, 11 schedule changes were made based on the use of the tool in about 37 days. ▪ In Illinois, the tool was not as useful primarily due to implementation and software problems. Over the 64 day evaluation period, 15 days were impacted by weather. Of these, the tool was able to provide notification only 3 times. ▪ Overall, alert features were valued but concerns regarding their timeliness were expressed during the evaluation.	High level of support in Iowa Low level of support in Illinois
4. Maintenance personnel view the use case as a useful and beneficial aspect of non-winter maintenance decision-making	▪ Interviews reveal acceptance of the potential of the tool but also indicate a need for further refinement of the software tool to be useful in daily operations. Overall, the interviewees thought the concept was sound and effective if software difficulties were overcome. ▪ Setting up the weather-related practices was a challenge to both the state DOTs. They reported that identifying the criteria for their non-winter activities was a complex task. ▪ Maintenance personnel rated the concept positively and indicated moderate agreement (~ 6/10) for the potential for the concept to improve operations.	Moderate level of support

4.2 Hypothesis 2

Use of the tool will result in improved scheduling efficiency and productivity of maintenance crews over the season.

> "One thing I discovered was our supervisors (the ones actually performing the daily scheduling) had a pretty firm grasp on looking at our current weather provider and deciding on their own if they could perform certain tasks that day/week.
>
> However, if I were to have inexperienced supervisors, this tool would be invaluable to them."
>
> - State DOT Representative

In both the experimental and control districts, the supervisors were able to conduct their activities and manage their crews effectively with minimal changes required day to day. In the control garages, crew scheduling was done using an existing private sector weather service by an experienced supervisor. In the experimental garages in Illinois and Iowa, they did not set up long-term activity plans for scheduling and used the tool only for tactical day-to-day changes (which are discussed under hypothesis 3). As such, the capability of the tool to make long-term schedules based on weather forecasts was not tested.

Upon further discussion and probing of maintenance supervisors during interviews, it was revealed that long-term scheduling of non-winter maintenance activities is not routinely done. Routine activities are scheduled on a nightly basis no more than a week in advance in the garages. This is done to optimize crew availability (who is at work today, what equipment are they capable of running, where are they currently located), equipment availability (what is the status of the equipment, has the material been delivered), triage needs (do other garages need help, are there any immediate concerns that need to be addressed).

However, the interviewees noted certain activities do require advance planning (which unfortunately did not occur this summer). These include major concrete and asphalt related activities and those requiring specialized equipment that are available to be used in a garage jurisdiction in rotation with the other areas in the state. It was noted that the tool's ability to provide forecast weather conditions for those occasional activities would be invaluable in deciding on long-term schedules.

Several interviewees noted that the activity scheduling interface needed to be greatly simplified and rethought in the next version of the tool. As they used the tool, they provided feedback on the potential changes to the interface. Specifically:

- An easier way to track forwards and backwards in time to see allowable times activities
- Flexibility to override blocked times
- Capability to plan multiple activities in one screen allowing them to balance their activities across time and locations

The MOEs for the hypotheses relating to crew downtime, materials and labor were not tabulated for the evaluation as no differences from the experimental and control districts were observed during the summer.

4.3 Hypothesis 3

Notifications and alerts from the tool will result in greater agency responsiveness and flexibility in adjusting maintenance and operations schedules on a day to day basis.

The use of the tool mostly was in tactical decision-making once the weather-related practices were set up. Supervisors in the garages in Iowa and Illinois relied on the tool to adjust their daily schedules based on alerts provided by the tool.

1. Increase in the number of instances of same day or previous day adjustments to O&M activity schedule based on tool information

Table 4 summarizes the use of the tool during the evaluation period in the control and experimental garages. The top part of the table summarizes the days with changes to daily plans based on alerts received from the tool. The bottom part of the table summarizes the comments reported for the days with weather-related changes to the operations. For each comment, a positive (+) or a negative (-) sign has been assigned to indicate whether the tool provided a benefit or not.

Overall, the results were mixed and were hampered by demonstration difficulties with the software. In Iowa, the supervisor was able to use the tool effectively to achieve greater responsiveness and flexibility in daily operations. He was able to make changes during 11 of the 37 days for which he reported data on usage (29%). Comments clearly indicate the ability to adjust plans based on the tool alerts.

In Illinois, the experimental garages found it difficult to use the software effectively, both because they already incorporated weather information into their schedule planning that they believed was adequate and because the weather alert information was not consistently and reliably communicated to the users. They made changes on 15 of the 93 days (16%) but only received alerts for three of the days with the tool missing several weather events including a couple of days where the crews were rained out. While it is not known why these alerts were not issued, the issue could have been due to communication problems, software problems, device hardware problems, or issues at the receiving end. The focus of this evaluation was on how the tool was used and did not include an evaluation of the performance of the tool itself per se. These users also indicated that on 14 days they made changes to their daily plans that were unrelated to weather. The control group experienced no changes to the daily plans during the evaluation period. This can be partly attributed to the experienced supervisor who uses an existing private weather service provider to schedule his crews' work assignments.

While these demonstration difficulties hindered the full testing of the tool, the interviewees reported that when the tool worked it was helpful to their operations, but it was not stable enough to fully rely on it. In fact, many of these demonstration difficulties have been addressed over the course of the summer. However, end-users have a very low tolerance for systems that provide non-actionable alerts, or worse, miss events to which they should have been alerted to.

Table 4. Changes to Schedules Enabled by the Tool and Notes on Changes by Supervisors

Site	Total days with data	Days with no changes in plans	Days with changes made to daily plans (weather related)		Days with changes made to daily plans due to non-weather issues		
			MODSS alert received	No MODSS alert	Manpower and/or equipment	Pulled away to other priorities	Other
Experimental – IL	93	64	3	12	11	2	1
Experimental - IA	37	22	11	0	0	0	4
Control -IL	108	105	0	1	1	0	1
Experimental – Illinois (Notes for weather-related changes)							
4/16/2010	(-)	Raining when reported to work. Received no email. Changed Plans					
4/23/2010	(+)	Assignments set up after notification from tool.					
4/28/2010	(+)	Tool email said conditions not good for mowing.					
5/7/2010	(-)	Jobs were changed due to heavy rain. No indication from tool					
5/12/2010	(-)	Plans were changed for dragging shoulders due to rain. No notice from tool					
5/13/2010	(-)	Assignments were changed due to flooding. No warnings from tool					
7/20/2010	(-)	Tool not working.					
7/26/2010	(-)	Getting false emails for work not planned.					
7/30/2010	(-)	Tool not working.					
8/3/2010	(-)	Changed work orders due to rain. No notice from Tool					
8/4/2010	(-)	Work orders needed to be changed. No notice from Tool					
8/10/2010	(-)	Jobs were changed due to the rain. No notice from Tool					
8/11/2010	(-)	Jobs were changed due to the rain. No notice from Tool.					
8/17/2010	(-)	Rained out. No notice from Tool.					
8/18/2010	(-)	Work assignments changed due to rain. No notice from Tool.					
9/1/2010	(-)	Rained out. No notice from Tool.					
9/24/2010	(+)	Work orders changed due to notification from Tool.					
Experimental – Iowa (Notes for weather-related changes)							
5/3/2010	(+)	The MODSS forecast rain. Adjusted plans					
5/10/2010	(+)	Changed plans due to rain. Received notice from Tool					
5/12/2010	(+)	Changed plans due to rain. Received notice from Tool					
5/17/2010	(+)	Rained in the morning. Received notice from Tool					
5/21/2010	(+)	Rained in the morning and early afternoon. Received notice from Tool					
5/25/2010	(+)	Heavy rain. Received notice from Tool					
6/1/2010	(+)	MODSS forecasted good weather. No changes					
6/3/2010	(+)	MODSS forecasted good weather. No changes					
6/10/2010	(+)	Switched jobs because of forecasted rain from Tool					
6/14/2010	(+)	Forecasted rain. Adjusted plans					
Control – Illinois (Notes for weather-related changes)							
5/12/2010	(-)	Shut down 2 hours from rain.					

4.4 Hypothesis 4

Maintenance personnel view the use case as a useful and beneficial aspect of non-winter maintenance decision-making.

Interviews with the maintenance personnel revealed their expectation of the concept and the actual use of the tool did not differ greatly. Overall, they felt that while the set up process was difficult and laborious, it was a one-time and necessary process. Both Iowa and Illinois DOTs set up over thirty-eight (38) and thirty (30) individual weather-related practices respectively for the demonstration. Both DOTs reported that alerts from the tool helped them make changes, with one of the DOTs being more positive about the use of the tool. Other comments expressed in the interviews included:

- “Boring summer”
- Flexibility allows crews to work around weather for most routine tasks
- Demonstration difficulties hampered usage and trust over the season
- System was unreliable with days of down-time
- Information sent out in alerts was not actionable much of the time
- However, overall feedback – “when it worked, it was great”
- Better weather interface needed for activity planning. The current interface is too restrictive in terms of allowed times for activities.
- Need the tool be more flexible in “boundaries” of weather conditions. For example if relative humidity is 80% instead of 75%, the supervisor should have the flexibility to decide if they should continue with the activity or not.
- If the weather information is not accurate and timely, people will quickly lose confidence and that will cause mistrust that is very hard to change once it happens. If you decide to unveil a finished product you need accurate weather forecasting and maybe some way to interact with a meteorologist if questions arise.
- The fewer “bugs” you have when you roll this out the better, as software problems will also cause mistrust and sour people on using it.

Overall, the agencies were asked to rate the tool in terms of the concept (a decision-support system for non-winter maintenance) and the specific tool readiness (the demonstration software’s operational maturity). The following figures summarize the five responses received.

1. Agency level of satisfaction

Figure 6 presents the results of the rating of the concept of a non-winter MODSS based on the five users of the tool during the demonstration. The middle solid line represents the average of the responses and is bounded by the first and the third quartile numbers. Variations in user responses are indicated by the width of the gap between the first and third quartiles.

Users varied in their perceived need for the concept but overall expressed a moderate need for the concept, acceptance of the concept and the adaptability of the concept. (~6/10). Safety benefits were rated low, as expected. The likelihood that the benefits of the concept would outweigh costs was also rated low by the users but comments included in the rating indicated that this was primarily because of lack of information on the cost of such a system.

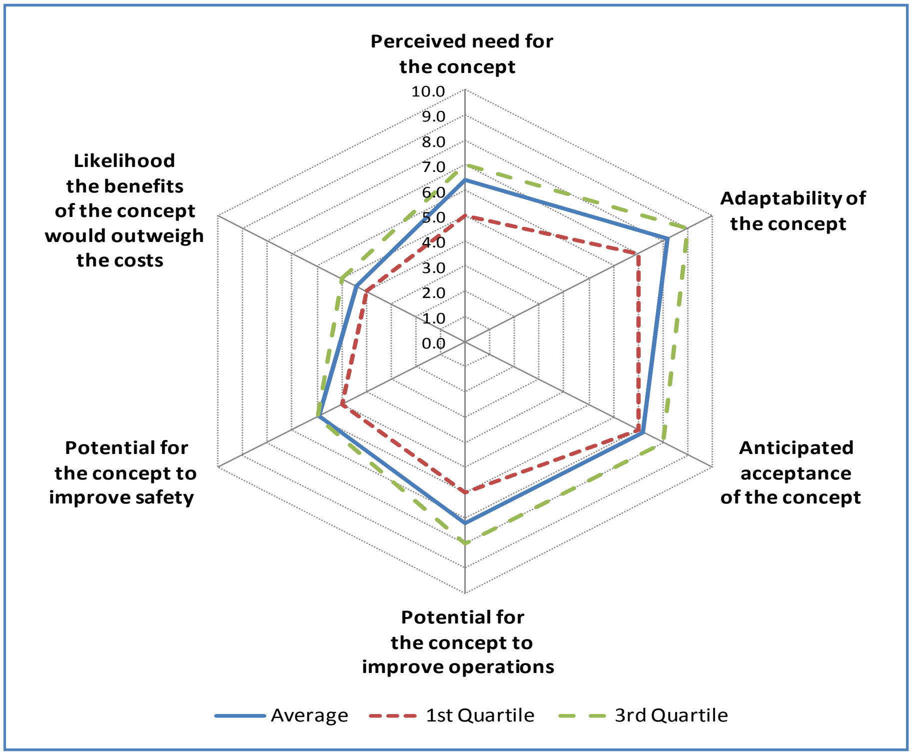


Figure 6. Assessment of Concept by State DOT Officials

Figure 7 provides the users' rating of the readiness of the tool demonstrated during the evaluation period. The users provided a moderate rating for dimensions related to ease to operation, interaction and navigation of the tool as well as the fit of the tool with their current tools. In fact, there was complete agreement on the high rating for the fit of this tool with their operations.

The users also had a uniformly middle rating for ease of set-up and configuration while noting this is a one-time activity and probably more cumbersome during the demonstration when WRPs had to be set up from scratch.

The users had low ratings for reliability and trust of the demonstration system. The ratings were obviously impacted by the technical difficulties encountered in the demonstration. Overall, the users felt that the tool was not yet ready for operational deployment. This difference between the tool's readiness and the need for the concept indicates an opportunity for tool enhancements.

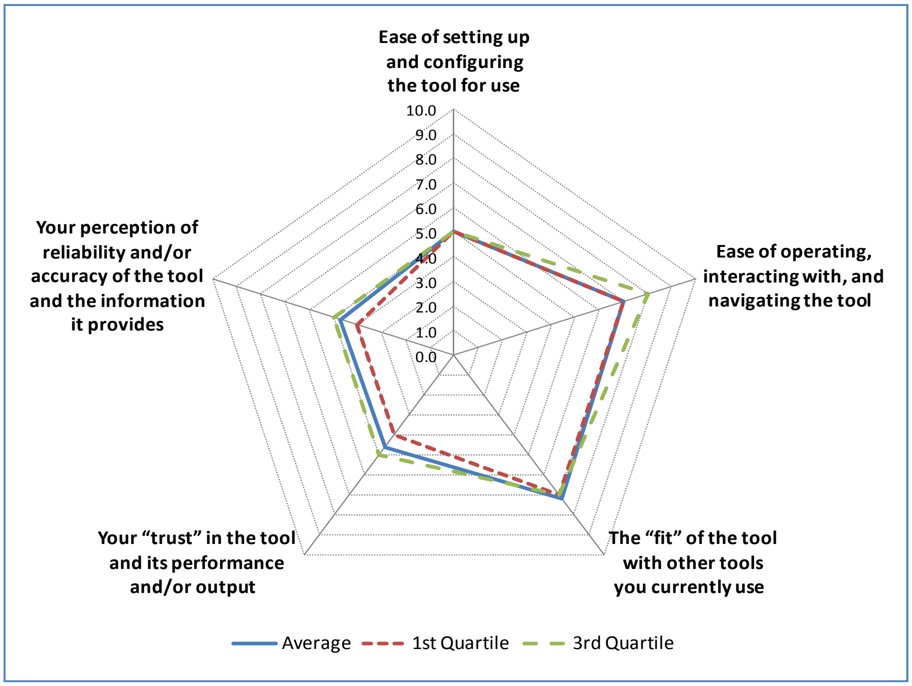


Figure 7. Assessment of Tool Readiness by State DOT Officials

5 Lessons Learned and Conclusions

The evaluation provided a good opportunity to document lessons learned as part of this demonstration. The following bullets summarize the lessons learned gleaned from interviews and interactions over the course of the project.

- **Integration of weather forecasts and observations in the tool is appreciated by users.** The tool integrated a wide variety of weather forecasts and observations into a single interface. This integration was appreciated by the users but a few interviewees also noted that they had a private sector weather provider who provided them hour-by hour forecasts daily. The text forecasts provided the hourly probability of precipitation, anticipated timing and duration of precipitation and type of precipitation. Users did not apparently perceive that the forecasts offered by the tool were inherently any more actionable than the weather forecasts that they already have available to them. The tool is set up to include integration of any weather service provider applications so potentially an agency could use their existing weather information service with which they are comfortable as input to the activity scheduling capability. It is the integration of weather forecasts with an alerting capability and thoughtfully scheduled weather-related practices that provides a system capable of more effectively guiding activities that are potentially impacted by weather.
- **Communications between the tool and field personnel are critical for success.** The utility of the tool is greatest when maintenance personnel in the field are alerted to changes in weather conditions. Interviews with the supervisors noted that once the day's plan has been communicated to the crew and they have been dispatched, the supervisors often leave the office and are out in the field monitoring their crew's actions. As a result, they noted that the greatest benefit of the tool is experienced when they are out in the field and not in front of a computer. The tool can alert them of changing weather conditions that may require modification of the set plans and reassignment of crew activities while out in the field. This necessitates a robust alerting system be included as part of the tool. Currently the demonstration was hampered by a complicated and evolving alert system in the tool that was viewed as cumbersome by some of the interviewees. Adding to the challenge of communicating with the field, as well as for future deployments, was that a lot of field personnel were not provided with state-owned communication devices. The demonstration tool would send alerts either as text messages or as emails. Several of the maintenance personnel either did not have communication data plans that would allow for the receipt of such information on their personal devices or were unwilling to receive text and emails on their personal devices.
- **Content of the alerts has to be better tailored for the supervisor.** Related to the above lesson, interviewees noted that the alerts needed to be not only location-specific but also clearly linked to the activity that triggered the alert.

- **Routine maintenance actions are conducted with a high degree of flexibility.** Crew supervisors consider a variety of factors in scheduling daily activities. While weather is an important factor, crew capabilities and availabilities, equipment availability, and daily priority needs often result in a flexible approach to scheduling routine maintenance activities. What this implies for the tool is that crew supervisors have enough "slack" and easily adapt their schedules to accomplish routine maintenance activities. Long-term scheduling of these activities is often unnecessary and not fruitful. As such, the alert capabilities and near-term (overnight or current day) weather information is most important to the supervisors.
- **However, for certain non-routine activities, this tool may provide a valuable long-term planning capability.** A few activities conducted by maintenance crews do allow for long-term scheduling. They are highly dependent on weather and can be planned several days or weeks in advance. Concrete and asphalt patching work were mentioned as two promising applications for the tool. Another promising activity pertains to specialized maintenance that requires equipment from another part of the state or would need to be contracted out. In these situations, better understanding of long-term weather forecasts would be very useful.
- **Weather-related practices are critical to new and inexperienced staff.** One of the benefits of the demonstration was the opportunity to create weather-related practices. Traditionally, these rules were ad-hoc and not formalized anywhere. Experienced supervisors knew what activities could be scheduled based on weather conditions but this demonstration helped create clear rules of practice. Over the course of the demonstration, both Iowa and Illinois adjusted their weather parameters but viewed the process of clearly defining the criteria as helpful. Interviewees noted that having these practices is invaluable for a new supervisor brought on board due to staff turnover.
- **Agencies need guidance in creating weather-related practices.** From the start of the demonstration, it became quickly clear that there were no standard weather-related practices for maintenance actions. Both Iowa and Illinois used their expertise to translate some of the loose rules of practice into specific criteria. Participants thought this might be an area worth investigating further. The interviewees noted that AASHTO or NCHRP could develop suggested practices and criteria that states could adopt with minimal effort.
- **Agencies need flexibility to work around weather-related practices.** Supervisors noted that while the weather related practices are useful, there needs to be flexibility provided to the supervisors to conduct the activity, especially when the weather criteria are close to the boundary condition. For example, they wanted the flexibility to schedule an activity requiring a temperature greater than 50F, even if the weather condition was only 48F.
- **Potential users of the tool extend beyond State DOTs.** The use of the tool in the construction and maintenance contracting industry should be explored. Interviewees noted that they, as a DOT with a wide range of job responsibilities can move crews from activity to activity without losing much time whereas a general contractor who does crack sealing exclusively, can benefit greatly from knowing when weather might interrupt their operations.

While technical issues regarding the software were challenging during the demonstration phase of the tool, the primary users of the tool (maintenance supervisors) provided continuous feedback that already has led to various software enhancements. In many ways, the supervisors were unsure of what technology or system they would need at the outset of this project, and this demonstration has helped clarify their needs and expectations similar to a prototype approach. A more clear expectation of the needs of a non-winter maintenance decision-support system should lead to better system development henceforth. Overall, both

Iowa DOT and Illinois DOT noted that the tool and the concept should be easy to adopt if some of the technical issues were resolved with respect to the software. They noted that once some of the demonstration issues have been worked out, this system would be helpful to use regularly and could be easily integrated into their operations philosophy.

References

Mixon Hill, Inc. 2009. *Development and Deployment of Clarus-enabled Services, Use Case #3: Non-Winter Maintenance and Operations Decision Support Tool, USE CASE SCENARIO.* (February).

Appendix A

Weather Related Practices for Illinois DOT and Iowa DOT

Table A-1. Weather Related Practices for Iowa DOT

ID	Plan Name	Observation	Units	Operator	Value	Qualitative	Duration (minutes)	Offset (Before/After) (minutes)	Message if Condition is Not Met
1	Maintain Pavements: Full Depth Concrete Replacement	Air Temperature	F	>=	50	NULL	120	-60	Temperature is going to be too low during the activity or relative humidity after the replacement is too low. Plan another activity.
		Relative Humidity	%	>=	60	NULL	300	0	
		Precipitation Rate	in/hr	<=	0.01	NULL	0	0	
		Prob of Precip 3Hr	%	<=	40	NULL	0	0	
2	Maintain Pavements: Pavement Leveling	Air Temperature	F	<	90	NULL	120	-60	
		Prob of Precip 3Hr	%	<=	40	NULL	0	0	
		Precipitation Rate	in/hr	<=	0.01	NULL	0	0	
3	Maintain Pavements: Sweep and Flush Bridges	Air Temperature	F	>	32	NULL	120	-60	
		Precipitation Rate	in/hr	<=	0.01	NULL	0	0	
		Prob of Precip 3Hr	%	<=	40	NULL	0	0	
4	Pavement Preventive Maintenance: Fly Coating	Air Temperature	F	>	70	NULL	120	-60	
		Air Temperature	F	<	90	NULL	120	-60	
		Relative Humidity	%	<	30	NULL	1,440	-60	
		Air Temperature	F	>	50	NULL	1,440	-60	
		Prob of Precip 3Hr	%	<=	40	NULL	0	0	
		Precipitation Rate	in/hr	<=	0.01	NULL	0	0	
5	Pavement Preventive Maintenance: Crack and Joint, Sealing	Air Temperature	F	>	30	NULL	120	-60	
		Air Temperature	F	<	60	NULL	120	-60	
		Precipitation Rate	in/hr	<=	0.01	NULL	0	0	
		Prob of Precip 3Hr	%	<=	40	NULL	0	0	
6	Pavement Preventive Maintenance: Crack and Joint: Edge Seals	Air Temperature	F	>	30	NULL	120	-60	
		Air Temperature	F	<	60	NULL	120	-60	
		Precipitation Rate	in/hr	<=	0.01	NULL	0	0	
		Prob of Precip 3Hr	%	<=	40	NULL	0	0	

ID	Plan Name	Observation	Units	Operator	Value	Qualitative	Duration (minutes)	Offset (Before/After) (minutes)	Message if Condition is Not Met
7	Pavement Preventive Maintenance: Crack and Joint: Mopping	Surface Status	Qualitative	=		Dry	240	-60	
		Air Temperature	F	<	90	NULL	120	-60	
		Prob of Precip 3Hr	%	<=	40	NULL	0	0	
		Precipitation Rate	in/hr	<=	0.01	NULL	0	0	
8	Pavement Preventive Maintenance: Scrub Seals	Air Temperature	F	>	65	NULL	60	-60	
		Air Temperature	F	<	73	NULL	60	0	
		Precipitation Rate	in/hr	<=	0.01	NULL	0	0	
		Prob of Precip 3Hr	%	<=	40	NULL	0	0	
9	Maintenance of Shoulders and Approaches: Fly Coating	Air Temperature	F	>	55	NULL	120	-60	
		Relative Humidity	%	<	30	NULL	120	-60	
		Prob of Precip 24Hr	%	<	5	NULL	2,160	-720	
		Precipitation Rate	in/hr	<=	0.01	NULL	0	0	
10	Maintenance of Shoulders and Approaches: Chip Seal	Air Temperature	F	>	50	NULL	120	-60	
		Relative Humidity	%	<	30	NULL	120	-60	
		Prob of Precip 24Hr	%	<	5	NULL	2,160	-720	
		Precipitation Rate	in/hr	<=	0.01	NULL	0	0	
11	Maintenance of Shoulders and Approaches: Pothole Patching	Surface Temperature	F	>	50	NULL	120	-60	
		Precipitation Rate	in/hr	<=	0.01	NULL	0	0	
		Prob of Precip 3Hr	%	<=	40	NULL	0	0	
12	Maintenance of Shoulders and Approaches: Blade Patching	Surface Temperature	F	>	50	NULL	120	-60	
		Precipitation 3 Hours	%	<=	40	NULL	0	0	
		Precipitation Rate	in/hr	<=	0.01	NULL	0	0	
13	Maintenance of Shoulders and Approaches: Edge Ribbon	Surface Temperature	F	>	50	NULL	120	-60	
		Precipitation Rate	in/hr	<=	0.01	NULL	0	0	
		Prob of Precip 3Hr	%	<=	40	NULL	0	0	

ID	Plan Name	Observation	Units	Operator	Value	Qualitative	Duration (minutes)	Offset (Before/After) (minutes)	Message if Condition is Not Met
14	Maintenance of Shoulders and Approaches: Repair Concrete	Surface Temperature	F	>	50	NULL	120	-60	
		Prob of Precip 3Hr	%	<=	40	NULL	0	0	
		Precipitation Rate	in/hr	<=	0.01	NULL	0	0	
15	Drainage Maintenance: Clean and Reshape Paved Ditches	Air Temperature	F	>	32	NULL	120	-60	
		Precipitation Rate	in/hr	<=	0.01	NULL	0	0	
		Prob of Precip 3Hr	%	<=	40	NULL	0	0	
16	Drainage Maintenance: Repair Paved Ditches and Slopes	Air Temperature	F	>	32	NULL	120	-60	
		Precipitation Rate	in/hr	<=	0.01	NULL	0	0	
		Prob of Precip 3Hr	%	<=	40	NULL	0	0	
17	Drainage Maintenance: Clean and Repair Pipe Culvert Flow Lines	Air Temperature	F	>	32	NULL	120	-60	
		Precipitation 3 Hours	in/hr	<=	40	NULL	0	0	
		Precipitation Rate	%	<=	0.01	NULL	0	0	
18	Drainage Maintenance: Repair Concrete Curbs	Air Temperature	F	>	45	NULL	120	-60	
		Surface Temperature	F	>	45	NULL	120	-60	
		Precipitation Rate	in/hr	<=	0.01	NULL	0	0	
		Prob of Precip 3Hr	%	<=	40	NULL	0	0	
19	Drainage Maintenance: Repair Asphalt Curbs	Air Temperature	F	>	60	NULL	120	-60	
		Surface Temperature	F	>	60	NULL	120	-60	
		Prob of Precip 3Hr	%	<=	40	NULL	0	0	
		Precipitation Rate	in/hr	<=	0.01	NULL	0	0	
20	Drainage Maintenance: Repair Drop Inlets and Storm Sewers	Air Temperature	F	>	45	NULL	120	-60	
		Surface Temperature	F	>	45	NULL	120	-60	
		Prob of Precip 3Hr	%	<=	40	NULL	0	0	
		Precipitation Rate	in/hr	<=	0.01	NULL	0	0	
21	Maintain Roadway Safety Features: Repair Traffic Barrier	Air Temperature	F	>	40	NULL	1,440	-60	
		Prob of Precip 3Hr	%	<=	40	NULL	0	0	
		Precipitation Rate	in/hr	<=	0.01	NULL	0	0	

ID	Plan Name	Observation	Units	Operator	Value	Qualitative	Duration (minutes)	Offset (Before/After) (minutes)	Message if Condition is Not Met
22	Maintain Bridges: Spot Painting of Bearings and Piling	Air Temperature	F	>	40	NULL	120	-60	
		Prob of Precip 3Hr	%	<=	40	NULL	0	0	
		Precipitation Rate	in/hr	<=	0.01	NULL	0	0	
23	Maintain Bridges Preventively: Linseed Oil, Linseed Oil	Air Temperature	F	>	80	NULL	120	-60	
		Relative Humidity	%	<	30	NULL	120	-60	
		Precipitation Rate	in/hr	<=	0.01	NULL	0	0	
		Prob of Precip 3Hr	%	<=	40	NULL	0	0	
24	Maintain Bridges Preventively: Linseed Oil, In-Deck	Air Temperature	F	>	55	NULL	120	-60	
		Prob of Precip 3Hr	%	<=	40	NULL	0	0	
		Precipitation Rate	in/hr	<=	0.01	NULL	0	0	
26	Shoulder Maintenance: Functions 628, 629, 632, 633	Precipitation Intensity	Qualitative	=		None	60	-60	Shoulder maintenance not possible.
		Prob of Precip 3Hr	%	<=	40	NULL	60	-60	
		Air Temperature	F	>=	45	NULL	60	-60	
		Wind Average Speed	mph	<=	25	NULL	60	-60	
		Visibility	mi	>=	0.5	NULL	60	-60	
27	Shoulder Maintenance: Function 634	Precipitation Rate	in/hr	<=	0.5	NULL	60	-60	Shoulder maintenance plan not possible.
		Prob of Precip 3Hr	%	<=	50	NULL	60	-60	
		Visibility	mi	>=	0.5	NULL	60	-60	
28	Shoulder Maintenance: Functions 636 and 645	Precipitation Rate	in/hr	<=	0.01	NULL	60	-60	Mowing activity not possible.
		Prob of Precip 3Hr	%	<=	40	NULL	60	-60	
		Wind Average Speed	mph	<=	25	NULL	60	-60	
		Air Temperature	F	>=	30	NULL	60	-60	
		Visibility	mi	>=	0.5	NULL	60	-60	

ID	Plan Name	Observation	Units	Operator	Value	Qualitative	Duration (minutes)	Offset (Before/After) (minutes)	Message if Condition is Not Met
29	Shoulder Maintenance: Hand Mowing, Function 638	Precipitation Rate	in/hr	<=	0.01	NULL	60	-60	Hand mowing no longer possible.
		Prob of Precip 3Hr	%	<=	40	NULL	60	-60	
		Air Temperature	F	<=	100	NULL	60	-60	
		Relative Humidity	%	<=	80	NULL	60	-60	
		Visibility	mi	>=	0.5	NULL	60	-60	
30	Traffic Services: Pavement Markings, Function 663, 664, 665	Precipitation Rate	in/hr	<=	0.01	NULL	60	-60	Paint marking no longer possible.
		Prob of Precip 3Hr	%	<=	40	NULL	60	-60	
		Air Temperature	F	>=	50	NULL	60	-60	
		Wind Average Speed	mph	<=	25	NULL	0	-60	
33	Roadway Surface: Machine Leveling, Function 611	Precipitation Rate	in/hr	<=	0.01	NULL	7,260	-7200	Roadway surface maintenance no longer possible.
		Prob of Precip 3Hr	%	<=	40	NULL	7,260	-7200	
		Air Temperature	F	>=	45	NULL	60	-60	
		Visibility	mi	>=	0.5	NULL	120	-60	
34	Roadway Surface: Joint and Crack Filling, Function 612	Precipitation Rate	in/hr	<=	0.01	NULL	120	-60	Roadway surface maintenance no longer possible.
		Prob of Precip 3Hr	%	<=	40	NULL	60	-60	
		Wind Average Speed	mph	<=	30	NULL	60	-60	
		Air Temperature	F	>=	30	NULL	60	-60	
		Visibility	mi	>=	0.5	NULL	60	-60	
35	Roadway Surface: Functions 614 and 618	Precipitation Rate	in/hr	<=	0.01	NULL	60	0	Surface maintenance no longer possible.
		Prob of Precip 3Hr	%	<=	40	NULL	60	0	
		Air Temperature	F	>=	60	NULL	60	0	
		Wind Average Speed	mph	<=	25	NULL	60	-60	
		Visibility	mi	>=	0.5	NULL	60	-60	
36	Roadway Surface: Function 619	Precipitation Rate	in/hr	<=	0.01	NULL	0	-60	Roadway maintenance no longer possible.
		Prob of Precip 3Hr	%	<=	40	NULL	0	-60	
		Air Temperature	F	>=	30	NULL	0	-60	
		Visibility	mi	>=	0.5	NULL	0	-60	

ID	Plan Name	Observation	Units	Operator	Value	Qualitative	Duration (minutes)	Offset (Before/After) (minutes)	Message if Condition is Not Met
37	Roadway Surface: Functions 620 and 684	Precipitation Rate	in/hr	<=	0.01	NULL	0	-60	Sweeping no longer possible.
		Prob of Precip 3Hr	%	<=	40	NULL	0	-60	
		Air Temperature	F	>=	30	NULL	0	-60	
		Visibility	mi	>=	0.5	NULL	0	-60	
38	Roadway Surface: Underseal/Raise Pavement	Precipitation Rate	in/hr	<=	0.01	NULL	0	-60	Roadway maintenance no longer possible.
		Prob of Precip 3Hr	%	<=	40	NULL	0	-60	
		Air Temperature	F	>=	60	NULL	0	-60	
		Wind Average Speed	mph	<=	25	NULL	0	-60	
		Visibility	mi	>=	0.5	NULL	0	-60	

Iowa Legend for Plan Activities with Codes

Plan Name with Codes	Description
Shoulder Maintenance: Functions 628, 629, 632, 633	Bituminous repair, sealing shoulders, shoulder joint repair.
Shoulder Maintenance: Function 634	Repair edge ruts with aggregate.
Shoulder Maintenance: Functions 636 and 645	Shoulder mowing and roadside mowing. Mowing for aesthetics and mowing weeds.
Shoulder Maintenance: Hand Mowing, Function 638	Hand mowing around guardrails.
Traffic Services: Pavement Markings, Functions 663, 664, 665	Paint center line, E/L and curb markings.
Roadway Surface: Function 609	Clean debris from hole and fill with HMA or Premix.
Blow-up Repair: Function 610 and 613	Relieve pressure and patch with PCC or HMA. Jackhammer debris from patch and fill with materials.
Roadway Surface: Machine Leveling, Function 611	Mill if needed, tack and lay HMA patch.
Roadway Surface: Joint and Crack Filling, Function 612	Clean joint or crack, fill with emulsion.
Roadway Surface: Functions 614 and 618	Seal coating, slurry seal, strip seal. Clean highway surface, apply material.
Roadway Surface: Function 619	Burn/plane or mill surface. Seal with emulsion and sand.
Roadway Surface: Functions 620 and 684	Brooming or sweeping. Sweeping surfaces by hand and mechanically.
Roadway Surface: Underseal/Raise Pavement	Drilling holes and pumping material to fill voids.

Table A-2. Work Related Practices for Illinois DOT

ID	Plan Name	Description	Observation	Units	Operator	Value	Qualitative	Duration (minutes)	Offset (Before/ After) (minutes)	Message if Condition is Not Met
17	435- Pipe and Culvert Cleaning	With Vac-Con	Air Temperature	F	>	32	NULL	120	-60	Conditions are not favorable for this activity. Check weather to determine to continue or reschedule activity.
28	444C - Weed Spraying from Cab		Wind Average Speed	mph	<=	15	NULL	120	-60	Conditions are not favorable for this activity. Check weather to determine to continue or reschedule activity.
			Wind Gust Speed	mph	<=	20	NULL	120	-60	
			Visibility	mi	>=	0.25	NULL	120	-60	
			Precipitation Rate	in/hr	<=	0.1	NULL	120	-60	
			Prob of Precip 1Hr	%	<=	60	NULL	120	-60	
29	444T - Weed Spraying from Open Tractor		Wind Average Speed	mph	<=	15	NULL	120	-60	Conditions are not favorable for this activity. Check weather to determine to continue or reschedule activity.
			Wind Gust Speed	mph	<=	20	NULL	120	-60	
			Precipitation 24 Hours	in	<=	1	NULL	180	-180	
			Visibility	mi	>=	0.25	NULL	120	-60	
			Precipitation Rate	in/hr	<=	0.1	NULL	120	-60	
			Prob of Precip 1Hr	%	<=	60	NULL	120	-60	
30	410 - Pothole Patching	Using cold mix	Visibility	mi	>=	0.25	NULL	120	-60	Conditions are not favorable for this activity. Check weather to determine to continue or reschedule activity. If visibility is poor, postpone to a later time of day.
			Precipitation Rate	in/hr	<=	0.1	NULL	120	-60	

ID	Plan Name	Description	Observation	Units	Operator	Value	Qualitative	Duration (minutes)	Offset (Before/ After) (minutes)	Message if Condition is Not Met
31	412 - Full Depth Patching	Patching with concrete	Air Temperature	F	>	45	NULL	120	-60	Conditions are not favorable for this activity. Check weather to determine to continue or reschedule activity. For days of high humidity, allow longer concrete set up times.
			Visibility	mi	>=	0.25	NULL	120	-60	
			Relative Humidity	%	<=	85	NULL	300	-60	
			Precipitation Rate	in/hr	<=	0.05	NULL	120	-60	
			Prob of Precip 1Hr	%	<=	40	NULL	120	-60	
32	415B - Bump Planing	With bump grinder	Visibility	mi	>=	0.25	NULL	120	-60	Conditions are not favorable for this activity. Check weather to determine to continue or reschedule activity.
			Precipitation Rate	in/hr	<=	0.1	NULL	120	-60	
			Prob of Precip 1Hr	%	<=	40	NULL	120	-60	
33	421 - Spreading Rock, Hand Method	Placing rock from rear of truck box and spreading with shovel	Precipitation Rate	in/hr	<=	0.1	NULL	120	-60	Conditions are not favorable for this activity. Check weather to determine to continue or reschedule activity.
34	422 - Spreading Rock - Machine Method	Using rock box or spreader to place rock	Precipitation 24 Hours	in	<=	1	NULL	180	-180	Conditions are not favorable for this activity. Check weather to determine to continue or reschedule activity.
			Visibility	mi	>=	0.25	NULL	120	-60	
			Precipitation Rate	in/hr	<=	0.1	NULL	120	-60	
			Prob of Precip 1Hr	%	<=	70	NULL	120	-60	
35	425 - Blading and Dragging Shoulders	Using grader, tractor mounted drag or tractor mounted blade	Precipitation 24 Hours	in	<=	1	NULL	180	-180	Conditions are not favorable for this activity. Check weather to determine to continue or reschedule activity.
			Visibility	mi	>=	0.25	NULL	120	-60	
			Precipitation Rate	in/hr	<=	0.1	NULL	120	-60	
			Prob of Precip 1Hr	%	<=	40	NULL	120	-60	

ID	Plan Name	Description	Observation	Units	Operator	Value	Qualitative	Duration (minutes)	Offset (Before/ After) (minutes)	Message if Condition is Not Met
36	430 - Slope Repair	Using dirt or rock	Precipitation Rate	in/hr	<=	0.1	NULL	120	-60	Conditions are not favorable for this activity. Check weather to determine to continue or reschedule activity.
37	432T - Ditch Cleaning	With trackhoe	Precipitation 24 Hours	in	<=	1	NULL	180	-180	Conditions are not favorable for this activity. Check weather to determine to continue or reschedule activity.
			Precipitation Rate	in/hr	<=	0.1	NULL	120	-60	
			Prob of Precip 1Hr	%	<=	40	NULL	120	-60	
38	432B- Ditch Cleaning	With backhoe or gradall	Precipitation 24 Hours	in	<=	1	NULL	180	-180	Conditions are not favorable for this activity. Check weather to determine to continue or reschedule activity.
		With backhoe or gradall	Precipitation Rate	in/hr	<=	0.1	NULL	120	-60	
		With backhoe or gradall	Prob of Precip 1Hr	%	<=	40	NULL	120	-60	
39	436 - Pipe and Culvert Repair/Replace	Replacing a section or entire culvert pipe	Precipitation Rate	in/hr	<=	0.1	NULL	120	-60	Conditions are not favorable for this activity. Check weather to determine to continue or reschedule activity.
41	440 - Tree, Brush and Shrub Removal	Cutting down and cleaning up	Precipitation Rate	in/hr	<=	0.1	NULL	120	-60	Conditions are not favorable for this activity. Check weather to determine to continue or reschedule activity.
			Wind Average Speed	mph	<	17	NULL	120	-60	
			Prob of Precip 1Hr	%	<=	40	NULL	120	-60	
42	442 – Mowing, Hand Method	Using weed whacker or weed whip	Precipitation Rate	in/hr	<=	0.1	NULL	120	-60	Conditions are not favorable for this activity. Check weather to determine to continue or reschedule activity.
			Prob of Precip 1Hr	%	<=	60	NULL	120	-60	
43	443C - Mowing with Cab Tractor	Includes guardrail mower	Precipitation 24 Hours	in	<=	1	NULL	180	-180	Conditions are not favorable for this activity. Check weather to determine to continue or reschedule activity.
			Precipitation Rate	in/hr	<=	0.1	NULL	120	-60	

ID	Plan Name	Description	Observation	Units	Operator	Value	Qualitative	Duration (minutes)	Offset (Before/ After) (minutes)	Message if Condition is Not Met
44	443T - Mowing with Open Tractor		Precipitation 24 Hours	in	<=	1	NULL	180	-180	Conditions are not favorable for this activity. Check weather to determine to continue or reschedule activity.
			Precipitation Rate	in/hr	<=	0.1	NULL	120	-60	
			Prob of Precip 1Hr	%	<=	60	NULL	120	-60	
45	445C - Guardrail Spraying from Cab		Wind Average Speed	mph	<=	15	NULL	120	-60	Conditions are not favorable for this activity. Check weather to determine to continue or reschedule activity.
			Wind Gust Speed	mph	<=	20	NULL	120	-60	
			Visibility	mi	>=	0.25	NULL	120	-60	
			Precipitation Rate	in/hr	<=	0.1	NULL	120	-60	
			Prob of Precip 1Hr	%	<=	60	NULL	120	-60	
46	445T - Guardrail Spraying from Open Tractor		Wind Gust Speed	mph	<=	20	NULL	120	-60	Conditions are not favorable for this activity. Check weather to determine to continue or reschedule activity.
			Wind Average Speed	mph	<=	15	NULL	120	-60	
			Precipitation Rate	in/hr	<=	0.1	NULL	120	-60	
			Prob of Precip 1Hr	%	<=	60	NULL	120	-60	
47	446T - Mechanical Sweeping from Open Tractor		Visibility	mi	>=	0.25	NULL	120	-60	Conditions are not favorable for this activity. Check weather to determine to continue or reschedule activity.
			Precipitation Rate	in/hr	<=	0.1	NULL	120	-60	
			Prob of Precip 1Hr	%	<=	60	NULL	120	-60	
48	446C - Mechanical Sweeping from Cab		Visibility	mi	>=	0.25	NULL	120	-60	Conditions are not favorable for this activity. Check weather to determine to continue or reschedule activity.
			Prob of Precip 1Hr	%	<=	60	NULL	120	-60	

ID	Plan Name	Description	Observation	Units	Operator	Value	Qualitative	Duration (minutes)	Offset (Before/ After) (minutes)	Message if Condition is Not Met
49	447 - Litter Pickup	Walking ditches and shoulders	Precipitation Rate	in/hr	<=	0.1	NULL	120	-60	Conditions are not favorable for this activity. Check weather to determine to continue or reschedule activity.
			Prob of Precip 1Hr	%	<=	60	NULL	120	-60	
51	741 - Tree and Shrub Planting		Precipitation 24 Hours	in	<=	1	NULL	180	-180	Conditions are not favorable for this activity. Check weather to determine to continue or reschedule activity.
			Precipitation Rate	in/hr	<=	0.1	NULL	120	-60	
			Prob of Precip 1Hr	%	<=	60	NULL	120	-60	
53	468 - Sign Maintenance and Flagging	Repairing signs, setting up signs and/or flagging for other crews	Visibility	mi	>=	0.25	NULL	120	-60	Conditions are not favorable for this activity. Check weather to determine to continue or reschedule activity. For poor visibility, reschedule for later in the day. If flagging for another special crew, contact their supervisor for further direction.
			Precipitation Rate	in/hr	<=	0.1	NULL	120	-60	
			Prob of Precip 1Hr	%	<=	60	NULL	120	-60	
61	433 - Drain and Catch Basin Cleaning		Air Temperature	F	>=	30	NULL	120	-60	Conditions are not favorable for this activity. Check weather to determine to continue or reschedule activity.
62	550H - Bridge Deck Cleaning by Hand		Visibility	mi	>=	0.25	NULL	120	-60	Conditions are not favorable for this activity. Check weather to determine to continue or reschedule activity.
			Precipitation Rate	in/hr	<=	0.1	NULL	120	-60	
			Prob of Precip 1Hr	%	<=	60	NULL	120	-60	
63	550S - Bridge Deck Cleaning with Sweeper	Cleaning bridge decks with sweeper with cab	Visibility	mi	>=	0.25	NULL	120	-60	Conditions are not favorable for this activity. Check weather to determine to continue or reschedule activity.
			Precipitation Rate	in/hr	<=	0.1	NULL	120	-60	
			Prob of Precip 1Hr	%	<=	60	NULL	120	-60	

ID	Plan Name	Description	Observation	Units	Operator	Value	Qualitative	Duration (minutes)	Offset (Before/ After) (minutes)	Message if Condition is Not Met
64	553 - Deck Drain Cleaning	By hand	Visibility	mi	>=	0.25	NULL	120	-60	Conditions are not favorable for this activity. Check weather to determine to continue or reschedule activity.
			Precipitation Rate	in/hr	<=	0.1	NULL	120	-60	
			Prob of Precip 1Hr	%	<=	60	NULL	120	-60	
65	415S - Bump Planing with Scraper	Grader or loader bucket	Surface Temperature	F	>=	75	NULL	120	-60	Conditions are not favorable for this activity. Check weather to determine to continue or reschedule activity.
			Visibility	mi	>=	0.25	NULL	120	-60	
			Precipitation Rate	in/hr	<=	0.1	NULL	120	-60	
			Prob of Precip 1Hr	%	<=	40	NULL	120	-60	
			Weather Warning	-	=		Active	120	-60	
			Wind Average Speed	mph	<=	20	NULL	120	-60	
			Prob of Precip 3Hr	%	<	75	NULL	120	-60	

Appendix B

Agency Interview Questions

Experimental Group Maintenance Supervisor:

- Has the non-winter MDSS changed how you do your job in any way? If so, explain how.
- Has the non-winter MDSS impacted (for better or worse) how crews are scheduled in your area? If so, explain how?
- Did you have to redo any maintenance activities because of weather conditions post the maintenance action?
- Did you encounter any unforeseen problems/issues in using the non-winter MDSS this past summer season? If yes, describe the problems/issues and describe how you addressed them.
- How trustworthy do you find the information provided by the non-winter MDSS? Forecast accuracy? Validity of activity plan windows? Notifications provided?
- Is the non-winter MDSS easy/difficult to use? Explain.
- Did you receive training on the use of the non-winter MDSS? Was your training adequate? Would you recommend any changes?
- Would you say that crew scheduling decisions are made any more proactively than before, as a result of having/using the MDSS?
- Do you think the crews are better utilized with this tool?
- Does the non-winter MDSS need refinements or improvements? Do you have any specific suggestions in that regard?
- Do you think non-winter MDSS is ready for full deployment by your region or state? Are all the supervisors and crew ready to use this tool?
- Are you comfortable with the idea of relying 100% for your decisions on what the non-MDSS is telling you in terms of activities? Comments?
- In your own opinion, is it worth it your agency to pay to have the tool? How/why? Discuss the pros and cons.
- What key messages would you want to offer other DOTs who may not yet have tried this system? What have you learned about using the tool that you think others should be aware of?

Experimental Group Maintenance Crew Representative:

- Compared to previous seasons, how would you categorize impacts on weather on your maintenance actions this year so far?
- Have you had any maintenance actions that were affected by weather (rain, lightning, heat, others)? Please describe the type of weather event and your response.
- Did you have to redo any maintenance activities because of weather conditions post the maintenance action?
- Did you change your daily assignments based on forecast information made available to you this season?
- Did you get alerts about upcoming weather conditions during this season to your mobile device during the day? Were they useful to you? Were they actionable? When were the alerts most/least effective?
- Do you believe crew scheduling has improved this season to minimize the impacts of weather? Do you think the crews being better utilized because of this tool?
- In your own opinion, is it worth it your agency to pay to have the tool? How/why? Discuss the pros and cons.

Control Group Maintenance Crew Supervisor

- Compared to previous seasons, how would you categorize impacts on weather on your maintenance actions this year so far?
- Have you had any maintenance actions that were affected by weather (rain, lightning, heat, others)? Please describe the type of weather event and your response.
- How do you account for weather in your crew scheduling decisions? What tools did you use?
- Did you change your planned daily assignments based on forecast information made available to you this season?
- Did you have to redo any maintenance activities because of weather conditions post the maintenance action?
- How do you think crew scheduling can be improved to minimize weather impacts? Is there value in a tool that provides forecasts and alerts for activity scheduling?
- Are you aware of the use case being tested by some others in your district? What are your opinions about it?

Control Group Maintenance Crew Representative

- Compared to previous seasons, how would you categorize impacts on weather on your maintenance actions this year so far?
- Have you had any maintenance actions that were affected by weather (rain, lightning, heat, others)? Please describe the type of weather event and your responses.
- Do you believe crew scheduling can be improved this season to minimize the impacts of weather?
- How do you think crew scheduling can be improved to minimize weather impacts? Is there value in a tool that provides forecasts and alerts for activity scheduling?
- Did you have to redo any maintenance activities because of weather conditions post the maintenance action?

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