Prototype Road Weather Performance Management Tool

Project Report

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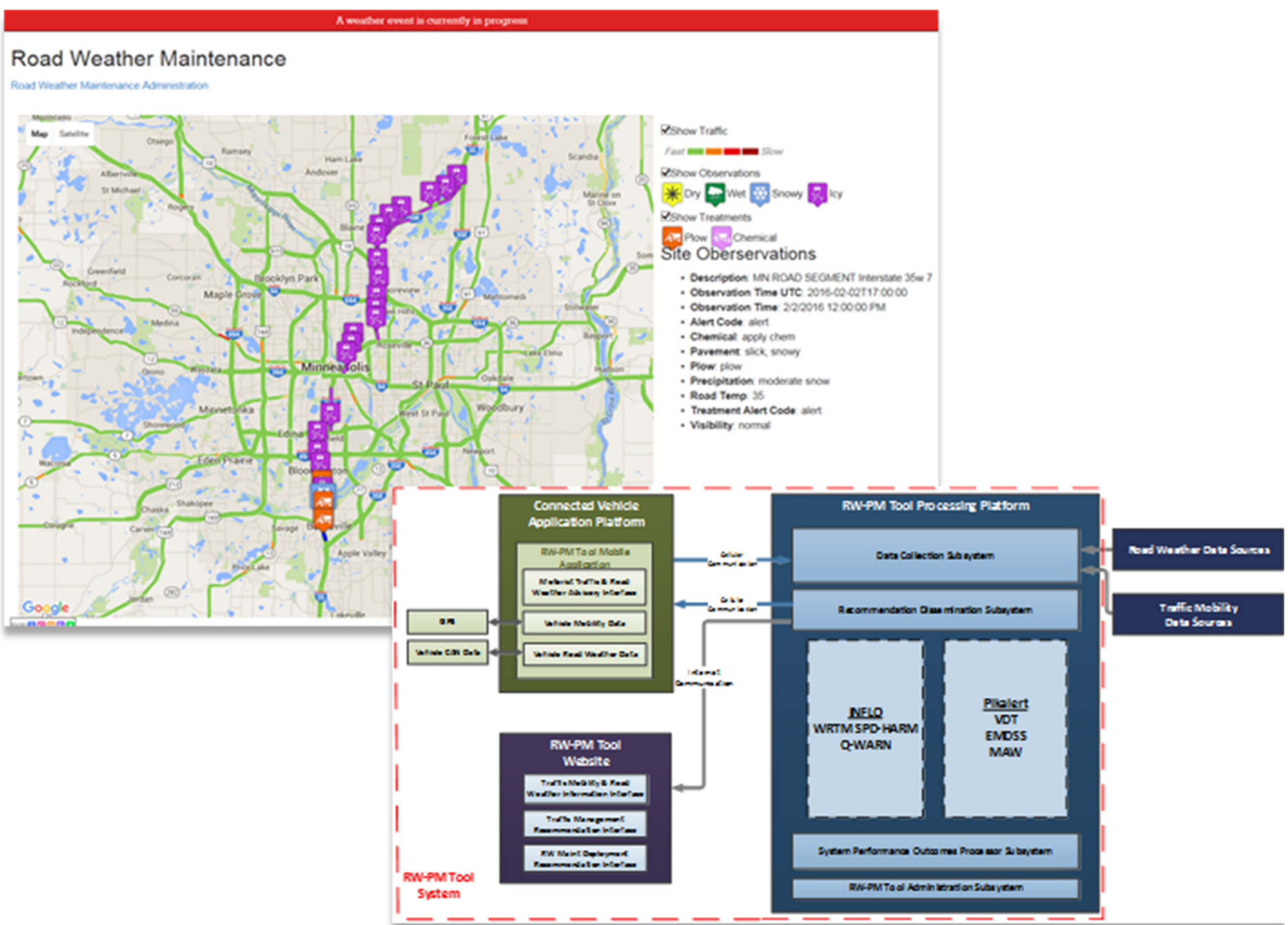

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16. Abstract

This report is the Project Report for the Road Weather Performance Management (RW-PM) Tool developed for the project on *Development and Demonstration of a Prototype Road Weather Performance Management Application that Uses Connected Vehicle Data* (RW-PM Tool Project), supporting improved road weather response performance during winter weather conditions.

The objective of this project was to utilize a Systems Engineering approach to prototype, test, deploy, and evaluate a Prototype Road Weather Performance Management Tool (RW-PM Tool) that would demonstrate the potential for connected vehicle data to enhance and transform road weather performance measurement and management processes in DOTs. The Tool provides a mechanism for the United States Department of Transportation (U.S. DOT) to assist DOTs in leveraging connected vehicle technologies and to advance the state of the art in road weather management.

17. Key Words	18. Distribution statement
Road Weather Performance, Road Weather Performance Measurement, Road Weather Performance Management Tool, RW-PM, RW-PM Tool	Unlimited.

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Table of Contents

List of Appendices

List of Tables

List of Figures

Executive Summary

This report summarizes the Road Weather Performance Management (RW-PM) Tool project. The project applied a Systems Engineering methodology to prototype, test, deploy, and evaluate a Prototype RW-PM Tool and demonstrate the potential for connected vehicle data to enhance and transform road weather performance measurement and management processes in DOTs' traffic management and RW maintenance operations. The Tool incorporated multiple fixed and mobile sources (e.g., fixed environmental sensor stations [ESS], connected vehicle mobile sensing devices) of traffic and road weather observations in supporting transportation agencies in performing weather-related traffic management and RW maintenance deployments.

Because performance measures important to DOTs can vary based on type and severity of weather events, as well as the priorities and constraints faced by each state, the Tool was developed to be scalable and flexible, and able to incorporate a variety of activities and performance measures as parameters for performance management. Additionally, this project intended to provide a mechanism for U.S. DOT to assist DOTs in leveraging connected vehicle technologies and to advance the state-of-the-art in road weather management. RW-PM methodologies described in this document focused primarily on response to winter weather and snow events, but the approach used by the tool applies to other road weather events that degrade highway safety, including fog, dust-storms, and heavy rain.

The Prototype RW-PM Tool leverages the latest developments in connected vehicle technology and the expected deployment of connected vehicle technology in new cars. It has capabilities to provide real-time feedback to Traffic Management managers and RW Maintenance managers during dynamic weather events, and allows them to adjust their traffic mobility and road weather controls on-the-fly to maximize the effectiveness of their limited resources. Functions and potential benefits include:

- Integrates traffic mobility, road weather data collection, and analysis support to inform traffic and RW Maintenance management responses to adverse weather conditions.
- Captures data wirelessly from mobile data sources in real-time and integrates with legacy and fixed data sources to provide a more robust, higher resolution and density traffic mobility and road weather data to support more accurate and precise traffic mobility and RW Maintenance decisions by traffic and maintenance personnel.
- Implements real-time data collection, processing, display, and messaging to support improved allocation of available RW Maintenance staff, equipment and material resources to maintain mobility, as well as more timely and targeted deployment of RW Maintenance response to dynamic variations in weather.
- Improves the deployment of RW Maintenance resources to help improve traffic mobility during an adverse weather event, and return mobility to normal more quickly following an event.
- Delivers in-vehicle real-time traffic mobility and road weather information and messaging to drivers to support more informed travel route decisions and safer decisions by drivers. This reduces the likelihood of accidents, thereby improving traffic safety and mobility.

Chapter 1 Project Report Summary

Adverse road weather conditions can significantly degrade traffic mobility, reducing speed and road capacity as well as increasing delays and travel time. State Departments of Transportation (DOTs) and public transportation agencies work hard to mitigate the effects of adverse weather events. In fact, it is estimated that DOTs spend over $2 billion each year on snow and ice control alone [1].

Although adverse weather and the resulting traffic is highly variable, DOTs rely largely on area weather forecasts, best practices, and past experiences to decide how to deploy their road weather maintenance (RW maintenance) resources to mitigate adverse effects while also continuously seeking to improve their response and performance. They need tools that can help them maximize the effectiveness of their maintenance resources and adjust their deployments dynamically as road conditions and traffic flow evolve during an event.

Connected vehicle technology holds great promise in improving DOT response to adverse weather through real-time monitoring of traffic mobility, local weather, and local road conditions. This technology can enable direct, real-time and after-action feedback to the DOTs on the effectiveness of their adverse weather mitigation efforts. As connected vehicle technology becomes widespread in new vehicles, mobile traffic and weather observations data from the vehicles can be captured and used by the DOTs to significantly improve their real-time response to dynamic weather and traffic conditions. Comprehensive real-time feedback could enable DOTs to refine and optimize mitigation measures reliably and on-the-fly, maximizing the efficiency and effectiveness of their available road maintenance resources.

1.1 Document Identification

This project report documents all activities performed and results achieved over the course of development of for the Prototype Road Weather Performance Management (RW-PM) Tool for the project on “Development and Demonstration of a Prototype Road Weather Performance Management Application that Uses Connected Vehicle Data” (RW-PM Tool Project). It is structured to help advance the body of knowledge related to the acquisition and communication of vehicle data and external sensor data that can be used for road weather performance management.

Minnesota DOT (MnDOT) helped deploy the RW-PM Tool and comments from MnDOT are included and discussed as part of the evaluation findings of the assessment of potential impacts of the Road Weather Performance Management Tool (RW-PM Tool) in support of improved road weather response performance during winter weather conditions.

This report concludes with recommendations for improving the prototype to increase its utility for transportation agencies. A program for promoting and transferring the tool to those agencies is also described.

1.2 Road Weather Performance Management Tool Project Overview

Federal Highway Administration's (FHWA's) Road Weather Management Program (RWMP) "seeks to better understand the impacts of weather on roadways, and promote strategies and tools to mitigate those impacts." As part of this vision, the FHWA RWMP is looking at ways to increase the role of connected vehicles in road weather management in order to reach its goal of "Anytime, Anywhere Road Weather Information" [2].

FHWA and FHWA RWMP efforts and the Intelligent Transportation System Joint Program Office's (ITS JPO's) Road Weather Connected Vehicle Applications program both seek to enhance safety and mobility by increasing transportation agencies' awareness of adverse weather and road weather conditions in real-time and supporting the quick restoration of driving conditions. The agencies have worked together to pilot weather-based mobile data integration programs across multiple states as well as to develop applications which utilize mobile data for maintenance decisions support and traveler information.

1.2.1 Goals and Objectives

The objective of the RW-PM Tool project was to apply a Systems Engineering methodology to prototype, test, deploy, and evaluate a Prototype RW-PM Tool that would demonstrate the potential for connected vehicle data to enhance and transform road weather performance measurement and management processes in DOTs' traffic management and RW maintenance operations. The Tool was intended to incorporate multiple fixed and mobile sources (e.g., fixed environmental sensor stations [ESS], connected vehicle mobile sensing devices) of traffic and road weather observations in supporting transportation agencies in performing weather-related traffic management and RW maintenance deployments.

Performance measures important to DOTs can vary based on type and severity of weather events as well as the priorities and constraints faced by each state. The Tool was intended to be scalable and flexible, and able to incorporate a variety of activities and performance measures as parameters for performance management. This project was also intended to provide a mechanism for U.S. DOT to assist DOTs in leveraging connected vehicle technologies and to advance the state-of-the-art in road weather management.

RW-PM methodologies described in this document focused primarily on response to winter weather and snow events. However, the broad RW-PM Tool approach is applicable to other road weather events that degrade highway safety, including fog, dust-storms, and heavy rain.

1.2.2 Project Tasks

The Project was organized into nine primary tasks:

- Task 1. Project Management and Planning
- Task 2. Stakeholder Engagement Plan and State of the Practice Review
- Task 3. Concept of Operations
- Task 4. System Requirements
- Task 5. Prototype Architecture
- Task 6. Prototype Design
- Task 7. Prototype Development and Testing
- Task 8. Prototype Deployment and Evaluation
- Task 9. Final Report, Presentations and Outreach

This report is a deliverable for Task 9, Final Report.

1.2.3 Audience for the Document

The intended audiences for this document are the U.S. DOT and State DOT stakeholders supporting the RW-PM Tool Project.

1.2.4 Participants and Advisors

The project is sponsored by the FHWA Office of Operations and falls within the FHWA Road Weather Management Program. Gabriel Guevara serves as the U.S. DOT Government Task Manager (GTM) with road weather program support provided by Booz Allen Hamilton.

This project was led by Battelle with support from the National Center for Atmospheric Research (NCAR), Venner Consulting, and the Texas A&M Transportation Institute (TTI). This project engaged stakeholders through a combination of participation in industry meetings, webinars, and targeted interviews. Current DOT RW-PM practices are summarized in the Task 2 report, *State of the Practice Review for Development and Demonstration of a Road Weather Performance Management Tool* [3].

Leading DOT stakeholders providing input to the project included:

- Steve Cook (Michigan)
- Tina Greenfield (Iowa)
- Denise Inda (Nevada)
- Dennis Jensen (Idaho)
- Mylinh Lidder (Nevada)
- Sue Lodahl (Minnesota)
- Jakin Koll (Minnesota)
- Denise Markow (New Hampshire)
- Steve Spoor (Idaho)
- Robert White (Vermont)

1.3 Summary of Prototype RW-PM Tool Functions and Benefits

The Prototype RW-PM Tool was designed to deliver substantial improvements and benefits for stakeholders. The RW-PM Tool leverages the latest developments in connected vehicle technology and the expected deployment of connected vehicle technology in new cars. It has capabilities to provide real-time feedback to Traffic Management managers and RW Maintenance managers during dynamic weather events, and allows them to adjust their traffic mobility and road weather controls on-the-fly and to maximize the effectiveness of their limited resources. Functions and potential benefits include the following:

- Integrating traffic mobility and road weather data collection and analysis to support more informed traffic and RW Maintenance management responses to adverse weather conditions.
- Capturing data wirelessly from mobile data sources in real-time and integrating with legacy and fixed data sources to provide a more robust, higher resolution and higher density traffic mobility and road weather data that support more accurate and precise traffic mobility and RW Maintenance decision making by traffic and RW Maintenance management.
- Implementation of real-time data collection, processing, display and messaging to support
    - Better allocation of available RW Maintenance staff, equipment and material resources to maintain mobility, and
    - More timely and targeted deployment of RW Maintenance response to dynamic variations in weather.
- Improvements in deployment of RW Maintenance resources supported by the RW-PM Tool to help
    - Improve traffic mobility during an adverse weather event and
    - Return mobility to normal more quickly following an event.
- Delivery of in-vehicle real-time traffic mobility and road weather information and messaging to drivers to support
    - More informed travel route decisions by drivers,
    - More informed and safer driving decisions by drivers, and
    - Reduce the likelihood of accidents, thereby improving traffic safety and mobility.

1.4 Document Organization

This document consists of the following chapters and content.

Chapter 1. **Project Report Summary** provides a basis, scope, and overview of the project, including a description of goals and objectives, project tasks, document audience, and a list of project participants/advisors. Also included is a summary of the anticipated benefits of the RW-PM tool.

Chapter 2. **Referenced Documents** identifies the external documentation referenced within this document**.**

Chapter 3. **Summary of Results and Deliverables** includes:

- A summary of the Prototype RW-PM Tool, including goals, connected vehicle applications/strategies, outreach and engagement, architecture and design, web and mobile application interfaces and functionality, and acceptance testing results;
- Prototype RW-PM Tool Deployment;
- Prototype RW-PM Tool Evaluation;
- Prototype RW-PM Tool Installation and Implementation; and
- Lessons Learned with Pikalert Integration.

Chapter 4. **Potential Next Generation RW-PM Tool Enhancements** identifies possible enhancements to the Prototype RW-PM tool based on Acceptance Testing findings, Pikalert integration lessons learned, stakeholder input, and RW-PM team connected vehicle development and deployment experience.

Appendix A. **List of Acronyms and Abbreviations** defines acronyms and abbreviations used in the document and project.

Appendix B. **RW-PM Tool Project Description** defined the scope of the project for initial discussions with stakeholders as part of outreach and engagement activities.

Chapter 2 Referenced Documents

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Chapter 3 Summary of Results and Deliverables

3.1 Prototype RW-PM Tool

3.1.1 Summary of Prototype RW-PM Tool Goals

The RW-PM tool helps DOTs improve road weather performance management by:

- Enabling real-time RW-PM data capture, analysis and response;
- Integrating traffic mobility and road weather information for more informed decisions by drivers and by traffic management and RW maintenance personnel;
- Helping refine and optimize road weather response measures; and
- Helping maximize efficiency and effectiveness of available resources.

The Tool utilizes existing data sources as well as data from emerging connected vehicle applications and technologies. The project began with an overview of relevant road weather connected vehicle applications and strategies as described below, along with a stakeholder engagement approach.

3.1.2 Summary of Existing Road Weather Connected Vehicle Applications and Strategies

The U.S. DOT, FHWA, and the ITS JPO have observed that road weather data can be used to enhance many connected vehicle applications and strategies. Including this data in the analysis, modeling, and prediction algorithms of these applications and strategies enhances DOT real-time traveler information and advisories, MDSS strategy and recommendation outputs, EMS response to incidents during weather events, and other maintenance and operation activities.

3.1.2.1 Vehicle Data Translator Applications

In an effort to combine personal vehicle probe data, DOT vehicle probe data, and other weather and road condition data, FHWA RWMP began working with the NCAR to develop the Vehicle Data Translator (VDT) software system. The VDT processes raw vehicle, roadway, and environmental data and conducts quality checks on mobile data observations (e.g., native and/or external) along with additional ancillary weather data (e.g., radar, satellite, fixed observations, and model data) to provide information for end-use applications [4]. The VDT process includes [5]:

- Extracting the necessary vehicle probe data to derive weather and road condition information (e.g., time, location, ambient temperature, windshield wiper status);
- Filtering the data to remove unnecessary or unwanted information;

- Quality-checking the information using other local surface observations and ancillary datasets (i.e., satellites, radar); and,
- Organizing and processing the data for user-defined road segment statistics (precipitation type, precipitation intensity, pavement condition, and visibility).

One use of the VDT is the Integrated Mobile Observations (IMO) project. FHWA developed the IMO project to pilot road weather related applications in three states (Michigan, Minnesota, and Nevada). These applications include the Pikalert®;[1] Enhanced Maintenance Decision Support System (EMDSS), which incorporates connected vehicle technology into the Maintenance Decision Support System (MDSS) and the Pikalert Motorist Advisory Warning (MAW) System which provides hyper-local and rapid-update road weather warnings to the traveling public [5].

- Pikalert EMDSS. The EMDSS, developed by NCAR, incorporates connected vehicle data into the forecast and decision process and can provide forecasts up to 72 hours in advance. The EDMSS ingests data from connected snowplows, agency fleet vehicles, and personal vehicles and uses an agency's decision support system for both weather and pavement forecasts to make snow and ice treatment/control strategy recommendations. Information is provided through a web-based interface (i.e., computer, tablet, or smartphone). Recommendations are pushed to both snowplow operators and agency maintenance vehicle drivers.

  The EMDSS allows users to obtain information along an entire stretch of roadway, and not just at road weather information system (RWIS) sites. This enables maintenance providers to better monitor and react to changing road conditions. Agencies are better equipped to make spot treatments on the road, helping to improve safety and mobility and reduce the environmental impact of de-icing chemicals.

- Pikalert MAW System. The MAW application uses connected vehicle data to provide assessments on visibility, road conditions, and road precipitation to drivers. It also blends the connected vehicle data with a forecast engine to provide 24-hour forecasts of road weather conditions. Information on deteriorating road and weather conditions is taken from connected snowplows, agency fleet vehicles, and personal vehicles. The data is processed and then pushed to travelers as in-vehicle advisories and alerts in near real-time, as well as through web-based user interfaces (computer, tablet, and smartphone). Advisories may either be medium-term (2 to 12 hours away) or long-term (over 12 hours into the future).

  Using the MAW, drivers are able to plan routes in advance of their travel, including knowing which path to take and whether to delay their trip. While on the road, the mobile application keeps drivers abreast of changing road weather conditions.

3.1.2.2 Prototype Intelligent Network Flow Optimization (INFLO) Weather Responsive Traffic Management Applications

The purpose of the Prototype Intelligent Network Flow Optimization (INFLO) Advanced Traffic Management Application is to aggregate Basic Safety Message (BSM) data from vehicles

[1] Pikalert® is a trademark of the University Corporation for Atmospheric Research (UCAR).

approaching a queue and assess it against current traffic, weather, and road surface conditions to determine an optimal harmonized speed to support traffic management decision making to enhance mobility and reduce the likelihood of accidents [6]. INFLO encompasses a number of applications, which include:

- Weather Responsive Dynamic Speed Harmonization (WRTM SPD-HARM): The INFLO WRTM SPD-HARM application aims to maximize throughput and reduce crashes by utilizing infrastructure-to-vehicle (I2V) communication to detect impending congestion that might necessitate speed harmonization; generating appropriate target speed recommendation strategies for upstream traffic; and communicating the recommendations to the affected vehicles using I2V communication. WRTM is implemented *as a subset of the Speed Harmonization Algorithm* in which recommended harmonization speeds may be adjusted based upon road weather conditions. For the purposes of the prototype development, recommended travel speed is based upon visibility and pavement surface conditions. While transportation management agencies will implement reduced travel speed recommendations for low visibility and slick pavement conditions, similar concepts could be used to produce recommended travel speeds based on high wind conditions.
- Queue Warning (Q-WARN): The INFLO Q-WARN application aims to minimize or prevent impacts of rear-end or secondary collisions by utilizing I2V and vehicle-to-vehicle (V2V) communication to detect existing queues and/or predict impending queues and communicate advisory queue warning messages to drivers in advance of roadway segments with existing or developing vehicle queues. The Q-WARN concept reflects an operational environment in which two essential tasks are performed: queue determination (detection and/or prediction) and queue information dissemination. In such an environment, the Q-WARN application may reside in the vehicle or within an infrastructure-based entity, or utilize a combination of both. The queue warning messages may either be communicated by the infrastructure-based entity using I2V communication or broadcast by vehicles that are in a queued state to nearby vehicles and infrastructure based entities.

3.1.2.3 Weather Response Traffic Management Strategies

Weather-Responsive Traffic Management (WRTM) involves the implementation of traffic advisory, control, and treatment strategies in direct response to, or in anticipation of, developing roadway and visibility issues that result from deteriorating or forecasted weather conditions. WRTM uses weather forecasting to provide proactive advisories and control strategies prior to the impacts of those conditions on traffic. WRTM is not a single strategy; rather, it is a combination of techniques, tools, and systems that transportation authorities can use for mitigating the impacts of weather on their operations. Following are some specific WRTM strategies [7]:

- Variable Speed Limits (VSL) for Weather-Responsive Traffic Management. VSL for WRTM uses road weather information from connected vehicles as well as current and historical data from other sources to determine the appropriate current safe speed. The application provides real-time information on the optimal safe speeds for current conditions and it warns drivers of impending road conditions. The information comes from either public or commercial vehicles [7].
- Weather Responsive Active Traffic Management. Weather Responsive Active Traffic Management (ATM), a WRTM strategy, is the use of ATM techniques for active

weather management. Strategies can be used to counter the effects of lost capacity and reduced operating speeds during inclement weather. Strategies like speed harmonization can be used to reduce the maximum posted speed limits based on snow, ice, wind, or other weather conditions. DMS can be used to implement truck prohibitions or restrict trucks to specific lanes on a freeway to separate slow moving vehicles from vehicles not impacted by the weather conditions. Lane control signals can also be deployed to provide travelers with end of queue warnings and lane closure information. Generally, these strategies are implemented at the request of police, emergency management, or maintenance personnel [7].

- Weather Responsive Traffic Signal Management. The weather responsive traffic signal management application, a WRTM strategy, takes information about roadway surface and weather conditions in real-time, and determines the optimal changes to traffic signal timing and intersection detector settings to improve traffic flow and safety during inclement weather conditions. These new settings are sensitive to the changes in vehicle operating characteristics caused by adverse weather. The vision for this strategy is to better match signal timing plans and parameters to the prevailing travel conditions to promote more efficient traffic operations and reduce the potential for weather related vehicle crashes [7].
- Seasonal Weight Restrictions. Seasonal Weight Restrictions, a WRTM strategy, is intended to provide decision-support to DOT roadways subject to freeze/thaw conditions. The decision-support capability uses atmospheric weather information, road surface information and any sub-surface information as inputs into a forecasting model to predict thaw, freeze depth, and the resiliency of the pavement. The goals of the strategy are to: allow State decision makers to more effectively determine when to place and remove load restrictions, preserving both the pavement integrity and commercial vehicle operator productivity; increase the level of confidence in restriction decision-making process; improve coordination and consistency between jurisdictions during load restriction season; and, improve communications and notifications to commercial operators about restriction placement and removal [7].
- Weather Responsive Traveler Information. The weather responsive traveler information application, a WRTM strategy, takes both real-time and forecasted road weather conditions in a region to predict roadway travel conditions. Information about predicted travel conditions would be used to provide travelers with estimates of what travel conditions would be like at a future time. The goal is to use this information to influence both pre-trip and en-route mode, route, and departure time decisions [7].

3.1.2.4 Other Potential Road Weather-Based Connected Vehicle Applications

The section below summarizes potential road weather-based connected vehicle application for which Concept of Operations have been developed [8, 7].

- Information for Maintenance and Fleet Management Systems. The Road Weather Information for Maintenance and Fleet Management Systems Application can be viewed as either a stand-alone application or as an adjunct to the EMDSS. Vehicle data is collected from winter maintenance vehicles and from other maintenance vehicles and equipment used all year. Data collected includes road weather data as well as specialized maintenance information such as status of vehicle systems, material distribution rate, and materials remaining. The data can be used by maintenance or fleet dispatchers to monitor the status of the maintenance operations, or as an input to the EMDSS [8].

- Information for Freight Carriers. The Road Weather Information for Freight Carriers application is a special case of the MAW application focused on Freight Carrier users. It collects road weather data from connected vehicles and uses the data to develop short term warnings or advisories for individual commercial vehicles or commercial vehicle dispatchers. The information may be collected from public vehicles, specialty vehicles, and/or public fleet vehicles. The raw data is processed to generate road segment-based data outputs. Short time horizon alerts are pushed to user systems and available to commercial vehicle dispatchers [8].
- Information and Routing Support for Emergency Responders. The Road Weather Information and Routing Support for Emergency Responders application collects road weather data from connected vehicles and other sources and develops short-term warnings or advisories for individual emergency response vehicles or to emergency response dispatchers. The information may come from either public vehicles, specialty vehicles, and/or public fleet vehicles. The raw data is processed to generate road segment-based data outputs. Short time horizon alerts are pushed to user systems and available to emergency response dispatchers. These alerts include information on high winds, standing water, and flooding of roadways [8].

3.1.3 Stakeholder Outreach Summary and Engagement Approach

The Battelle Team[2] engaged stakeholders through a combination of participation in industry meetings and webinars and of targeted interviews. The Battelle Team facilitated that involvement in several ways, including seeking and encouraging their involvement. Those opportunities to hear and discuss with practitioners fed into the *Prototype Road Weather Performance Management Tool Evaluation Report* [9].

Due to the Paperwork Reduction Act, the Battelle Team was allowed to perform no more than 9 State DOT interviews for the project; however, a variety of means and networks were utilized to broadly reach out to stakeholders, leveraging industry contacts. The team:

- Provided the project description to stakeholders (see Appendix B)
- Leveraged stakeholder engagement meeting opportunities
- Compiled a stakeholder contact list for review and use
- Conducted targeted interviews
- Reported on tasks

To introduce the RW-PM Tool project to stakeholders, the Battelle Team assembled a one-page summary description of the project shown in Appendix B. This summary was distributed to stakeholders as part of introducing the program and prior to engaging in interviews.

The following is an overview of opportunities that the Battelle Team used to engage with stakeholders and learn more of their needs.

[2] The Battelle Team includes Venner Consulting, National Center for Atmospheric Research (NCAR) and the Texas A&M Transportation Institute (TTI).

3.1.3.1 Road Weather Management Stakeholder Meeting

U.S. DOT's Road Weather Management Meeting generally occurs once a year and offers valuable opportunities to hear from a number of practitioners concerning their RWIS and weather-related maintenance and operations performance management activities. The 2014 Road Weather Management Stakeholder Meeting occurred just after Battelle received notice of award of the RW-PM Tool project. Ms. Venner attended this meeting and participated in a number of valuable conversations with practitioners, as well as collected information for the *State of the Practice Review for Development and Demonstration of a Road Weather Performance Management Tool* [3]. Lead states and prospects were identified for later phases of the project including Iowa, Idaho, Michigan, Minnesota, Utah, and Wisconsin, among others.

3.1.3.2 Transportation Research Board (TRB) Maintenance and Operations Webinar

Battelle team member Marie Venner introduced the RW-PM Tool project to potentially interested stakeholders as part of a TRB webinar (held on October 2, 2014) titled: *Maintenance and Operations Resilience: Improving System Management and Performance during Adverse and Extreme Weather Events* [10]. See Appendix A of the *Road Weather Performance Management Tool Updated Stakeholder Engagement Plan* [33] for an agenda of the webinar. The program for the webinar was developed and participants were identified to share and profile leading DOT road weather performance management approaches, and to gather initial DOT input in support of the project.

To achieve maximum outreach, the webinar utilized the TRB webinar system, which is free to all DOTs and government agencies and can be utilized to profile cutting edge research and best practices, such as weather-related DOT performance in maintenance and operations and identifying how/which maintenance and TSM&O activities can be employed to achieve targets. Further description and objectives of this webinar are included in Appendix A of the *Road Weather Performance Management Tool Updated Stakeholder Engagement Plan* [33].

Presenters included a geographic range of DOTs (e.g., not just winter maintenance issues) and profile DOTs that are leaders in the integration of maintenance, operations, and performance measurement. These presenters included:

- Steve Cook, Michigan DOT
- Jakin Koll and Sue Lodahl, Minnesota DOT
- Steven Olmstead, Arizona DOT
- Rukhsana Lindsey, Utah DOT

Following presentations given on transportation agency best practices, Ms. Venner introduced the RW-PM Tool project and explained that the team was looking to:

- Gather Input from State DOT stakeholders on:
  - Their needs and metrics for gauging performance in adverse weather-related maintenance and operations.
  - How connected vehicle data can be employed in adverse weather-related TSM&O activities to achieve targets.
- Conduct a State-of-the-Practice Review

- Review existing performance measurement and management programs and tools related to road weather in the states.
- Identify road weather performance measurement and management activities that can benefit from connected vehicle data
- Describe implementation through existing and prospective performance management tool(s).

Ms. Venner used this opportunity to invite and solicit identification of stakeholders, verbally and via TRB's chat system for attendees, who were interested in:

- Receiving occasional updates on the project developments.
- Helping the Battelle Team gather information on the state-of-the-practice in performance measurement and management activities related to road weather.
- Being interviewed by telephone to help the Battelle Team understand needs and metrics for gauging performance in maintenance and operations and how connected vehicle data can be employed in to achieve targets.

The information presented in this webinar was rolled into the *State of the Practice Review* [3] and leveraged in development of the *Prototype Road Weather Performance Management Tool Concept of Operations* [11].

3.1.3.3 American Association of State Highway and Transportation Officials (AASHTO) Subcommittee on Transportation Systems Management and Operations (STSMO)

The AASHTO Subcommittee on Transportation Systems Management and Operations (STSMO) is the State DOT group that appeared to have more connection to and interest in connected vehicles than any other. The STSMO previously hosted a series of webinars on connected vehicles. In the first webinar, Bob Arnold and Jonathan Walker from the Federal Highway Administration (FHWA) gave a presentation on Connected Vehicles 101. Topics included an introduction to the connected vehicle environment, connected vehicle applications, connected vehicle testing and deployment, and policy and institutional issues.

As the STSMO Technical Working Group on Performance Measures meets quarterly by conference call, Ms. Venner coordinated with Patrick Zelinski of AASHTO to introduce the RW-PM Tool project in a conference call on September 18, 2014. While supportive, feedback from this group was limited. While road weather mitigation is a consideration for this group, it is incorporated in more broad congestion mitigation measures.

3.1.3.4 American Meteorological Society (AMS) and TRB Annual Meetings in January 2015

Brenda Boyce, a Booz Allen Hamilton support contractor for the Road Weather Management Program, included the RW-PM Tool Project in her presentation at the January 2015 AMS Annual meeting and solicited comments and questions.

Battelle Team members attended project-related presentations at the January 2015 TRB Annual meeting presentation and attempted to interface parties with potential interest in the RW-PM Tool.

3.1.3.5 RW-PM Tool Stakeholder Working Group

As the concepts for the RW-PM Tool began to take shape, the Battelle Team agreed that it would be valuable to recruit and engage a stakeholder working group to provide direct feedback on the RW-PM Tool concepts and strategies. U.S. DOT issued a request for participation in the stakeholder group to State DOTs with a keen interest in the topic and a history of support for road weather research. The following representatives and states agreed to support the effort.

- Steve Cook (Michigan)
- Tina Greenfield (Iowa)
- Denise Inda (Nevada)
- Dennis Jensen (Idaho)
- Mylinh Lidder (Nevada)
- Sue Lodahl (Minnesota)
- Jakin Koll (Minnesota)
- Denise Markow (New Hampshire)
- Steve Spoor (Idaho)
- Robert White (Vermont)

These stakeholders participated in the following webinars:

- RW-PM Tool Concept Review and Discussion – April 30 and May 7, 2015 (two sessions of the same presentation to support availability of stakeholders)
- RW-PM Tool Concept of Operations Walk Through – June 30, 2015

The comments and feedback received from these webinars were incorporated in the revision and enhancement of the *Prototype Road Weather Performance Management Tool Concept of Operations* [11].

Following the initial deployment of the RW-PM Tool, these stakeholders participated in a webinar and live demonstration of the RW-PM Tool on December 1, 2015. Comments made were captured and were reflected within the *Prototype Road Weather Performance Management Tool Evaluation Plan* [12].

3.1.3.6 RW-PM Tool Stakeholder Evaluation Webinars

In addition to the stakeholder engagements described above, focus groups were conducted at several points throughout the 2015-2016 winter season to gather input from involved stakeholders, including the Minnesota DOT (MnDOT), RW-PM Tool stakeholders, and the FHWA RW-PM Tool team. These focus groups were conducted in conjunction with webinars to be organized at the beginning of the 2015-2016 winter season, and during select weather events in February-March 2016. These focus groups allowed a targeted discussion on the potential benefits a fully developed and implemented tool might provide, based on the prototype outputs.

3.1.3.7 Outreach Presentations

As part of its ongoing outreach support, the project team provided outreach presentation materials to U.S. DOT, and offered to make outreach presentations where invited. Key outreach presentations were:

- U.S. DOT Dynamic Mobility Applications Webinar Series – May 4, 2015
- 3rd National Weather Responsive Traffic Management (WRTM) Meeting, October 20, 2015, Kansas City, Missouri
- 2016 Road Weather Management Stakeholder Meeting, June 28-30, 2016, Atlanta, Georgia

3.1.4 Prototype RW-PM Tool Conceptual Design

3.1.4.1 Prototype RW-PM Tool Concept

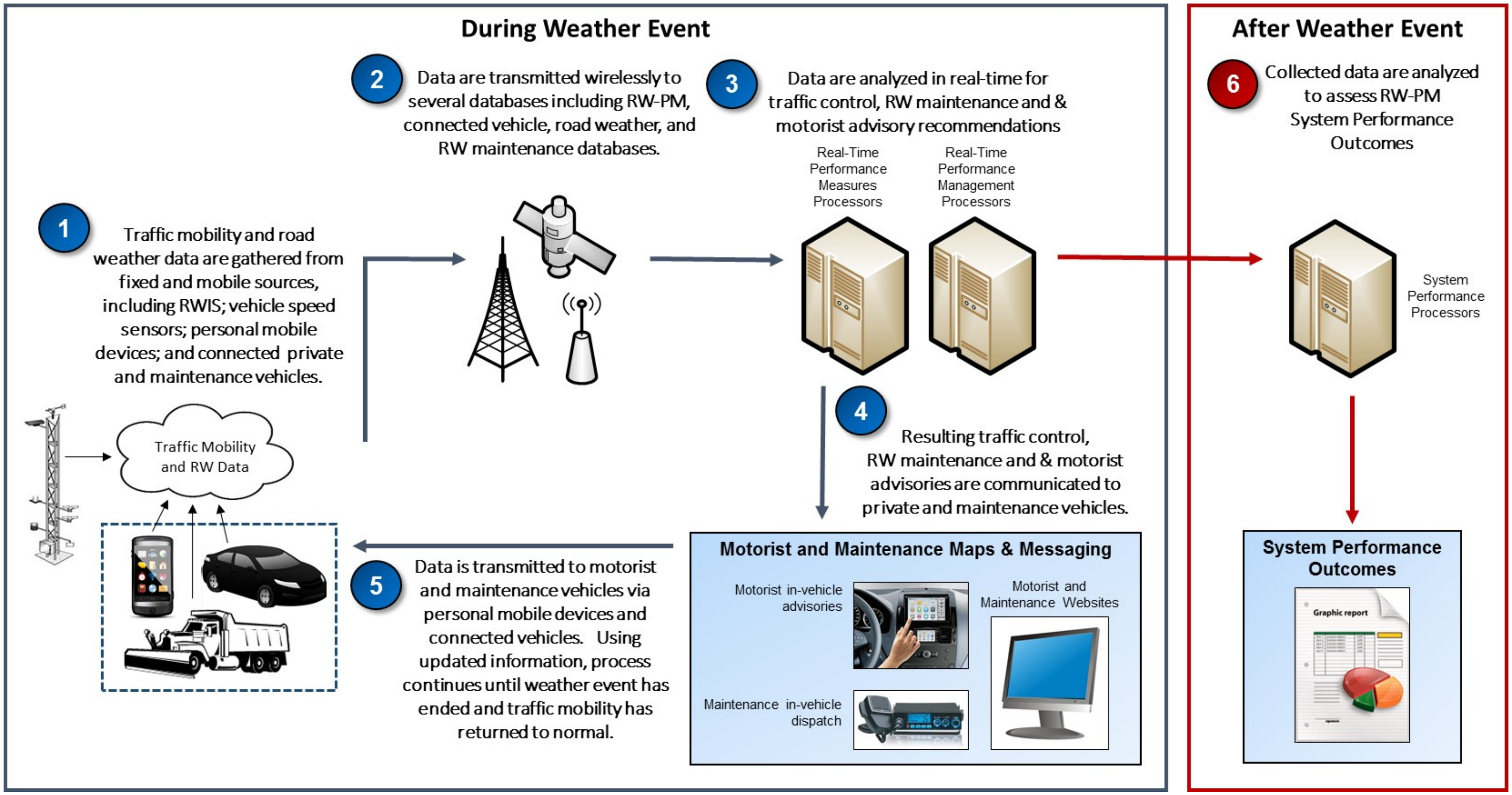
The RW-PM Tool Design is illustrated in Figure 3-1. The tool captures and analyzes applicable traffic mobility and road weather data continuously from multiple sources, shown as Item 1 in the figure. This includes capturing road weather data from fixed weather stations (e.g., environmental sensor stations) and traffic mobility data from fixed speed sensors (e.g., inductive loop detectors) and/or subscription services. The Tool is capable of capturing data from mobile sources such as RW maintenance vehicles[3] and connected vehicles. As illustrated in Item 2, the data are transmitted wirelessly and are stored in suitable traffic mobility, road weather, and RW-PM databases.

The captured raw data are next analyzed by multiple processors operating in parallel and in near real-time (Item 3). One set of processors analyzes the raw data to compute local real-time traffic mobility and road weather performance “measures and metrics” and stores them in a “measures and metrics” database. Another set of processors analyzes the raw data and performance measures and metrics to develop real-time traffic management, RW maintenance deployment and motorist advisory recommendations. Traffic management and RW maintenance personnel are alerted when DOT criteria for a weather event likely to degrade traffic mobility are met. Upon verification and authorization by the appropriate personnel (Item 4):

- Traffic management and RW maintenance deployment recommendations are deployed to traffic management and RW maintenance systems;
- Motorist traffic management and road weather advisories are deployed to connected vehicles; and
- RW maintenance deployment information and messages are issued to connected maintenance vehicles.

This process continues iteratively throughout the weather event (Item 5), adjusting dynamically until the weather event concludes, the roads are cleared, and traffic mobility returns to normal. Following the event, system performance processors aggregate the data, measures, and metrics and assess performance and effectiveness outcomes for the entire event (Item 6). The outcomes are then used by traffic management and RW maintenance personnel to refine and optimize RW-PM strategies for implementation in responding to future weather events. System performance is evaluated seasonally and/or annually and strategies are updated to enhance seasonal and annual performance.

[3] For the purposes of this document, the term “RW maintenance vehicle” is used as a generic term to describe winter maintenance vehicles such as snowplows and salt treatment trucks. While this implementation of the prototype RW-PM Tool is focused on winter weather events, the concepts may be applied to other adverse weather events that affect traffic such as such as heavy fog or flooding. Hence, generic terms are used where possible to support broad applicability.



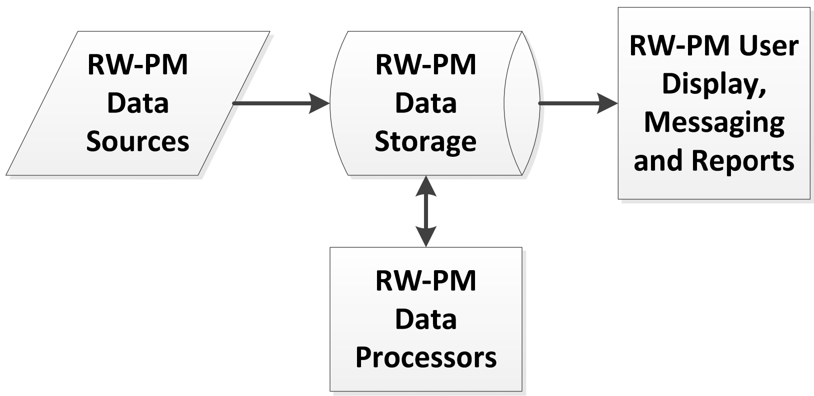
Source: Battelle

Figure 3-1. Illustration of the RW-PM Tool Design

3.1.4.2 Prototype RW-PM Tool Conceptual Architecture

Figure 3-2 provides a high-level illustration of the four primary components of the RW-PM Tool Design that support the described concept.

- RW-PM Data Sources
- RW-PM Data Storage
- RW-PM Data Processors
- RW-PM User Displays, Messaging, and Reporting



Source: Battelle

Figure 3-2. Conceptual Architecture of the Prototype RW-PM Tool

The **RW-PM Data Sources** block represents multiple fixed and mobile sources of traffic mobility and road weather data that will be used for the RW-PM Tool.

The central element of the Tool is **RW-PM Data Storage**. The RW-PM Tool will collect, process and distribute substantial amounts of data, information and messages. Conceptually, RW-PM Data Storage is a central repository for data inputs collected from sources, for the data outputs from processors, and for messages and information to be displayed to users upon request. While shown above as a single entity, RW-PM Data Storage will house a variety of traffic mobility, road weather, and RW-PM data which may be spread across multiple databases on multiple platforms.

The **RW-PM Data Processors** block represents processors which perform calculations and processes on the collected data and return information and messages for distribution to end users. These include the:

- *Real-time Performance Measures Processors* which compute RW-PM measures and metrics from raw data and posts them in the databases.
- *Real-time Performance Management Processors* which assess the measures and metrics from the Performance Measures Processors and returns traffic management, RW maintenance deployment, and motorist advisory recommendations to the database.
- *System Performance Outcome Processors* which aggregate and assess the data, measures and metrics from the Performance Measures Processors and deliver event, seasonal and yearly performance reports for analysis and processing.

The **RW-PM User Display, Messaging, and Reports** block represents five types of user outputs envisioned for the tool: motorist information website (map view), motorist in-vehicle advisories via connected vehicle display, RW maintenance deployment website (map view), RW maintenance in-vehicle messaging, and system performance outcome reporting.

From a Systems Engineering perspective, the Prototype RW-PM Tool is a "system of systems". Each of these boxes represents multiple systems or subsystems that are integrated to support the RW-PM needs of a DOT. These systems or subsystems often exist as part of other projects. More background on the development of the RW-PM Tool concept may be found in the *Prototype Road Weather Performance Management Tool Concept of Operations* [11].

3.1.5 Prototype RW-PM Tool Architecture and Design

3.1.5.1 Prototype RW-PM Tool Prototype Functional Architecture for Implementation

Figure 3-3 shows the system-level architectural diagram for the Prototype RW-PM Tool, organized by functional system and subsystem, with arrows indicating the direction of information flows between the primary components. The three primary components being developed in this project are the

- RW-PM Tool Processing Platform,
- RW-PM Tool Mobile Application (residing on the Connected Vehicle Application Platform), and
- RW-PM Tool Website with User Interfaces.

The functional architecture shown in Figure 3-3 illustrates the design implementation planned for the current project. The tool captures data from DOT road weather and traffic mobility sensor systems. Outputs are displayed through Web interfaces and the RW-PM Tool Mobile Application residing on the Connected Vehicle Application Platform. Each of these components is described in more detail below.

This implementation is for DOTs for which the RW-PM Tool operates in parallel with existing DOT systems. This implementation is also for DOTs which capture RW maintenance vehicle data as an external data source. The *Prototype RW-PM Tool System Architecture and Requirements* [24] document provides an illustration of a Prototype RW-PM Tool implementation in which the RW-PM Tool is integrated with existing DOT information systems.

Background on the concepts behind this architecture and its elements is provided in the Prototype RW-PM Tool ConOps [11] and System Architecture and Requirements [24] documents. Background on current practices in road weather performance management is provided in the *State of the Practice Review for Development and Demonstration of a Road Weather Performance Management Tool* [3].

3.1.5.2 Prototype RW-PM Tool Component Descriptions

RW-PM Tool Processing Platform – Computational platform which supports the data processing and data storage resources required to support the Prototype RW-PM Tool. This platform supports the following functional subsystems:

- **Data Collection Subsystem** – RW-PM Tool subsystem that provides the interfaces for collecting relevant real-time data from fixed and mobile traffic mobility and road weather data sources. This data may come from connected vehicles, from DOT RW maintenance vehicles, from infrastructure-based sensor systems (i.e. RWIS), and/or from public or private external data sources. This subsystem collects the data and stores it in the Data Storage Subsystem for use by various processors.

- **Recommendation Dissemination Subsystem** – RW-PM Tool subsystem that manages the deployment and distribution of traffic management, RW maintenance and motorist advisory recommendation information to DOT personnel and motorists.
- **Data Storage Subsystem** – Data repository for both short-term and long-term storage of RW-PM Tool data including storage of raw traffic mobility and road weather data collected from fixed and mobile data sources, traffic mobility and road weather metrics and measures, and traffic management, RW maintenance, and motorist advisory recommendations. The subsystem also includes long-term storage of data and information needed to assess system performance outcomes.
- **Performance Measures Processor Subsystem** – Processors which aggregate raw data from data sources and compute RW-PM Tool traffic mobility and road weather performance measures and metrics[4] by road segment and stores them in appropriate databases in the Data Storage Subsystem.
- **Performance Management Recommendation Subsystem** – Processors which assess the performance measures and metrics generated by Performance Measures Processors and generates traffic management, RW maintenance deployment, and motorist advisory recommendations and stores them in appropriate databases in the Data Storage Subsystem.
- **System Performance Outcome Processor Subsystem** – Processors which aggregate and assess the raw data, performance measures and metrics, and performance management recommendations and then generate seasonal and yearly performance reports for assessment by Traffic Management, RW maintenance and DOT Management. These results can be used by state DOT leadership teams to update strategies for response to future events. This element also supports the evaluation element of the RW-PM Tool project.
- **RW-PM Tool Administrative Subsystem** – Processors for administration, management, maintenance, access control and security of the RW-PM Tool.

Connected Vehicle Application Platform – Computational and communications platform upon which the RW-PM Tool Mobile Application operates. The platform may be installed in a vehicle permanently or temporarily. For this implementation, an Android smartphone is used as the Connected Vehicle Application Platform. The Connected Vehicle Application Platform provides the following interfaces:

- **Motorist Advisory Interface** – Displays traffic management and road weather information from the RW-PM Tool to the driver.

[4] For this investigation, *performance measures* are considered concrete or objective traffic and road weather attributes that can be captured from sensors, such as vehicle speed. The term "measures" is also considered to include statistical summaries of individual measures, such as average traffic speed. Measurable road weather quantities such as water depth, snow depth or road surface friction coefficient and other similar attributes are also considered to be measures. *Performance metrics* are the parameters that DOTs use to judge the effectiveness of their RW-PM strategies. Performance metrics are typically more subjective traffic mobility and road weather attributes that are computed from measures. Examples of metrics include "time to regain bare-lane driving conditions" also known as Bare Lane Regain Time or "time until traffic is restored to within 10 MPH of its normal speed" also known as Regain Time.

- **Connected Vehicle (CV) Communications Interface** – Exchanges relevant data wirelessly with the RW-PM Tool Processing Platform via cellular communications[5].
- **Vehicle Mobility Data Interface** – Captures vehicle location, speed and heading data from the Connected Vehicle Application Platform GPS system and sends that data to the RW-PM Tool through the CV Communications Interface.
- **Vehicle Road Weather Data Interface –** Captures vehicle road weather data from the vehicle controller area networks (CAN) and sends that data to the RW-PM Tool through the CV Communications Interface.

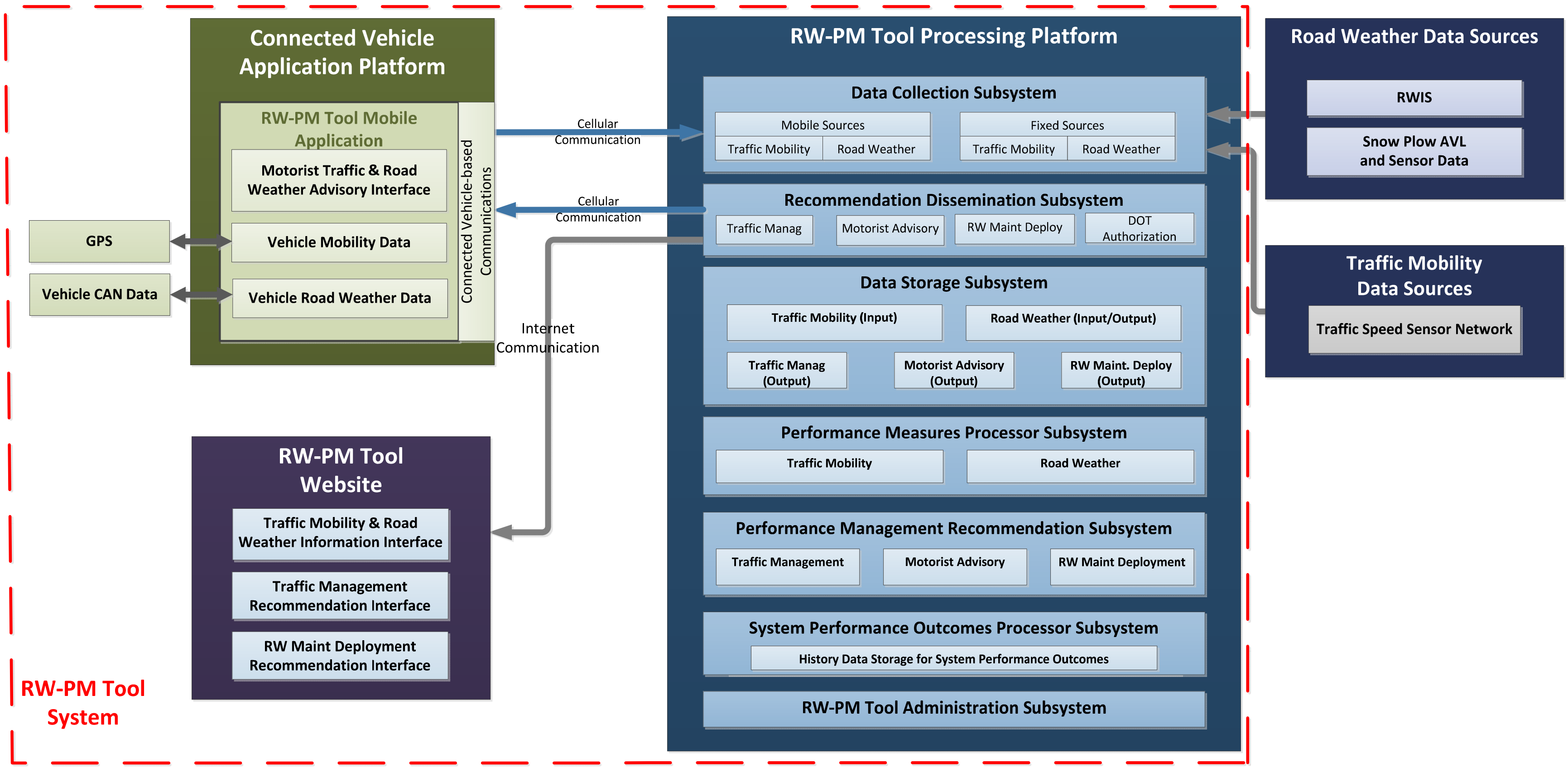
RW-PM Tool Website – Website through which the RW-PM Tool deploys traffic mobility and road weather information to DOT personnel and to motorists. Website through which DOT personnel authorize deployment of Traffic Management and RW Maintenance Deployment recommendations. The Website includes the following subsystems:

- **Traffic Mobility and Road Weather Information Interface** – Displays integrated traffic mobility and road weather information to DOT personnel and motorists.
- **Traffic Management Recommendations Interface –** Displays traffic mobility information and Traffic Management Recommendations for authorization by DOT personnel to deploy recommendations.
- **RW Maintenance Deployment Recommendations Interface** – Displays road weather information and RW Maintenance Deployment Recommendations for authorization by DOT personnel to deploy recommendations.

External Road Weather Data Sources – RW-PM Tool Interface for collection of data in real-time from existing DOT fixed and mobile road weather sensors and other measurement equipment. This includes road weather data accessed through Road Weather Information System (RWIS) and data captured from road weather sensors mounted on RW Maintenance Vehicles (e.g. snowplows).

External Traffic Mobility Data Sources – RW-PM Tool Interface for collecting data from external public and private traffic mobility data storage entities. Examples of external public traffic mobility data sources include DOT websites providing real time speed detector data containing volume, occupancy, speed and flow data. Examples of potential external private data sources that a DOT may consider include INRIX [30], Google Traffic [31], and WAZE [32].

[5] Connected vehicle communications will be implemented in this prototype using cellular communications to leverage its existing infrastructure. Future implementations could implement DSRC for this interface when a DSRC communications infrastructure is available.



Source: Battelle

Figure 3-3. RW-PM Tool Functional Architecture

3.1.5.3 Prototype RW-PM Tool Design Implementation of Traffic Management and RW Maintenance Strategies

As outlined above and in the *Prototype RW-PM Tool ConOps* [11], the RW-PM Tool is a process intended to support optimization of a DOT's response to adverse weather conditions. The Tool may use different strategies for traffic management and different strategies for RW maintenance, depending upon the nature of adverse weather and the needs of the DOT. The specific strategies are selected by the DOT responsible for maintaining traffic mobility to best suit their weather environment and their operational constraints. For the purposes of this prototype development project, Battelle has proposed to implement the Prototype Intelligent Network Flow Optimization (INFLO) weather responsive traffic management dynamic speed harmonization (WRTM SPD-HARM), and queue warning (Q-WARN) applications for Traffic Management Recommendations and for Motorist Traffic Advisories.

Battelle used the National Center for Atmospheric Research (NCAR) Pikalert Enhanced Maintenance Decision Support System (EMDSS) application for RW Maintenance Recommendations and the Pikalert Motorist Advisory and Warning Application for Motorist Road Weather Advisories. Motorist Advisories from both INFLO and Pikalert will be shown to drivers in a combined display. The design, development, testing, deployment and field demonstration of INFLO applications are described in References [13, 16, 18, and 25] and Pikalert applications are described in Reference [26].

INFLO and Pikalert are standalone application bundles which respectively support traffic management and RW maintenance deployment. They each have their own Data Storage, Performance Measures, and Performance Management Recommendation Subsystems. Rather than break them up, INFLO and Pikalert are treated as "black boxes" in this RW-PM Tool implementation, as illustrated in Figure 3-4. The RW-PM Tool Data Collection Subsystem collects relevant input data and inputs it into INFLO and Pikalert applications. The INFLO WRTM SPD-HARM application uses Pikalert road weather hazard and alert information as inputs for vehicle speed recommendations.

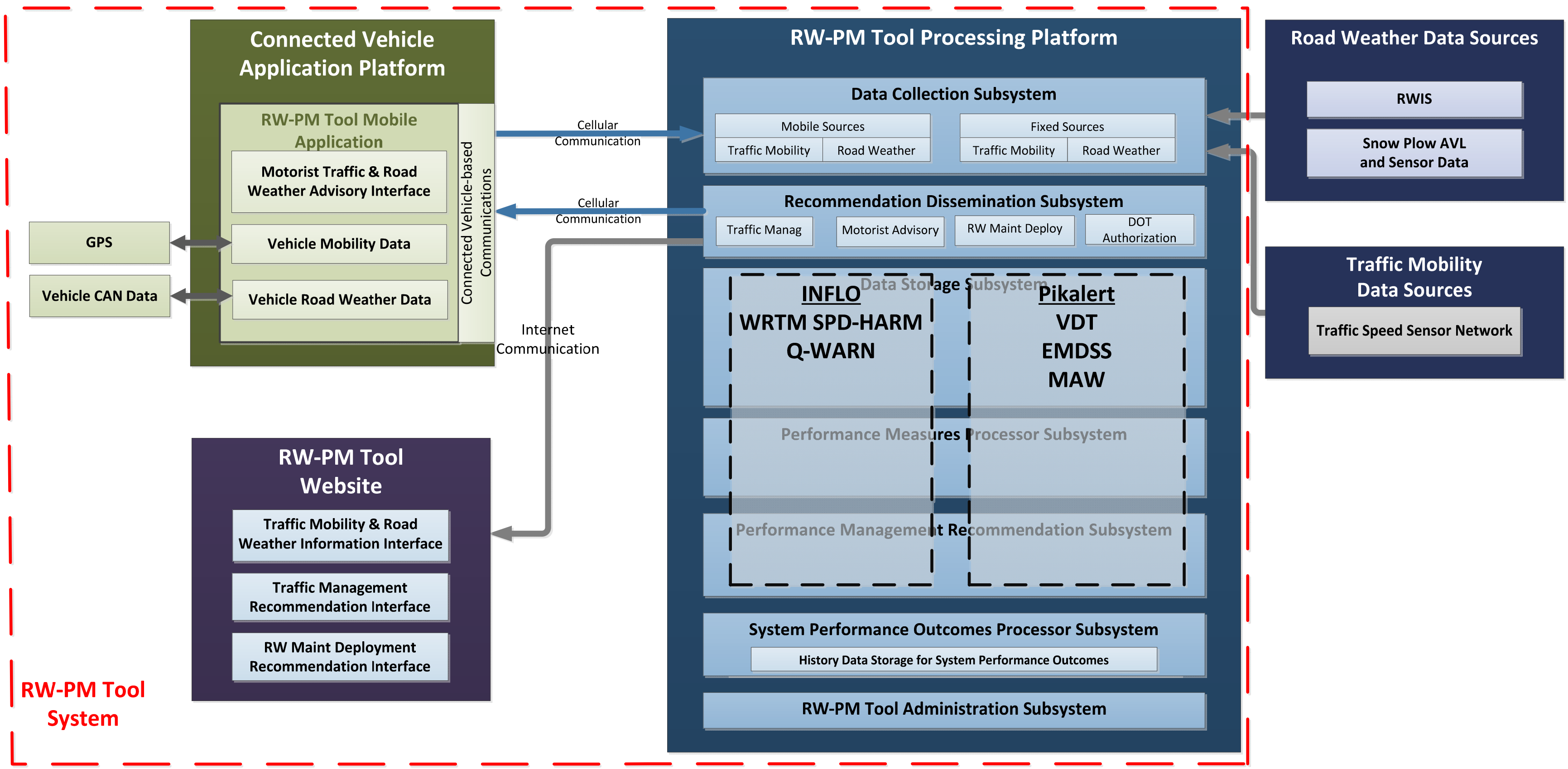
User outputs from the INFLO and Pikalert applications are captured by the Recommendation Dissemination Subsystem and are deployed to Traffic Mobility & Road Weather Information, Traffic Management Recommendation, and RW Maintenance Recommendation interfaces, summarized in Table 3-1. The RW-PM Tool Mobile Application will display text and icon-based Traffic Management and Road Weather Advisories. The Motorist Website will display map-based traffic mobility and road weather information. The DOT Website will display Traffic Management and RW Maintenance Deployment recommendations for approval prior to deployment.

Table 3-1. Prototype RW-PM Tool Output Displays

Display	User	Display Type	Display Content	Information Sources
Motorist Traffic & Road Weather Advisory Interface	Motorist	Connected Vehicle Application Platform	Advisory Text and Icons	• Traffic Management Advisories from INFLO • Road Weather Advisories from Pikalert
Traffic Mobility & Road Weather Information Website Interface	Motorist & DOT Personnel	Webpage	Map Overlay	• Traffic Mobility Map from Google Maps Traffic & DOT Speed Sensor Overlay • Road Weather Conditions from Pikalert MAW Overlay on Map
DOT Traffic Management Recommendation Web Interface	DOT Personnel	Webpage	Map Overlay	• INFLO Traffic Management Recommendation Overlay on Map with Accept/Decline/Edit
DOT RW Maintenance Recommendation Web Interface	DOT Personnel	Webpage	Map Overlay	• Pikalert RW Maintenance Recommendation Overlay on Map with Accept/Decline/Edit

Source: Battelle

The following section details the Prototype RW-PM Tool Process using INFLO as the Traffic Management Performance Management Subsystem and Pikalert as the RW Maintenance Performance Management Subsystem.



Source: Battelle

Figure 3-4. Prototype RW-PM Tool Functional Architecture Illustrating Implementation of INFLO and Pikalert Applications as Black Boxes

3.1.5.4 Prototype RW-PM Tool Flowchart

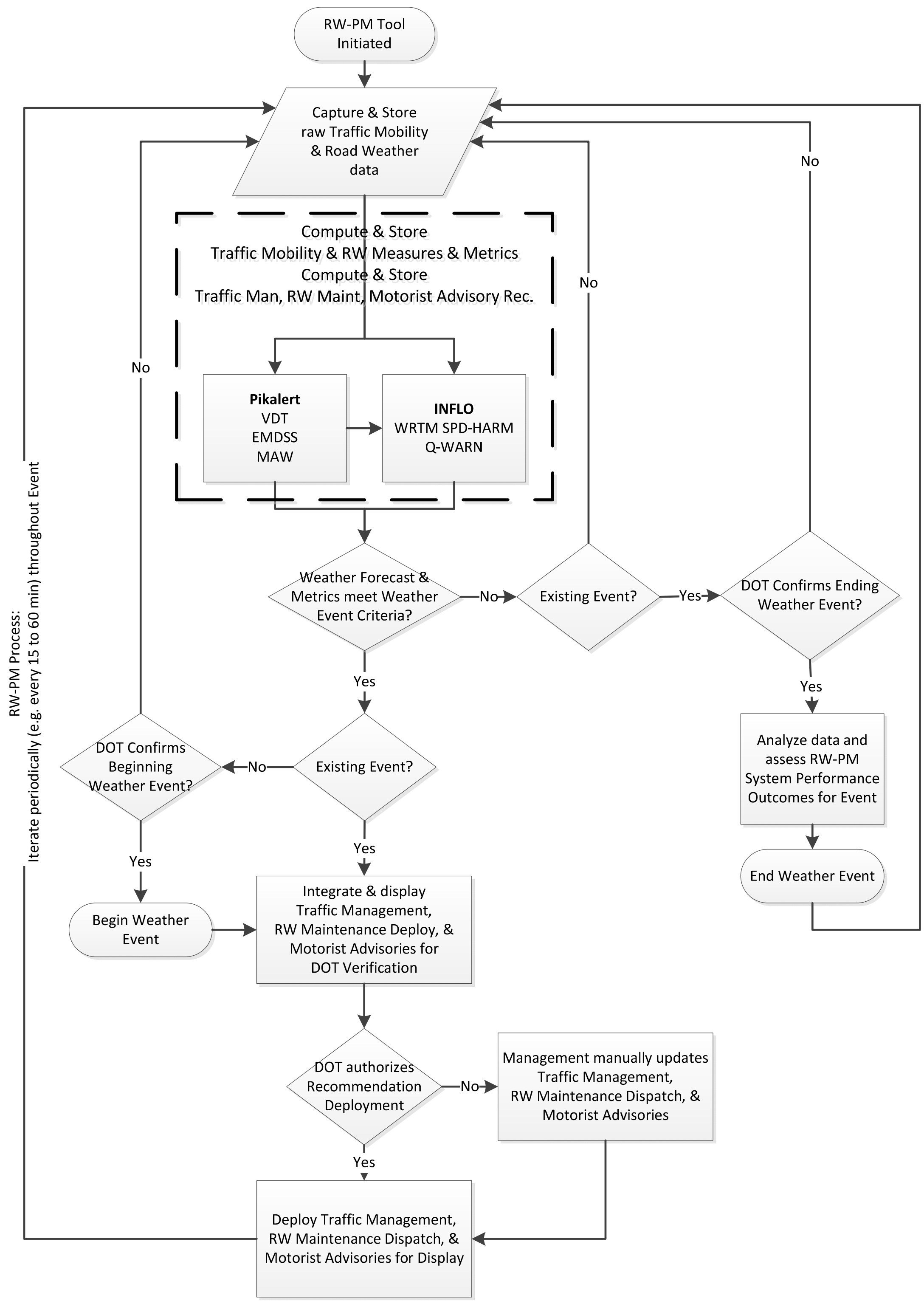
Figure 3-5 illustrates the flow of information processing and Prototype RW-PM Tool decision making during an adverse weather event. Following is a discussion of the steps outlined in the diagram.

- The RW-PM Tool is initiated by the DOT and then runs on continuously collecting and processing traffic mobility and road weather data from multiple fixed and mobile sources. Data are stored in RW-PM databases.
- The raw data are analyzed by the Pikalert and INFLO Real-time Performance Measures Processor to generate updated RW-PM measures and metrics and post them in databases.
- The RW-PM measures and metrics are analyzed by the Pikalert and INFLO Performance Management Recommendations Processors as follows:
    - The INFLO WRTM SPD-HARM Traffic Management Processor generates speed harmonization recommendations and the Q-WARN Processor generates queue warning information and motorist traffic advisories.
    - The Pikalert EMDSS RW Maintenance Processor generates RW maintenance deployment recommendations.
    - The Pikalert MAW generates road weather information and motorist road weather advisories.
    - The Motorist Advisory Processor integrates INFLO WRTM SPD-HARM and Q-WARN traffic management and Pikalert MAW road weather advisories and displays them to the motorist.
- The traffic mobility and road weather measures and metrics data are analyzed by the RW-PM Tool to determine whether the measures and metrics meet the RW-PM Tool Adverse Weather Event Activation thresholds.
- If an *Event is not in progress* and the *thresholds are met*, the Tool will advise DOT personnel of the potential beginning of an Adverse Weather Event[6].
    - If DOT personnel confirm beginning the Adverse Weather Event, then the RW-PM Tool notes the beginning time and proceeds with display of Traffic Management and RW Maintenance Recommendations to DOT personnel for verifications.
    - If DOT personnel do not confirm beginning the Adverse Weather Event, the Tool will return and continue to capture and process traffic mobility and road weather data, notifying DOT personnel when thresholds are met.
- If an *Event is not in progress* and the *thresholds are not met*, the Tool will return and continue to capture and process traffic mobility and road weather data, notifying DOT personnel when thresholds are met.
- If an *Event is in progress* and the *thresholds are not met*, the Tool will advise DOT personnel of the potential ending of an Adverse Weather Event.

[6] Data are collected and stored continuously, regardless of the adverse weather event status. The beginning and ending time of an adverse weather event are recorded and used to select data used for System Performance Outcome Processing.

  - If DOT personnel confirm ending the Adverse Weather Event, the RW-PM Tool generates System Performance Outcomes for the Event. The Tool then returns to capturing and processing traffic mobility and road weather data, notifying DOT personnel when thresholds are met.
  - If DOT personnel do not confirm ending the Adverse Weather Event, then the RW-PM Tool displays Traffic Management and RW Maintenance Recommendations to DOT personnel for verification.

- If an *Event is in progress* and the *thresholds are met*, then the RW-PM Tool proceeds with display of Traffic Management and RW Maintenance Recommendations to DOT personnel for verification.
- Traffic management and RW maintenance personnel review and assess recommendations, messages and informational displays and consult.
- If DOT personnel do not concur with RW-PM Tool recommendations, advisories, and informational displays, then they may be manually revised by DOT personnel or rejected.
- Upon verification and confirmation or revision by DOT Personnel, recommendations, advisories and informational displays are deployed to traffic management, RW maintenance deployment and motorist advisory display systems.
- The Tool then returns and continues to capture and process traffic mobility and road weather data, notifying DOT personnel when thresholds are met.
- This process is repeated at a configurable rate of the order of every 15 to 60 minutes, depending upon the rate of change of weather conditions and the desire of DOT personnel to support RW-PM needs.



Source: Battelle

Figure 3-5. Flowchart of Prototype RW-PM Tool Process showing Real-time Integration and Optimization of Traffic Management, Motorist Advisories, and RW Maintenance Deployment

Detailed descriptions of the following components may be found Chapters 5-7 in the *Prototype Road Weather Performance Management Tool System Design Document* [23].

- Processing Platform Design – Chapter 5
- Mobile Application Design – Chapter 6
- Message Data Definitions – Chapter 7

3.1.6 Prototype RW-PM Web-Based Application and Mobile Application Interface and Functionality

The RW-PM Web-Based application was developed in Microsoft Visual Studio 2015 and contains five separate Microsoft Azure web site projects, allowing the RW-PM tool to utilize cloud computing services. Each website uses the same authentication method, so that users can access them with the same credentials. The users are restricted by which sites they are permitted access, and by the access level that they have in that site. There is a landing home page that contains the links to the other sites an authenticated user may visit. In addition to managing and reviewing RW-PM tool access and current and historic weather events, the three core sites are summarized as follows:

- Home Page
  - RW Maintenance
    - Administration
      - RW Maintenance Recommendation Management (modification and rejection of recommendations)
      - User Management
      - Weather Event Management (Start / Stop Weather Event)
    - Map View (display all active RW Maintenance Recommendations)
    - RW Maintenance Recommendation Detail (Full Details of a selected RW Maintenance Recommendation)
  - Motorist Advisory
    - Administration
      - Motorist Advisory Management (modification and rejection of alerts)
      - User Management
    - Map View (display all active Motorist Alerts; MAW, SPD-HARM, Q-WARN)
    - Motorist Alert Detail (Full details of a selected motorist alert)
  - Traffic Control
    - Administration
      - User Management
      - Weather Event Management (Start / Stop Weather Event)
    - Map View (display all active SPD-HARM, and Q-WARN alerts)
    - SPD-HARM and Q-WARN Alert Detail (Full details of a selected alert)

The RW-PM Mobile Application is the main connected vehicle interface between the RW-PM system and the driver. The Mobile Application displays Motorist Alerts generated by RW-PM system and shares vehicle data with RW-PM system, inclusive of vehicle data from the vehicle OBD-II port and location data from the GPS. The RW-PM mobile application runs on an android device with cellular and Bluetooth connectivity. The RW-PM mobile application uses a cellular connection to send data into the RW-PM cloud system using the RW-PM web API, and the Bluetooth connection to retrieve vehicle telemetry data from the vehicle's CAN bus using a Bluetooth enabled OBD-II reader.

A complete description of the web-based and mobile application interface design, functionality, and operation details may be found in the *Prototype Road Weather Performance Management Tool Installation Instructions and User Manual* document [27].

3.1.7 Prototype RW-PM Tool Acceptance Testing Results

Acceptance Testing was conducted in accordance with the Prototype *Road Weather Management Tool Acceptance Test Plan* document [28]. This testing was designed to verify and demonstrate that the RW-PM Tool has the functionality and performance capabilities necessary to deliver the features described in the project Concept of Operations document [11] and that the Tool meets its functional and performance requirements described in the project's System Architecture and Requirements document [24]. The Tool design is described in the Prototype RW-PM Tool System Design Document [23].

3.1.7.1 Participation

Acceptance testing was conducted from 19-20 April, 2016 by Brenda Boyce (Booz Allen Hamilton), representing U.S. DOT. Acceptance testing was hosted by Battelle and conducted at Battelle Columbus Operation (BCO) room 11-7-112, located in Columbus, Ohio. All functionality tested was developed and maintained by Battelle with the support of the National Center for Atmospheric Research (NCAR) and the Texas A&M Transportation Research Institute (TTI).

3.1.7.2 Summary of Prototype RW-PM Tool Functions and Benefits

The acceptance testing found that the Prototype RW-PM Tool has the potential to deliver substantial improvements and benefits for stakeholders. As described in the Concept of Operations document [11], the RW-PM Tool leverages the latest developments in connected vehicle technology and the expected deployment of connected vehicle technology in new cars. It has capabilities to provide real-time feedback to Traffic Management managers and RW Maintenance managers during dynamic weather events, and allows them to adjust their traffic mobility and road weather controls on-the-fly and to maximize the effectiveness of their limited resources. Functions and benefits include the following:

- Integrating traffic mobility and road weather data collection and analysis to support more informed traffic and RW Maintenance management responses to adverse weather conditions.
- Capturing data wirelessly from mobile data sources in real-time and integrating with legacy and fixed data sources to provide a more robust, higher resolution and higher density traffic mobility and road weather data that support more accurate and precise traffic mobility and RW Maintenance decision making by traffic and RW Maintenance management.

- Implementation of real-time data collection, processing, display and messaging to support
  - Better allocation of available RW Maintenance staff, equipment and material resources to maintain mobility, and
  - More timely and targeted deployment of RW Maintenance response to dynamic variations in weather.
- Improvements in deployment of RW Maintenance resources supported by the RW-PM Tool to help
  - Improve traffic mobility during an adverse weather event and
  - Return mobility to normal more quickly following an event.
- Delivery of in-vehicle real-time traffic mobility and road weather information and messaging to drivers to support
  - More informed travel route decisions by drivers,
  - More informed and safer driving decisions by drivers, and
  - Reduce the likelihood of accidents, thereby improving traffic safety and mobility.

3.1.7.3 Summary of Requirements Not Met

A detailed account of all acceptance testing results can be found within Chapter 4 and Appendix A of the *Prototype Road Weather Performance Management Tool Acceptance Testing Report* document [29].

Appendix A of that report summarizes performance of the RW-PM tool against each of the requirements described in the *Prototype RW-PM Tool Architecture and Requirements* document [24]. That matrix contains a reference to the evaluation method employed, the test case(s) through which the requirement is evaluated (if applicable), and the performance result and notes. The evaluation methods are described in the *Prototype Road Weather Management Tool Acceptance Test Plan* document [28]. Not all requirements were verified through test cases. Typically, requirements to be evaluated via demonstration (D) were confirmed via test cases, while requirements to be evaluated via inspection (I) or analysis (A) were confirmed through reviewing analyzing results from planned or ad hoc tests, or by reviewing database results or evidence.

Chapter 4 of *Acceptance Testing Report* document [29] details the test cases that were executed during acceptance testing to confirm the majority of the requirements, including the objective of each test case, requirements tested, description of what is accomplished in the test, details of the setup and configuration for the test, test procedures conducted, expected results for each procedure, a pass/fail rating, and notes.

This remainder of this section summarizes the four primary deficiencies identified. A brief summary of each deficiency is provided, as well as an explanation of the design choices made for the RW-PM and/or possible future modifications. In some cases, design choices were made that perhaps should have altered the system requirements and test plan documents; however, the effort to revise those corresponding documents was not undertaken. Associated requirements considered not met which result from these deficiencies are specified in the *Acceptance Testing Report* document [29]. All other requirements not referenced were either met or the intent was met with or without exceptions.

1. **The RW-PM Tool Lacks Performance Metrics.** Although some performance measures were provided, no performance metrics are provided by the RW-PM tool. Over the course of the project, U.S. DOT and Battelle did generally discuss ways in which performance metrics could be handled; however, actionable stakeholder feedback was not obtained.

2. **The RW-PM Tool Does Not Notify of, or Permit Operator to Verify/Decline, Alerts and Events.** Rather than notifying operators such as Traffic Management Center (TMC) users to of alerts and events and allowing the operator to verify or dismiss them, alerts and events are automatically generated based on selected conditions and criteria without notification. Each alert or event can be cancelled manually from the applicable site, and events can be manually initiated. Over the course of the project, Battelle had several discussions with U.S. DOT regarding this topic and consequently pursued the approach listed above to avoid presenting nuisance alerts and events to users to confirm. Also, the entity to be notified was never identified by the DOT/stakeholder team.

3. **The RW-PM Tool Does Not Possess an Authorization Interface.**

   a. **Traffic and Maintenance personnel cannot accept/reject motorist road and weather advisories.** Weather-oriented pavement conditions are provided on the Road Weather Maintenance page and – together with speed/queue warnings – are presented to connected vehicle drivers on the RW-PM mobile application interface. However, Motorist Advisories and Warnings (MAW) are not displayed on the Motorist Advisories page. Pavement conditions and/or MAW alerts should have been provided on the Motorist Advisories and Traffic Control pages. MAW alerts were added to the Motorist Advisories and Traffic Control pages following Acceptance Testing. Pavement conditions were from MnDOT feed data.

   b. **Traffic and Maintenance personnel cannot accept/reject maintenance deployment recommendations.** Maintenance deployment recommendations are condition-based and, arguably, should not be verified or rejected. An exception to this might be to temporarily exclude some recommendations that are cross-checked and found to be erroneous. It should be understood that there is not a "feedback loop" input into Pikalert. This means that even if maintenance recommendations were to be authorized for "rejection" within the RW-PM tool, doing so would not prevent the continued re-generation of potentially erroneous maintenance recommendations at the next processing point (performed at 5 minute intervals).

   c. **Traffic personnel cannot accept/reject traffic management recommendations in the Traffic Management site.** Although the ability to accept/reject traffic management recommendations is provided in the RW-PM tool, it is provided on the Motorist Advisories page rather than the Traffic Control page (or on both pages).

   d. **Access to authorization interfaces is not limited to authorized users.** Arguably, this requirement was met for weather event and Q-WARN/SPD-HARM alerts presented as there is at least the ability to authorize cancellation of individual alerts or events exists, and the manual creation of events is provided. The RW-PM tool does limit the cancellation of alerts to authorized individuals.

4. **The RW-PM Tool Provides Most Required Information but Not Always in the Required Application Page.** MAW alerts do not belong on the Road Weather Maintenance page and should instead be presented on the Motorist Advisories and Traffic Control pages.

Additionally, Q-WARN, SPD-HARM, and MAW alerts should only be able to be resolved from the Traffic Control page and not the Motorist Advisories page. As mentioned above, the RW-PM tool was modified after Acceptance Testing to provide MAW alerts on the Motorist Advisories page and Traffic Control page, and Q-WARN, SPD-HARM, and MAW alerts can be removed only from the Traffic Control page and not the Motorist Advisories page. Some associated requirements should arguably remain unmet to avoid too much information being presented on a single website page, where information is already presented at a location better acted upon from another page.

One additional observation made during Acceptance Testing that does not directly correspond with a test case or requirement(s) was that no quality checks are performed on RW-PM inputs, especially regarding traffic mobility data. Additionally, no confidence levels are provided. Not providing this information was intentional with respect to information presented that is processed by INFLO and Pikalert, as it is assumed that the quality checks performed by INFLO and Pikalert are sufficient.

3.1.7.4 Summary of Modifications Made to RW-PM Tool Following Acceptance Testing

Table 3-2 summarizes the corrections made to the RW-PM tool based upon acceptance testing findings. Because these modifications were made after acceptance testing was conducted, the results summarized above and detailed below do not reflect their implementation.

Table 3-2. Prototype RW-PM Tool Modifications Following Acceptance Testing

Req. #	Test Cases	RW-PM Modification Description
--	7.X	RW-PM information was not presented to users with read-only access level. This problem has been corrected.
--	2.1	When selecting speed and then SPD-HARM, it was found that they continued to toggle. This glitch was resolved.
--	2.1	Timestamps were not being provided for SPD-HARM and need added to the Motorist Advisories and Traffic Control pages. This information was added.
3.04, 3.11, 3.13, and 3.25	7.1	MAW alerts were not present and need to be added on the Motorist Advisories and Traffic Control pages. These were added.
		Q-WARN, SPD-HARM, and MAW alerts needed to be made removable from the traffic control page and not the Motorist Advisories page. The tool was modified to permit this.
--	4.3	MAW alerts needed to be recorded in the database. This is now possible.

Source: Battelle

Finally, it was found when inspecting timestamps of road weather data during Acceptance Testing that the system was running 15-20 minutes behind. The system was restarted and the timestamps were no longer found to lag.

3.2 Prototype RW-PM Tool Deployment

3.2.1 Deployment Site Description

As part of this project, Battelle worked with the U.S. DOT and its DOT stakeholders to identify a suitable location for deployment and demonstration of the Prototype RW-PM Tool. They desired a DOT which has existing infrastructure that can be leveraged to easily demonstrate Tool features and benefits. Accordingly, they requested an expression of interest from DOTs which had the following systems and equipment:

- Existing implementation of Pikalert Enhanced Maintenance Decision Support Systems (EMDSS) such as that deployed as part of the Integrated Mobile Observations (IMO) project.
- RW Maintenance Vehicles with automatic vehicle location (AVL) and RW Maintenance Data Sensor Suite such as those deployed in the IMO project.
- Fixed Traffic Mobility Data Sources such as Imbedded Loop detectors
- Fixed Road Weather Data Sources such as Road Weather Information System (RWIS) or Meteorological Assimilation Data Ingest System (MADIS)
- Fleet of up to a dozen similar make, model and recent year light duty vehicles with road weather data accessible through on-board diagnostic system (OBD-II) ports

The deployment objective was to leverage existing traffic mobility and road weather systems at a venue to demonstrate the integration of existing Traffic Management, RW Maintenance and Motorist Advisory systems. While a number of DOTs are working toward RW-PM systems that can utilize connected vehicles system, the U.S. DOT and Battelle found that Minnesota DOT (MnDOT) best met the criteria above with existing infrastructure and with RW Maintenance vehicles having road weather sensors. A corridor on I-35W in Minneapolis, shown in **Error! Reference source not found.** above, was selected as the candidate deployment site with the resources best able to demonstrate of the features and benefits and RW-PM Tool.

MnDOT and NCAR worked together previously under the IMO project to implement the latest version of Pikalert EMDSS and MAW applications. As a consequence, the Prototype RW-PM Tool was able to utilize existing MnDOT Pikalert interfaces for capturing road weather data including an existing interface through MADIS interface for capturing road weather data from fixed sources and an existing interface through Ameritrak for capturing RW Maintenance vehicle mobility and road weather sensor data. MnDOT had an established, publicly accessible, interface for capturing traffic mobility data from MnDOT traffic mobility sensors. Finally, MnDOT had a fleet of light duty pickup trucks that operated along this corridor during adverse weather events.

3.2.2 Implementation Details

Implementation details were as follows.

- Installed RW-PM Tool CV equipment on 9 light duty incident response vehicles that traverse the I-35 West corridor through Minneapolis
- Additionally, the RW-PM Tool captured MnDOT RWIS data through MADIS and Snowplow Data through Pikalert

- RW-PM Tool uses NCAR Pikalert Applications for Road Weather and Battelle INFLO Applications for Weather Responsive Traffic Management (Speed Harmonization)
- Traffic Speed Data Inputs use Google Maps Traffic, MnDOT traffic sensors, and CV performance
- The RW-PM Tool determines traffic control, motorist advisory, and road weather maintenance recommendations during weather events
- Real time conditions and recommendations are available on an internet accessible Web Page interface, with motorist and road weather maintenance advisories presented to CVs

3.2.3 Tool Deployment Timeline

- Deployed the developed RW-PM tool prototype on 11/15/15
- Demonstrated the tool to DOT, MnDOT, and its RW-PM stakeholder group from 11/20/15-12/1/16
- Experienced issues with MnDOT Pikalert data feed from 12/19/15-1/28/16, with a few other days in early February having issues that are now corrected. Issues resulted from changes to data structure implemented by Ameritrak.
- Conducted an evaluation with stakeholder group on 2/24/16 in which a weather event from February, 2016 was reviewed.
- A second evaluation was planned for March, 2016.
- Deployment ended in April 2016 following acceptance testing by DOT

3.3 Prototype RW-PM Tool Evaluation

This section describes summarizes the results of the evaluation of the Prototype Road Weather Performance Management (RW-PM) Tool. The evaluation described within this document was led by Battelle with the support of Venner Consulting.

The objective of evaluating the Prototype RW-PM Tool was to assess the potential impacts of the Tool in supporting improved road weather response performance during winter weather conditions, as described in Chapter 3 of this report and in the Prototype RW-PM Tool Concept of Operations [11]. This section presents the evaluation hypotheses, analysis, and findings that resulted from testing during the 2015-2016 winter season.

The team developed and demonstrated the first Prototype RW-PM Tool of its kind to demonstrate potential functionality, features, and benefits. This Prototype Tool was intended as a first generation Tool for review and critique by stakeholders and for stakeholders to recommend refinements and enhancements that maximize its usefulness and value. This project included data capture from 9 connected vehicles to demonstrate integration of this data in an RW-PM Tool. While instructive for demonstrating functionality of the Tool, this number of vehicles is not sufficient to quantify potential benefits of the effects of connected vehicle data on RW-PM at this time. Thus, benefit evaluations of this Prototype Tool are qualitative here. The evaluation concluded that stakeholder-recommended refinement and enhancements documented herein could support development of the next generation RW-PM Tool, which could be implemented in stakeholder operations and support quantitative benefits assessments.

3.3.1 Evaluation Hypotheses and Data Sources

The evaluation focused on four quantitative-qualitative hypothesis pairs that were evaluated using both quantitative and qualitative data. The quantitative hypotheses examined functionality of the Prototype RW-PM Tool and qualitative hypotheses assessed the potential benefits of a more widely implemented RW-PM Tool.

3.3.2 Evaluation Findings and Evidence

Evaluation findings and evidence are summarized below. Full details are available in the Prototype Road Weather Performance Management Tool Evaluation Report [9].

3.3.2.1 Evaluation of Quantitative Hypotheses

Hypothesis 1a: The Prototype RW-PM Tool delivers updates of traffic mobility and road weather conditions, weather responsive traffic management, and road weather maintenance and motorist advisories to DOT Personnel and motorists every 15 minutes.

This hypothesis was supported. Acceptance testing showed that the Prototype RW-PM Tool utilization of connected vehicle technology and data enabled the implementation of RW-PM processes in near real-time. This hypothesis was assessed through comparison of the timestamps of captured input data and of advisories delivered to DOT personnel and motorists.

Hypothesis 2a: The Prototype RW-PM Tool integrates weather responsive traffic management, road weather maintenance, and motorist advisories for deployment by DOT Personnel.

This hypothesis was partially supported due to noted deficiencies. Acceptance testing showed that the Prototype RW-PM Tool integrated data and processing into a single series of outputs for use by DOT personnel. This hypothesis was assessed through evaluation of the Prototype RW-PM Tool outputs website.

Hypothesis 3a: The Prototype RW-PM Tool captures traffic mobility and road weather data from connected vehicles and integrates it with data from other sources for use in weather responsive traffic management, road weather maintenance and motorist advisories.

This hypothesis was supported. Acceptance testing showed that the Prototype RW-PM Tool integrated data from multiple existing sources, with additional data provided from connected vehicles. This hypothesis was assessed through evaluation of the Prototype RW-PM Tool receiving inputs from fixed and mobile sources of traffic mobility and road weather data, including RWIS, vehicle speed sensors, personal mobile devices, and connected maintenance vehicle data. This hypothesis was also assessed through examination of outputs from the INFLO and Pikalert applications.

Hypothesis 4a: The Prototype RW-PM Tool delivers in-vehicle weather responsive traffic management recommendations and road weather advisories to connected vehicle motorists within 5 minutes of their generation.

This hypothesis was supported. Acceptance testing showed that the Prototype RW-PM Tool, by leveraging connected vehicle technology, supported the integration of traffic control, road weather maintenance and motorist advisory strategies in real-time to further improve the effectiveness of response during weather events. In-vehicle recommendations and advisories were provided to connected vehicle drivers within five minutes after they were generated. This hypothesis was assessed through comparison of the timestamps of captured input data and of motorist advisories.

3.3.2.2 Evaluation of Qualitative Hypotheses

The primary basis for evaluating each qualitative hypothesis was a focus group led by the RW-PM Evaluation Team on February 24, 2016 to collect responses from three stakeholder groups: an *MnDOT stakeholder* (i.e., the deploying agency), *RW-PM Tool stakeholders* (i.e., stakeholders from other state agencies), and the *U.S. DOT RWMP Team*. The following summarizes at a high level the position of the RW-PM Tool stakeholders. The *Prototype Road Weather Performance Management Tool Evaluation Report* [9] provides additional detailed feedback from the three stakeholder groups, including from individual stakeholders, relative to each hypothesis.

For context, focus group participants were first asked how the RW-PM Tool relates to the current approach or tools used by their agencies for road weather management. The *MnDOT stakeholder* noted that the Tool is far from the other tools that are currently used operationally in the Maintenance Decision Support System (MDSS), but recognized that not all agencies have access to those same types of tools. This stakeholder indicated that the tool seemed to function as expected and would be able to provide benefit for agencies that do not have the tools that MnDOT has. One concern was in regard to the accuracy/timeliness of information provided. It was later revealed, during Acceptance Testing, that a problem experienced with Pikalert precipitation and MnDOT MDSS versus RWIS output differentials was because the RW-PM system had not been re-started recently prior to the evaluation team demonstration. During Acceptance Testing, the system was found to be running about 15-20 minutes behind. The system was restarted and no timestamps were found to lag. The *RW-PM Tool stakeholder* from ITD stated interest in the concept and saw value in what the Tool offers and how it continues to work because ITD is trying to automate as much possible. The *U.S. DOT RWMP Team* commented that the Tool allows operations and maintenance adjustments to be made in real time as a storm is progressing and evolves. By knowing vehicle speeds before, during, and after the event as well as the performed maintenance actions, the TMC can change signs or use the speed harmonization tool to adjust variable speed limits.

Focus group participants were also asked their opinion on whether the RW-PM Tool could replace some or all of the tools that DOTs currently rely upon. The *MnDOT stakeholder* expressed interest in utilizing some features of the Tool that this stakeholder currently does not possess. Using parts of the Tool and incorporating those parts to enhance what MnDOT already has is more likely than utilizing the developed Prototype Tool operationally on a day-to-day basis. *RW-PM Tool stakeholders* from MDOT responded that the Prototype Tool has good potential as a means of combining information. Specifically, MDOT has separate traffic and advanced traffic management systems (ATMS) sites, but it would be nice to have the information in one location or the information coming into one spot and then sent to the different areas.

Overall, all stakeholders agreed that the Prototype Tool is a good step forward for operations and maintenance.

Hypothesis 1b: The RW-PM Tool near real-time delivery of traffic mobility and road weather conditions, traffic management, and road weather maintenance and motorist advisories to DOT Personnel and motorists will enable:

a) Improved traffic mobility during an adverse weather event, and
b) Return to normal mobility more quickly following an event.

This hypothesis was supported. Focus group responses indicated that a more widely deployed and further developed RW-PM Tool could support the continuous assessment of the effectiveness of response during dynamic weather events and support the real-time adjustment and optimization of traffic management and road weather maintenance strategies. This could result in improved traffic mobility during an adverse weather event, and a quicker return to normal mobility afterward.

Hypothesis 2b: RW-PM Tool integration of weather responsive traffic management, road weather maintenance, and motorist advisories will enable:

- ***a) More informed traffic management and road weather maintenance management responses to adverse weather conditions,***
- ***b) Better allocation of available road weather maintenance staff, equipment, and material resources to maintain mobility,***
- ***c) Reduced agency costs of weather-related maintenance and operations***

This hypothesis was supported. Focus group responses indicated that the Prototype RW-PM Tool could advance the field in this direction. A more widely deployed and further developed RW-PM Tool could build upon these developed decision support systems to enable DOTs to make more informed responses to adverse weather conditions and better allocate resources, resulting in reduced agency costs.

Hypothesis 3b: Capturing and using high density traffic mobility and road weather data from connected vehicles will enable more timely and targeted deployment of road weather maintenance response to dynamic variations in weather.

This hypothesis was supported. Focus group responses indicated that the Prototype RW-PM Tool demonstrated how a more widely deployed and further developed RW-PM Tool with road weather data from connected vehicles could enable a more timely and targeted response to dynamic variations in adverse weather conditions.

Hypothesis 4b: Delivery of weather responsive traffic management recommendations and road weather advisories to motorists in near real-time will support more informed and safer driving decisions by drivers.

This hypothesis was supported. Focus group responses indicated that the Prototype RW-PM Tool successfully demonstrated that a more widely deployed and further developed RW-PM Tool would support more informed and safer driving decisions by drivers.

3.4 Prototype RW-PM Tool Installation and Implementation

Details for installing and implementing the Prototype RW-PM Tool are described in the *Prototype Road Weather Performance Management Tool Installation Instructions and User Manual* document [27]. These details include prerequisite requirements for installing and using the RW-PM Tool environment, application, and platform; aligning data sources; aligning data sources; implementing web API components and interfaces; and networking. Setting up data storage and installing the web-based and mobile equipment applications is also covered.

The Prototype RW-PM Tool source code and documentation is available on DOT's OSADP. To obtain the tool and documents, search for "RW-PM" at: http://www.itsforge.net/.

3.5 Lessons Learned with Pikalert Integration

3.5.1 Summary of Pikalert Integration Effort

The National Center for Atmospheric Research (NCAR) was contracted by Battelle to provide engineering and consulting services to integrate Pikalert into the Prototype RW-PM tool and provide support for a demonstration of the RW-PM. NCAR created a distribution of Pikalert for deployment in a Cloud environment, where Pikalert was installed in a Linux Virtual Machine (VM) instance on Microsoft's Azure cloud computing platform. NCAR installed and configured a custom version of Pikalert backend and display. Installation of Apache2, web development, along with networking configuration was performed by NCAR. While supporting the RW-PM deployment, NCAR responded to an outage of Ameritrak data to MnDOT.

This following sections present findings and observations made primarily by NCAR during this project. They focus on the challenges experienced with building, configuring, and maintaining the Pikalert configuration deployed using Microsoft Azure Cloud service.

3.5.2 Build and Installation

Challenges were experienced by both Battelle and NCAR during the build and installation steps. Battelle had challenges building and installing the Pikalert software on Battelle machines. As NCAR had not previously attempted to hand off the Pikalert software to another entity to build, install, and configure, the complexity and breadth of skills necessary to accomplish the task were initially underestimated. Challenges were encountered creating a complete source code release, managing the third-party libraries, and building the Pikalert applications. Owing to these difficulties, Battelle requested NCAR to install the Pikalert system in a Linux VM instance on the Microsoft Azure cloud computing platform.

The installation of the core system in the Microsoft Azure Cloud, excluding data ingest, was straightforward for NCAR. To avoid data ingest challenges, the system installed in Microsoft Azure did not include the road weather forecasting system. Instead, weather forecasts for the roads were copied from machines at NCAR to the Azure cloud instance. Also, vehicle observations were still ingested at NCAR and then relayed to the Azure instance. This was an effective solution.

3.5.2.1 Source Code Release

- The Pikalert system does not currently possess an automated system test and checkout capability. As a result, system checkout must be performed manually. The documentation does not include detailed guidelines on how to check system integrity.
- Incorporating an automated system test and checkout capability would improve NCAR's ability to deploy the Pikalert system.

3.5.2.2 Third Party Libraries

- A prerequisite to building the Pikalert system is to install a number of third party libraries.
- The libraries can either be installed manually or by using package management software like APT or YUM.

- Manually building third party libraries requires previous experience building and installing open source libraries. This alone can be challenging for technical staff who do not have previous experience in this area.
- Using package management tools such as APT or YUM is a simpler process and is generally preferable to manual builds.
- System administration skills are required in using package management tools.

3.5.2.3 The Pikalert Applications

- Building the Pikalert applications can also be challenging even when the third party libraries are properly installed.
- Environment variables such as CC_FLAGS, LD_LIBRARY_PATH, etc. have to be set properly otherwise the build will be unsuccessful.

3.5.2.4 Alternatives to Requiring a Build from Source

- NCAR could provide pre-built binary executables. This could entail building binaries for multiple operating systems
- NCAR could clone a VM image including both Linux Operating System and data disks. For an example see: https://azure.microsoft.com/en-us/documentation/articles/virtual-machines-linux-capture-image/
- Once the cloned VM image is executed, the user would still have to modify Pikalert's configuration. For example, the user would potentially need to:
  - Update the road segments for a state that was already configured
  - Configure Pikalert for a new state
  - Update software to acquire the appropriate connected vehicle data
  - Re-install the Pikalert Crontab to execute the system processes
- Cloning can potentially take care of a number of data ingest issues.
  - Data that are freely available that do not require new login/password credentials can be automatically acquired after cloning. For example, RTMA files are publicly available using ftp and could be automatically acquired through installing. The cloud instance did not ingest vehicle observations from MnDOT or Ameritrak directly – instead they were relayed from NCAR.
- The cloud is a viable platform for running the Pikalert system.
  - Providing proper CPU, memory, and disk space provisioning is important. The Battelle VM provided approximately 197GB of disk storage, 3.4GB RAM, and 2 processors.
  - The cloud provides great elastic storage capabilities, but disk scrubbing and monitoring free storage is important as the system consumes and produces a large volume of data and disk expansion and associated costs may be required.
  - Since the cloud provides elastic compute capabilities, the scalability of Pikalert could potentially be expanded through the use of Apache Spark to perform parallel statistics calculations, data quality control, road weather forecasting, and other tasks. Spark has a Python API that could potentially be integrated with the existing Pikalert Python modules to allow a greater volume of real-time vehicle data to be processed.

3.5.3 Data Ingest

Setting up the data ingest for the Pikalert system is challenging. Pikalert data ingest includes:

- Mobile vehicle observations ingest
- Radar mosaic ingest
- RWIS observation ingest
- METARS observation ingest
- RTMA grid ingest
- Forecast model grid ingest

Data ingest from the myriad of different sources is time consuming to setup and configure. Each state utilizes different methods for accessing mobile observations, mobile observation formats often differ from state to state, and states can change access methods and/or formats without prior notification. A component of the data ingestion, the Vehicle Data Translator (VDT), was constructed to handle data quality issues associated with mobile observations. The VDT uses radar data, RTMA data, RWIS data, and METARS data in performing quality control. Data quality can affect the performance of the VDT. Some observation about the data quality are:

- The RWIS data itself also has data quality issues.
- Road temperature data can be incorrect.
- Road state data can be incorrect.
- Further quality control development is needed for assessing the quality of the RWIS and METARS data.

Managing data ingest with the cloud deployment is possible. Rsync was used to push data from NCAR to the cloud VM hourly. A custom stream aggregator would allow multiple input data sources to be pushed to multiple cloud nodes without using Rsync and provide a centralized point of maintenance.

3.5.4 Web Services and Display

3.5.4.1 Web Services

Web services provide the mechanism for the display to request data from the Pikalert system, allowing presentation to the user. The web services installation consists of mapping a set of locations on the Apache web server to behaviors in the Pikalert system.

- During setup of Pikalert on the Azure server, it became clear that configuration of the web services requires some expertise in web development and system configuration. It cannot be accomplished by a step-by-step set of commands to execute. Expertise required includes:
  - Experience configuring and administering Apache2
  - Experience with networking configuration
  - Knowledge of the Pikalert system
  - Documentation for setup of the web services should include a test URL for each required service to allow the person doing the setup to verify the correct configuration of each web

service without using the web display for testing. Failure to include these test URLs in the documentation was an oversight.

3.5.4.2 Display

The Pikalert display written in Javascript currently uses the Sencha Touch Javascript framework. The display is installed by copying the source code into a directory in the web server's DocumentRoot and entering the host name of the Azure server into the display configuration file. The display relies upon numerous web services to retrieve data from Pikalert. Without these web services, the display will not load due to load time diagnostic checks.

There are scalability problems with the current architecture for loading road segments into the display. The display runs inside a web browser on the client computer, and there are memory and computational limitations associated with the browser environment. The number of road segments in the Minnesota display has increased considerably. This has caused a minor load issue with the Pikalert display software. As states become more and more interested in high resolution road weather coverage, new techniques will be required to handle the dense road coverage.

- The current architecture involves loading road segments for the requested state at load time, by delivering the road segments to the display in JSON text format.
- The highest overhead appears to be the conversion of JSON strings to floating point numbers. When the road segments file approaches 100, 000 point locations, loading begins to slow down dramatically.
- An attempt to store the road segments in the browser local storage ran up against storage limits (e.g. 10MB per origin in Google Chrome).
- Possible solutions to improve road segment loading performance include:
    - Loading road segments from a shapefile (transmitting them in digital format instead of text format).
    - Creating a service to provide road segments to the display. This approach would allow road segments to be provided to the display matching the requested map area and resolution. However, this would require loading road segments whenever the user pans or zooms the map.
    - Using a third-party service for road segments.
    - Switching the mapping software used by Pikalert from GoogleMaps API to another framework, such as OpenLayers.
- Other Javascript frameworks than Sencha Touch should be evaluated for future use in Pikalert.

3.5.4.3 Communication and Coordination

There was a significant change in the data ingest processing paradigm of vehicle observations from Minnesota. In particular, the host NCAR was receiving data from was changed from Ameritrak to MnDOT. There were also changes in the software doing the processing. As a result, the firewall and host access mechanisms changed. It took a few weeks to identify that MnDOT data was no longer being received (there was no prior notification of the change). To exacerbate matters, this occurred during the Christmas holiday break, when staff were on vacation. After identifying the problem, it was necessary to coordinate with MnDOT and Ameritrak to resolve the problem. This took a few more weeks after the problem was first identified. It is recommended that notices of significant system changes should be conveyed to users to apprise them of potential challenges.

The communication between Battelle and NCAR was very good. However, the length of the data outage could have been mitigated if there was better communication and coordination amongst the stakeholders. The development of monitoring tools with e-mail notifications or other alerts to an administrator would provide the most reliable and expedient notification of performance issues.

Chapter 4 Conclusion and Future RW-PM Tool Enhancements

4.1 Summary of Prototype RW-PM Tool Successes

Connected vehicle technology holds great promise in improving DOT response to adverse weather through real-time monitoring of traffic mobility, local weather, and local road conditions. This technology can enable direct, real-time and after-action feedback to the DOTs on the effectiveness of their adverse weather mitigation efforts. As connected vehicle technology becomes widespread in new vehicles, mobile traffic and weather observations data from the vehicles can be captured and used by the DOTs to significantly improve their real-time response to dynamic weather and traffic conditions. Comprehensive real-time feedback could enable DOTs to refine and optimize mitigation measures reliably and on-the-fly, maximizing the efficiency and effectiveness of their available road maintenance resources.

The RW-PM Tool project has helped to advance the body of knowledge related to the acquisition and communication of vehicle data and external sensor data that can be used for road weather performance management. It successfully developed a RW-PM tool which Minnesota DOT helped deploy. This deployment and its evaluation demonstrated the potential for connected vehicle data to enhance and transform road weather performance measurement and management processes in DOTs' traffic management and RW maintenance operations in part because of its scalable and flexible design facilitation of various road weather users and incorporation of inputs that support of road weather performance management. Indeed, this project and Prototype RW-PM tool helped to provide a mechanism for U.S. DOT to assist DOTs in leveraging connected vehicle technologies.

The RW-PM Tool leveraged numerous recent developments in connected vehicle technology expected to be deployed in new cars. It provides real-time feedback to Traffic Management managers and RW Maintenance managers during dynamic weather events, and allows them to adjust their traffic mobility and road weather controls on-the-fly and to maximize the effectiveness of their limited resources. Benefits supported by the Prototype RW-PM tool include:

- Integrated traffic mobility and road weather data collection and analysis to support more informed traffic and RW Maintenance management responses to adverse weather conditions.
- Wireless data capture from mobile data sources in real-time and integration with legacy and fixed data sources to provide robust, high resolution and high density traffic mobility and road weather data permitting more accurate and precise traffic mobility and RW Maintenance decision making by traffic and RW Maintenance management.
- Implementation of real-time data collection, processing, display and messaging to support:

  - Better allocation of available RW Maintenance staff, equipment and material resources to maintain mobility, and
  - More timely and targeted deployment of RW Maintenance response to dynamic variations in weather.

- Improvements in deployment of RW Maintenance resources supported by the RW-PM Tool to help
  - Improve traffic mobility during an adverse weather event and
  - Return mobility to normal more quickly following an event.

- Delivery of in-vehicle real-time traffic mobility and road weather information and messaging to drivers to support
  - More informed travel route decisions by drivers,
  - More informed and safer driving decisions by drivers, and
  - Reduce the likelihood of accidents, thereby improving traffic safety and mobility.

However, prototyping, testing, deploying, and evaluating the Prototype RW-PM Tool revealed opportunities for tool enhancements and improvements. The remaining sections of this chapter summarize several potential enhancement opportunities revealed while testing, integrating, evaluating, and deploying the Prototype RW-PM Tool.

4.2 Potential Enhancements from Acceptance Testing Findings

The following candidate enhancements were derived from Acceptance Testing of the Prototype RW-PM Tool (see Section 3.1.9.3 above and the Prototype Road Weather Performance Management Tool Acceptance Test Report [29] for more details):

- Develop and implement performance measures and metrics useful to stakeholders. Clear and actionable stakeholder input needs to be gathered in support of this potential enhancement.
- Develop a method for notifying DOT/TMC operator(s) of alerts and events. Determination of the applicable person/entity needs to be clarified by stakeholders and care would need to be taken in the design and implementation of the alerting mechanism so as to prevent DOT/TMC operators from receiving nuisance notifications or receiving notifications at times or in manners which do not
- Develop an authorization interface for accepting or rejecting Motorist Advisories, Maintenance Deployment recommendations, and/or Traffic Management recommendations. The candidate advisories and recommendations should be limited to those that are not directly detected conditions unless the operator with access is also provided a means to know the data are inaccurate.
- Additional data should be included on some of the webpage sites rather than, or in addition to, some current data provided to reduce the need for the operator to visit multiple sites. Access levels should be revisited to determine if control by type of content can be improved. Care will need to be taken to ensure that operators are not presented too much data.

  - **Note:** Some corrections were made to the Prototype RW-PM Tool after acceptance testing to help ensure the proper information is displayed on the applicable sites.

- Provide additional vehicle data that is more reflective of local road weather conditions such as, perhaps, wiper status.

4.3 Potential Enhancements from Pikalert Integration Experience

The following candidate enhancements were derived from Pikalert integration experiences (see Section 3.5.2.4 above for more details):

- Incorporate an automated system test and checkout capability to streamline deployment. This provision would obviate the need for manual system checkout of system integrity.
- Clone a VM with Linux and data disks to address a number of data ingest issues experienced with the Prototype RW-PM Tool deployment.
- Expand the scalability of Pikalert through the use of Apache Spark to perform parallel statistics calculations, data quality checking, road weather forecasting, and other tasks. Additionally, via a Python API, enable a greater volume of real-time vehicle data to be processed.
- Develop a custom stream aggregator to allow multiple data sources to be pushed to multiple Cloud nodes without using Rsync, allowing a centralized point of maintenance.
- Increase the scalability of the current architecture for loading road segments into the display.
- Develop monitoring tools that can be used by the RW-PM system administrator to monitor the “health” of the RW-PM system and its data feeds.

4.4 Potential Enhancements from Stakeholder Input

- The following bullets summarize positive feedback from stakeholders about the Prototype RW-PM Tool:
  - The tool is useful in its current form for small DOTs without pooled-fund MDSS or similar tools
  - The tool is ideal to detect congestion in rural areas for larger and smaller DOTs
  - Larger DOTs will find the real-time traffic conditions provided by the RW-PM tool to be useful (e.g., speed sensor data)
  - The provision of RW-PM Tool data in areas where there is a big gap between fixed stations or mobile sources can be very beneficial
  - Stakeholders believe that the RW-PM tool is likely to improve mobility recovery time
  - Though the Prototype RW-PM tool is not intended to compete with or replace existing road weather tools, being modular/extensible and available via OSADP (open source), DOTs can develop/expand it for their own needs and integrate

- The following bullets summarize recommended enhancements of the Prototype RW-PM tool by stakeholders:
  - More detailed treatment recommendation functionality is needed to include tracking material amount and type, cycle time and other treatment management performance details. However, it is recognized that it might be challenging to develop a specific solution because it might need to be reflective of local rules of practice, which may differ across DOTs.
  - Consider adapting the structure of RW-PM tool traffic control outputs such that it can be used to interface and automatically push changes to DOT VSLs.
  - Any information presented by the RW-PM tool needs to be accurate and reliable. It was suggested that real-time weather-related recommendations need improved. This may be improved as CV inputs are expanded and connected vehicle data plays a larger role in road and traffic conditions updates. Weather inputs may need adjustments.

4.5 Potential Enhancements from RW-PM Team CV Development and Deployment Experience

- Present more Pikalert information and make even wider use of DOT-based sensor data. There are a number of details that DOTs might find useful that are readily available.
- Consider using alternate modules for performance measures / management processing (for example, IVP vs. Pikalert). A benefit – cost assessment should be performed as a basis for determining the attractiveness of these alternatives.
- Take steps to hasten the acquisition of more dense data and real-time inputs from connected vehicles. This could include:
  - Migrate the mobile (CV) interface in the Prototype to an application available via Android/Apple store (e.g., WAZE) to allow CV drivers to use their own smart phone interface. This would likely increase connected vehicle participation as this approach conveniently removes the need for receiving/installing equipment, and simultaneously permits enhanced mobility and travel time by providing CV operators real-time turn guidance to avoid traffic.
  - Consider working with on-board data OEM(s) to communicate vehicle telematics
  - Enhance road weather input data available from CV by capturing, communicating, and using – as a basis for updates / advisories – additional vehicle telematics (e.g., wheel slip)
- Investigate and potentially pursue DSRC communications instead of cellular communications for the CV platform. This may potentially improve performance and/or reduce communications cost.
- Identify, capture, and utilize common maintenance vehicle/AVL sensor information.
- Provide system-level performance outcomes detail to improve staffing, equipment, and material resources.

APPENDIX A. List of Acronyms and Abbreviations

AASHTO	American Association of Highway and Transportation Officials
AMS	American Meteorological Society
ATM	Active Traffic Management
ATMS	Advanced Traffic Management Systems
AVL	Automatic Vehicle Location
BCO	Battelle Columbus Operations
BSM	Basic Safety Message
CAN	American Meteorological Society
ConOps	Concept of Operations
CV	Connected Vehicle
DOT	State Department of Transportation
DSRC	Dedicated Short-Range Communications
EMDSS	Enhanced Maintenance Decision Support System
ESS	Environmental Sensor Stations
FHWA	Federal Highway Administration
GTM	Government Task Manager
I2V	Infrastructure-to-Vehicle
IMO	Integrated Mobile Observation
INFLO	Intelligent Network Flow Optimization
ITS	Intelligent Transportation Systems
ITS JPO	Intelligent Transportation System Joint Program Office
LOS	Level of Service
MADIS	Meteorological Assimilation Data Ingestion System
MAW	Motorist Advisory warning
MDSS	Maintenance Decision Support System
MMS	Maintenance Management System
MnDOT	Minnesota Department of Transportation
NCAR	National Center for Atmospheric Research
OBD-II	On-Board Diagnostics II
PII	Personally Identifiable Information
Q-WARN	Queue Warning
RW	Road Weather
RWIS	Road Weather Information System

RWMP	Road Weather Management Program
RW-PM	Road Weather Performance Management
RW-PM Tool	Road Weather Performance Management Tool
SPD-HARM	Dynamic Speed Harmonization
STSMO	Subcommittee on Transportation Systems Management and Operations
TMC	Traffic Management Center
TRB	Transportation Research Board
TSM&O	Transportation System Management and Operations
TTI	Texas A&M Transportation Institute
U.S. DOT	United States Department of Transportation
V2V	Vehicle-to-Vehicle
VDT	Vehicle Data Translator
VM	Virtual Machine
VSL	Variable Speed Limit
WRTM	Weather Responsive Traffic Management
WxDE	Weather Data Environment

APPENDIX B. RW-PM Tool Project Description

Prototype Road Weather Performance Management Tool that Uses Connected Vehicle Data

State DOTs and public transportation agencies work hard to mitigate the effects of adverse weather on traffic mobility with the tools and resources they have available. Despite advances in technology such as RWIS and weather forecasting systems such as FORTELL, DOTs rely on area-wide weather forecasts (e.g., television and radio), best practices, and past experience to decide how to deploy their resources (e.g., snow plows, de-icing solution) to mitigate adverse weather effects. Due to the highly dynamic and locally variable nature of weather and traffic though, DOTs generally do not have the tools to get the maximum benefit from their limited resources. While DOTs gain experience and generic “lessons learned” from each event, they are limited in their ability to determine the effectiveness of their mitigation measures on traffic flow and adjust their response in real-time or to improve current mobility, safety, and productivity.

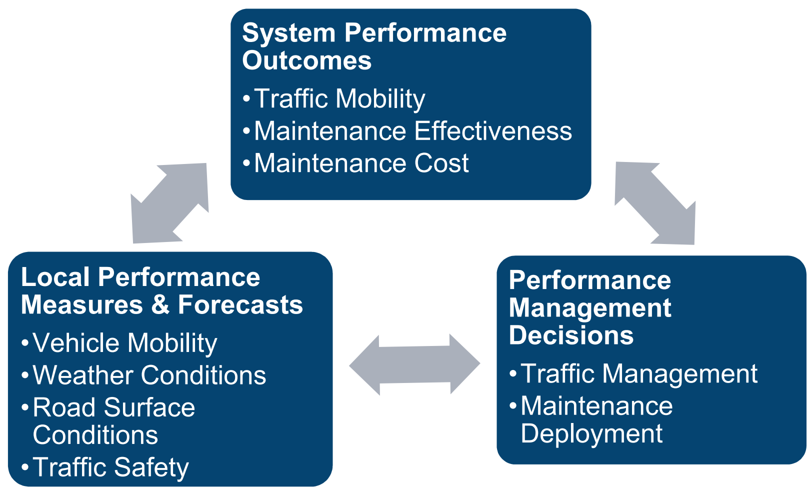


Figure B-1. Components of a Prototype Road Weather Performance Management Tool

With funding from the Intelligent Transportation Systems Joint Program Office (ITS JPO), the RWMP is starting a project to develop a “*tool*” that will integrate traffic, weather, and maintenance data in ways that contribute to the enhancement of DOTs road weather performance measurement processes; and to the maintenance and operations management processes overall. It will boost state and local DOTs ability to respond to adverse weather through real-time monitoring of traffic mobility, local weather, and local road conditions, thus enabling direct, real-time and after-action feedback to the DOTs on the results of their adverse weather mitigation efforts, potentially down to even the specific lane of a roadway.) The “tool” will incorporate, and benefit from, the use mobile/connected vehicle data. This tool will highlight the potential for connected vehicle data to enhance and transform road weather performance measurement and management processes in State DOTs. This project will help advance the state-of-the-art in road weather management and its use of connected vehicle technologies. The RW-PM Team is being led by Battelle, with Venner Consulting, the National Center for Atmospheric Research (NCAR), and the Texas A&M Transportation Institute (TTI) as supporting team members.

The project is kicking off by engaging DOT leaders to capture their needs and metrics for gauging performance in maintenance and operations and how connected vehicle data can be employed in Transportation Systems Management & Operations (TSM&O) activities to achieve targets. At the same time, the project team is conducting a review of the state-of-the-practice in DOT performance measurement and management activities related to road weather that are used by various State DOTs. This review includes reviewing existing performance measurement and management programs and tools related to road weather, identifying road weather performance measurement and management activities that can benefit from Connected Vehicle data and describing how they can be implemented using a performance management tool. The results of the engagement with DOTs and the review of the state-of-the-practice were used to define the requirements for the Prototype Road Weather Performance Management Tool and guide its development and testing. The project is on an accelerated schedule with the goal of having a prototype tool ready for testing by a state agency in late 2015.

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Prototype RW-PM Tool reports referenced in Chapter 2 not published by the FHWA Joint Program Office may be found at: https://collaboration.fhwa.dot.gov/dot/fhwa/RWMX/default.aspx.

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