Weather-Responsive Transportation Management

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Abstract. Nearly twenty five percent of non-recurring delays and congestion on freeways is due to adverse weather conditions. The Federal Highway Administration (FHWA) Road Weather Management Program has been focusing its efforts to better understand the impacts of weather on traffic flow and develop tools for alleviating those impacts. Information about weather and its impacts on the transportation system are currently not well integrated into the operational framework of most transportation agencies. This paper describes three efforts by the FHWA Road Weather Management program to advance the state-of-the practice in weather-responsive transportation management. The first is a prototype weather response system (WRS) for transportation management that was developed in partnership with the Missouri Department of Transportation. The WRS takes advantage of weather data and products from the National Weather Service (NWS) and other sources to support the application of traffic management, maintenance, and operations activities within the agency. The paper also describes how the system can be deployed in statewide Transportation Management Centers (TMCs), Traffic Operations Centers, and District Maintenance Facilities. The second effort consisted of a study on the integration of weather into TMCs. This paper summarizes how weather information is being integrated into the TMC operations of several agencies in the country. The third effort involves an empirical study on weather and traffic data to model traffic flow under varying weather conditions. Such information is vital for accurate traffic flow analysis and modeling, and determination of appropriate traffic management strategies to mitigate the impacts of weather.

INTRODUCTION

Weather affects the performance of the highway system everyday. More than 1.5 million highway crashes per year can be attributed to weather, resulting in more than 800,000 injuries and 7,000 fatalities. Adverse weather is also the second largest cause of non-recurring highway congestion, accounting for about 25% of delays on the freeways. About 1 billion hours are lost each year on the U.S. highway system due to weather-related delays. Moreover, it is estimated that weather affects about 1/3 of the nation's Gross Domestic Product (GDP).

While we cannot change the weather, we can reduce its impact on highway safety and operations. Today, we can predict weather changes, identify threats to the highway system, and respond proactively.

To do so, accurate and timely road weather information is essential, allowing transportation managers to warn people of changing weather, manage the infrastructure, and respond to conditions in real-time. Making this information available requires the active involvement of a range of participants in the transportation and weather industries. Since this information is not readily available today, a strong research program is required to address the various technical, policy and institutional issues associated with the providers and users of weather-related information.

The Federal Highway Administration (FHWA) Road Weather Management Program (RWMP) has been involved in research, development and deployment of strategies and tools for weather responsive transportation management. The goal is to minimize the delay and improve the safety of motorists during bad weather. Three types of strategies are being advanced by FHWA and used by transportation agencies:

- Advisory – information dissemination
- Control – methods to regulate or optimize traffic flow
- Treatment – ensuring that the roads are clear of obstructions.

The impacts of these strategies on transportation operations include better or more informed decision-making by the agency and motorists, availability of real-time weather and traffic information, and improved mobility, safety and reliability of the transportation system during inclement weather.

This paper describes three recent activities by the FHWA RWMP to advance the state-of-the practice in weather-responsive transportation management. These are: (1) A prototype weather response system (WRS) for transportation management developed in partnership with the Missouri Department of Transportation, (2) A study on the integration of weather into Transportation Management Center (TMC) operation, and (3) An empirical study on weather and traffic data to model traffic flow under varying weather conditions. Each effort is discussed in detail below.

WEATHER RESPONSE SYSTEM

Information about weather and its impacts on the transportation system are currently not well integrated into the operational framework of most State transportation agencies. Operations personnel in those agencies obtain weather information from multiple sources, and in many cases this information is non-specific, conflicting, and not tailored to support the needs of the specific decision makers. FHWA has been working to address the needs of the surface transportation community for better, more tailored weather and road condition information. Still, there is a need to bring together advanced weather and road condition technologies for addressing various operational categories including maintenance, traffic, incident, and emergency management.

In 2004, FHWA initiated a 2-yr cooperative agreement with the Missouri DOT (MODOT) to develop and implement a Weather Response System (WRS) to support transportation operations management. The DOT WRS project was conceived as a way to fill the void that exists in weather information management and decision-support capabilities. Missouri was chosen as a test bed for the system because it recognized the need for the system and understood how the system can be developed and implemented in the State.

The goal for the WRS is to utilize available data from the National Weather Service (NWS) and other sources to provide tailored, timely and accurate weather and road condition information to the DOT personnel. Developing and deploying the system brings together advanced weather and

road condition technologies to support transportation operations decision-making including the application of advisory, control and treatment strategies described above. The WRS data can be processed into relevant information for dissemination over Dynamic Message Signs (DMS), Highway Advisory Radio (HAR), internet sites, 511 Traveler Information System and other public and private media. FHWA also sees the Missouri WRS experience as a potential model for development and deployment of similar systems in other locations.

The WRS prototype was developed in December 2005 and is being tested in Kansas City, MO through May 2006. The system uses the NWS national digital forecast database (NDFD), which is a database consisting of gridded digital forecasts of weather elements (e.g., cloud cover, maximum temperature, humidity, wind speed, probability of precipitation, etc.) that are available for the public to use in creating text, graphic, gridded and image products of their own.

The prototype system consists of seven modules as follows:

- National - Displays weather maps for the entire United States.
- Statewide - Displays weather maps for individual States (currently only Midwest States)
- Local - Displays weather maps for NWS-defined regions around Missouri
- Map Show - Sequentially displays weather maps for any or all user-specified geographic divisions (national, statewide, local) and weather elements
- Activity Planner – Defines what days and time periods over the next 7 days the weather parameters will match the user-specified values or ranges for those parameters. The user can identify specific locations on a map (such as highway intersections) for which to generate weather forecasts. This module is called Activity Planner because it helps the user plan his/her future activities based on forecast weather conditions.
- Graph - Displays the Activity Planner module outputs on a chart.
- Radar – Displays the weather radar images for different locations in the US. In addition to weather, the images contains other information layers such as geographical and transportation features.

A screen shot of one of the modules is shown in Figure 1. Transportation managers, engineers and planners can use forecast weather elements from the WRS modules to provide advisory or warning messages to motorists through the agency's dynamic message signs or other public broadcast systems (radio, telephone, television, or internet), adjust traffic control devices as needed, or predict when and where particular maintenance, construction, or other transportation operations activities can be planned to coincide with desired weather conditions. The system can potentially be upgraded to provide the users with specific locations where a set of weather conditions are expected to occur in the next several days.

The results of the WRS testing and evaluation in Kansas City will be used to refine the system and develop a plan for statewide deployment. FHWA will also encourage other transportation agencies to take advantage of the experiences gained from the WRS project in Missouri. As part of a national system deployment evaluation, the FHWA will promote the WRS concept and requirements, identify institutional issues, assess engineering processes, articulate lessons learned, and measure the deployment impacts.

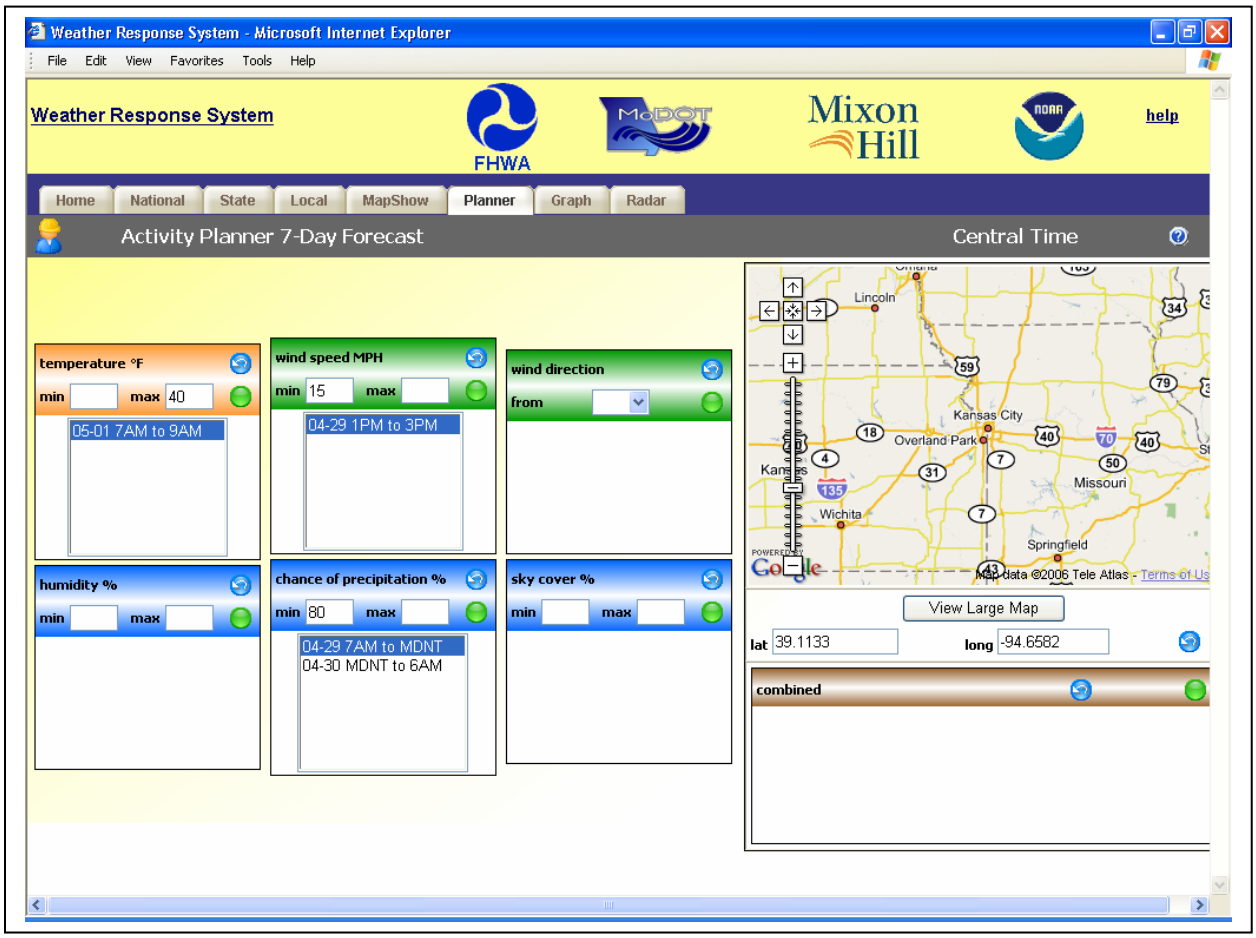

Figure 1 - Prototype Weather Response System

INTEGRATING WEATHER IN TMC OPERATIONS

The FHWA Road Weather Management Program and Emergency Transportation Operations Program recently completed a survey and analysis of how weather and emergency information are being integrated in the operations of Transportation Management Centers (TMC's) throughout the U.S. The goal of the study is to identify best practices and develop guidance to enhance the operations of TMC's during inclement weather and emergency situations. The final report, "Integration of Emergency and Weather Elements into Transportation Management Centers" (Report No. FHWA-HOP-06-090, Feb. 2006) summarizes how weather and emergency information and decision-support systems are being integrated in thirty eight TMC's around the country, and explains the strategies for applying practical, effective concepts and methods of integration in the future. The report discusses a framework for integration, the current state of the practice, potential benefits, and challenges associated with integrating weather and emergency information. In addition to the final report, a more detailed baseline report was produced containing prior research work, integration concepts, and the results of TMC site screening and evaluation.

Integrating weather information and decision-support functions in TMC operations supports the agency's ability to manage traffic, dispatch maintenance forces, and respond to weather-related problems on the transportation system. It provides TMC operators with valuable and timely weather, road condition, and traffic information to support transportation management decisions. In order to identify and implement weather mitigation strategies, transportation managers need to integrate route-specific weather and traffic condition information in the appropriate time frame and format with their existing management/decision-support systems or operations practices. While the highway maintenance units in most agencies have been very proactive in utilizing current and forecast road weather data in making highway treatment decisions, the use and integration of weather information in traffic management operations in most agencies are still uncommon.

The TMC's that have integrated weather information in their daily operations have experienced significant benefits. Although a comprehensive analysis of the benefit to cost of weather integration has yet to be done in any objective, systematic manner, it is apparent that integration provides substantial value to current TMC operations. Observed benefits include the following:

- Better targeted, more timely, and higher quality content for traffic advisories and information provided to both the traveling public and field operations staff.

- Coordinated transportation system control actions across integrated agencies.

- More consistent management of transportation operations under both nomal and inclement weather conditions.

- Enhanced TMC ability to anticipate weather conditions and take appropriate mitigation actions before experiencing adverse system impacts, including staffing adjustments and implementation of traffic advisories and control strategies.

The FHWA study defined and used five integration measures – physical, technical, procedural institutional and operational - to characterize the nature and extent of weather integration in the TMC's (see Figure 2). Using the measures shown in Figure 2, various types and levels of weather integration were observed in how data from various sources is collected, processed, and disseminated internally and externally by the TMC's; what systems are used to notify the transportation system operators and decision-makers of developing and potentially dangerous weather conditions; and what types of actions or strategies are implemented to respond to weather. While the study examined some of the most advanced and integrated TMC's, majority of them have either not begun to integrate weather information and functions in their operations or have made relatively little progress towards integration. In general, very limited integration and application of weather information for TMC operations were observed. The FHWA survey in 18 TMC's found that 16 received weather information daily, but only 4 integrated weather in their normal operations. Half of those surveyed used weather information to initiate some type of weather response strategies. In those cases where good examples of weather integration were found, the approaches taken by the agency were specific to the needs of the region or State. Clearly there is a need to advance the state of the practice and help agencies overcome the challenges associated with weather integration in TMC's.

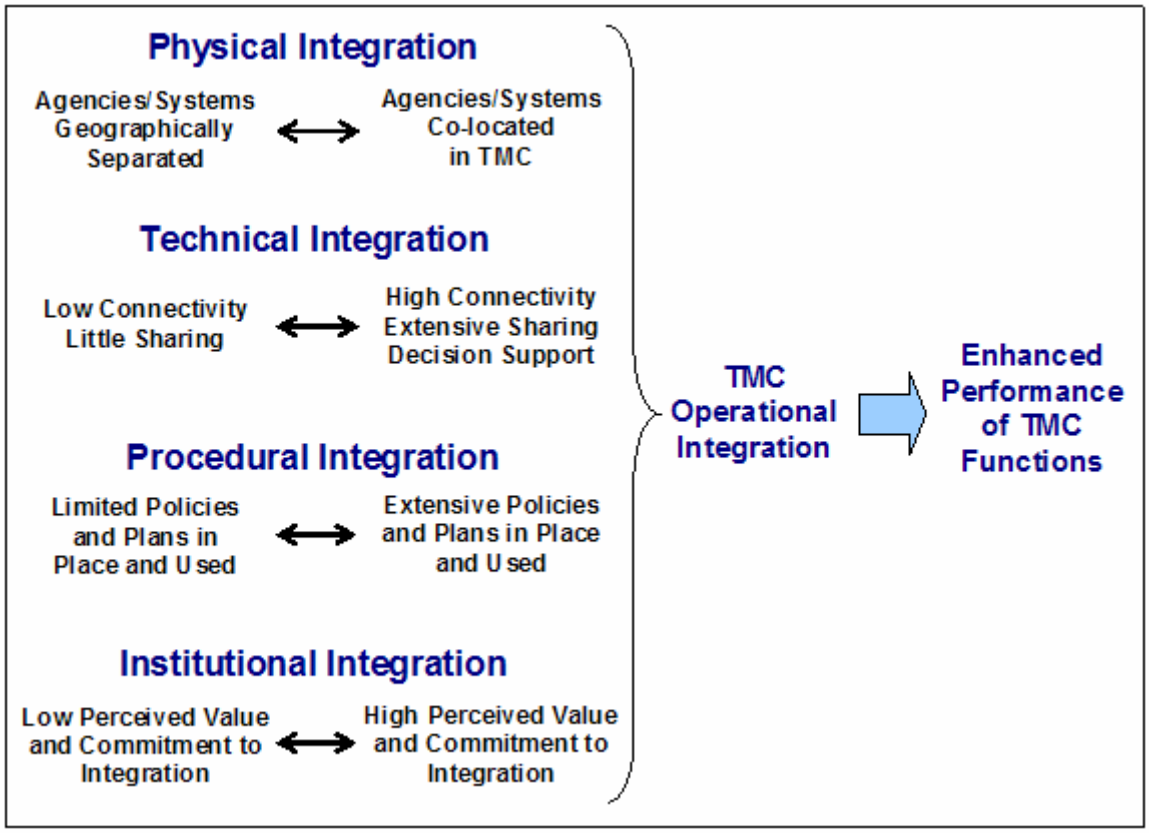

Figure 2 - Measures and Levels of Weather Integration in TMC

The many combinations of current integration concepts and methods identified in the study offer pathways for TMC's to advance their integration to meet the particular needs of their situation. However, more substantial improvements in integration can be achieved through the evolution of new concepts and methods that will require significant research and development investments. The study came up with several recommendations to help facilitate or advance the integration process. The recommendations include building awareness and creating a culture within TMC's that acknowledges the value of weather information and makes integration a standard business practice, improving communications among the users of weather information in the TMC's and the field, developing guidelines and conducting self-assessment programs, and developing new concepts and tools to help facilitate the weather integration process. The report specifically recommends that TMC's undertake a careful self-assessment process and prepare an integration plan to guide the selection and implementation of appropriate integration strategies. Depending on the concepts and methods of integration pursued by a TMC, the time and effort required will vary. Any weather integration effort requires agency leadership, a supportive institutional environment, and the political will to invest in the process. Objective benefit-cost analyses of weather integration strategies are also extremely valuable. FHWA will be pursuing most of the recommendations identified above and will be working with the TMC's around the country to assist with their weather integration initiatives including helping them overcome the challenges.

WEATHER AND TRAFFIC FLOW MODELS

The FHWA Road Weather Management Program is currently undertaking a research project to utilize existing data and knowledge, and develop new models, to quantify the impacts of weather on traffic flow parameters including speed, volume and delay. The goal is to better understand the effects of adverse weather on traffic conditions to help identify appropriate traffic management strategies. Models that use historic, current and forecast traffic and weather data to explain or predict traffic flow conditions are important to help identify where and how weather events impact the mobility and safety of the transportation system. These models enable managers, engineers and planners to determine areas and conditions that are most vulnerable to incidents, and estimate the safety impacts of both weather events and response strategies. Some of the tools and strategies that these practitioners can use include advisory strategies that provide information on weather and traffic conditions to the public and control strategies that alter the state of roadway devices to regulate traffic flow and roadway capacity such as modifying signal timings/plans and speed limits, closing lanes, and implementing detour routes.

The research project to conduct empirical studies on weather and traffic is designed to achieve two specific objectives: (1) to analyze and quantify the impacts of weather on speed, capacity and congestion, and (2) modify existing traffic models to account for weather impacts. The research project consists of the following tasks:

- Conduct a literature review and synthesis of prior research on this topic. This was completed in early 2005. The review found that past research on the impacts of weather on traffic flow is relatively sparse and limited in scope.

- Based on the literature review, the research team will develop a detailed plan for collecting and analyzing weather and traffic data. This includes identifying the potential sites for data collection and analysis. The plan was finalized in mid-2005. Three sites were selected based on the availability of weather and traffic data and weather geography - Minneapolis, Seattle and Baltimore.

- Collect and analyze data using the plan and develop adjustment factors and/or empirical models of traffic flow under variable weather conditions. Analyses of Minneapolis and Seattle data were completed in May 2006 and the results are still being finalized.

- Following all data collection and analyses, the research team will use this information to recommend updates to existing traffic models to incorporate weather impacts.

The FHWA research approach is a lot different and more comprehensive than those that have been conducted in the past. First, we are looking at the impacts of weather parameters on macroscopic traffic flow over a full range of traffic states – both uncongested and congested. Previous research on this topic have been limited to free flow or uncongested conditions. We are also evaluating several traffic flow variables as they are affected by weather, unlike prior studies that only looked at reduction in capacity and free flow speed. Previous studies also lacked detailed weather information in terms of the different ranges of weather conditions and the locations of the observations. In our research we are using disaggregated and localized weather

data. Additionally, we are investigating whether there are any regional differences in how traffic flow is affected by weather – for example drivers' response to snow may be different in Minnesota compared to Baltimore or Seattle area.

The types of data and analyses we are using are also quite different than those used in prior studies. We are gathering and analyzing speed, volume and density data during fair weather conditions and comparing them with the traffic data when there is rain, snow, or low visibility. Traffic data is collected from loop detectors on the study sites, and weather data is obtained from weather stations including airport and road weather sensor stations. The traffic model that we adopted for this study is the Van-Aerde model, a multi-regime traffic model that also allows us to look at capacity, free flow speed, speed at capacity, and density of traffic flow.

As indicated above, we have completed the analyses of multi-year traffic and weather data for Minneapolis and Seattle, and are beginning to look at the Baltimore data. Our preliminary analyses indicate that:

- In general, snow has more impact on free-flow speed and capacity than rain.
- Impaired visibility has minimal impact on free flow speed, and only observed when visibility drops below three-fourths of a mile.
- The reduction in freeway capacity is independent of the intensity of the rain, but increases with snow intensity.
- The variability of traffic flow (speeds, etc.) is more pronounced when it is snowing that when it's raining or dry.

Specific adjustment factors for various traffic parameters will be available when the analyses of Baltimore data is completed. A more generalized set of weather impact factors will be derived from the combined analyses of the three sites. In addition, any geographical differences in traffic flow response to weather will be identified from the analyses.

Also as part of this research, FHWA will be developing a data collection and analysis plan for conducting a human factors analysis of traffic behavior under inclement weather. Understanding individual driver behavior and responses to different weather and traffic conditions can offer valuable insight on the effectiveness of various traffic management and control strategies.

CONCLUSIONS

Transportation managers and decision-makers strive to maintain the safety and mobility of their systems. Weather events add an element of variability to their day-to-day operations. However, these events can be forecast, and their impacts predicted and responded to, if data and decision support tools are available and utilized effectively. Accurate and timely road weather and traffic data, combined with robust analytical and forecast models as well as road weather information/management systems, are critical for effective operational response. The FHWA

Road Weather Management Program has been helping highway agencies respond both proactively and reactively to adverse weather conditions. The program continues to develop and deploy a variety of management and decision-support tools to improve transportation operations in inclement weather.

This paper describes three efforts by FHWA to advance the weather-responsive management capabilities of transportation agencies. The Weather Response System (WRS) prototype that is being tested and evaluated in Missouri DOT utilizes available weather data from various sources and tailors the information to support highway operations including advisory, control and maintenance activities. The TMC integration study provides baseline information on weather integration across the country, analyzes existing practices, explains integration concepts, benefits and challenges, and offers recommendations to advance the state- of- the practice. The empirical studies on weather and traffic will help improve our knowledge and understanding of the impacts of weather on traffic flow, enabling transportation practitioners to identify and implement appropriate management strategies that will minimize highway delays and crashes during bad weather. As the demand for highway transportation continues to grow and the negative impacts of weather on the mobility and safety of the system becomes more pronounced, agencies will have to rely on effective weather-responsive transportation management tools and strategies, such as the ones described in this paper, to carry out their functions.

ACKNOWLEDGMENTS

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