Road Weather Management Performance Metrics

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16. Abstract

This report presents the results of a study to identify appropriate measures of performance that can be attributed to the Federal Highway Administration's (FHWA) Road Weather Management Program (RWMP) products and activities. Specifically, the study sought to identify performance measures that can be used to assess program success in meeting the goals of SAFETEA-LU Section 5308 pertaining to Road Weather Research and Development Program. Measuring RWMP performance is important because weather impacts transportation safety, mobility, and productivity. The focus of this effort is on identifying meaningful and implementable output and outcome metrics that address the SAFETEA-LU goals through RWMP activities. Both quantitative and qualitative performance metrics associated with program results were identified with the help of numerous stakeholders working in a variety of government and private agencies across the country. A workshop was held initially to define and discuss a potential list of metrics that were then distributed to over 250 practitioners and stakeholders through a request for information. Feedback was solicited regarding which metrics should be kept, further refined, or dropped from further consideration. Some respondents also suggested new measures. The results were analyzed and the metrics were prioritized and narrowed down into a more manageable set of measures for implementation.

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1 Introduction

1.1 Background

Working with stakeholders across the country, the Federal Highway Administration's (FHWA) Road Weather Management Program (RWMP) has undertaken a study to identify performance measures that can be used to evaluate the success of its products and activities in achieving key program goals. This project identified performance metrics that convey the progress of FHWA's RWMP activities in addressing the program objectives established under the Safe, Accountable, Flexible, Efficient, Transportation Equity Act – A Legacy for Users (SAFETEA-LU) Section 5308, Road Weather Research and Development Program, within Subtitle C – Intelligent Transportation System Research. These SAFETEA-LU goals include:

- Maximize the use of available road weather information and technologies.
- Expand road weather research and development efforts to enhance roadway safety, capacity, and efficiency while minimizing environmental impacts.
- Promote technology transfer of effective road weather scientific and technological advances.

The challenge lies in establishing meaningful, understandable, and practical measures of performance that can help evaluate the social, scientific, and organizational benefits expressed in the SAFETEA-LU goals and achieved through RWMP products and activities.

This report summarizes the work undertaken and the results generated to identify a set of metrics appropriate for implementation based on 1) their relevance to the RWMP, 2) endorsement by the stakeholders, 3) availability of data, and 4) resources needed to support implementation.

1.2 RWMP R&D Activities

The high level SAFETEA-LU goals were identified by the U.S. Congress in 2005 to help focus the research and development activities of the RWMP. The RWMP has developed a roadmap to define and guide their current and future activities. Some of the important RWMP initiatives underway include the following:

- **Environmental Sensor Station (ESS) Siting Guidelines**. This project will produce and support consistent guidance for state and local agency personnel responsible for procuring, siting, operating, and maintaining weather stations along the highways.
- **Maintenance Decision Support System (MDSS) and Maintenance Operations Decision Support System (MODSS)**. The MDSS is a multi-year program to prototype and field test advanced decision support systems for use by winter road maintenance managers in order to enhance the efficiency and cost-effectiveness associated primarily with the timing of treatments and the choice of material types and amounts to use for snow removal and ice control. MODSS is an extension of the MDSS that seeks to apply decision support technologies for weather-responsive maintenance and traffic operations throughout the year.

- ***Clarus***. This is a multi-year nationwide initiative to assure the provision of timely and high quality weather information to transportation operators and system users. Drawing from a host of available weather data sources, Clarus integrates this information in a common format and converts it to valuable road weather information.
- **Weather Responsive Traffic Management (WRTM)**. The RWMP is engaged in several research studies to evaluate the macroscopic and microscopic impacts of weather on traffic operations and traffic flow, and develop models and strategies for traffic management during inclement weather conditions. A concept of operations for weather responsive traffic management has been drafted that addresses road weather impact mitigation strategies, including data collection, assessment of weather impacts on roadway networks, operational strategies to control traffic during adverse weather, and future research needs. The MODSS initiative described above includes various WRTM concepts.
- **Traffic Management Center (TMC) Weather Integration**. This initiative seeks to identify strategies for the effective integration of weather information in the day-to-day TMC operations, and assist TMC managers and operators in developing and implementing strategies for their agencies. One of the current activities is developing a weather integration self-evaluation and planning guide.
- **Vehicle Infrastructure Integration (VII)**. VII benefits derive from vehicles wirelessly connected with each other and with roadside equipment in order to enable a host of safety, mobility, and commercial applications. VII offers the opportunity to know much more about traffic and roadway conditions, including weather, than ever before. Vehicles equipped with VII technology will be able to anonymously send and receive information that includes travel time, environmental conditions, and weather information. This information will lead to improved traffic signal control, traveler information, transportation planning, and reduced costs for system operations. The RWMP has worked with the federal research laboratories to develop processing algorithms that enable the data collected through VII to provide relevant road weather conditions encountered by vehicles. These processing algorithms permit the aggregated VII data to be combined with other weather observations to produce an enhanced depiction of the weather status of the roadway environment.
- **Fundamentals of Road Weather Management Training Course**. This training course developed by FHWA and available through the National Highway Institute is designed for traffic, emergency, and maintenance managers, as well as safety engineers and others involved in highway operations and maintenance. A web-based version of the course is also now available.

1.3 Performance Measurement: Definition and Relevance to Road Weather Management

Performance measurement can be defined as a process of assessing progress toward achieving predetermined goals and objectives, including information on the efficiency with which resources are transformed into goods and services (outputs), the quality of those outputs (how well they are delivered to clients and the extent to which clients are satisfied), and the results or benefits of a program activity compared to its intended purpose (outcomes), and the effectiveness

of government operations in terms of their specific contributions to program goals and objectives.

Performance measurement has been conducted relatively informally across the range of road weather programs and agencies throughout the country. For this study, FHWA needed to identify relevant measures of performance for evaluating road weather management products and services. The ultimate objective is to operationalize the selected measures using appropriate data to determine RWMP accomplishments and progress in meeting the goals of SAFETEA-LU pertaining to Road Weather Research and Development.

1.4 Performance Measures Study

The importance of performance measurement and evaluating the effectiveness of road weather management strategies cannot be overstated because weather has significant impacts on transportation safety, mobility, and productivity. Thus, the purpose of this study is to identify meaningful, relevant, and practical output and outcome metrics that address the SAFETEA-LU objectives through FHWA's RWMP activities. Several quantitative and qualitative performance metrics were identified and analyzed to measure program results in the following areas:

- Traffic management (including traveler information)
- Maintenance management
- Emergency management
- Transit management
- Transportation system performance
- Driver performance

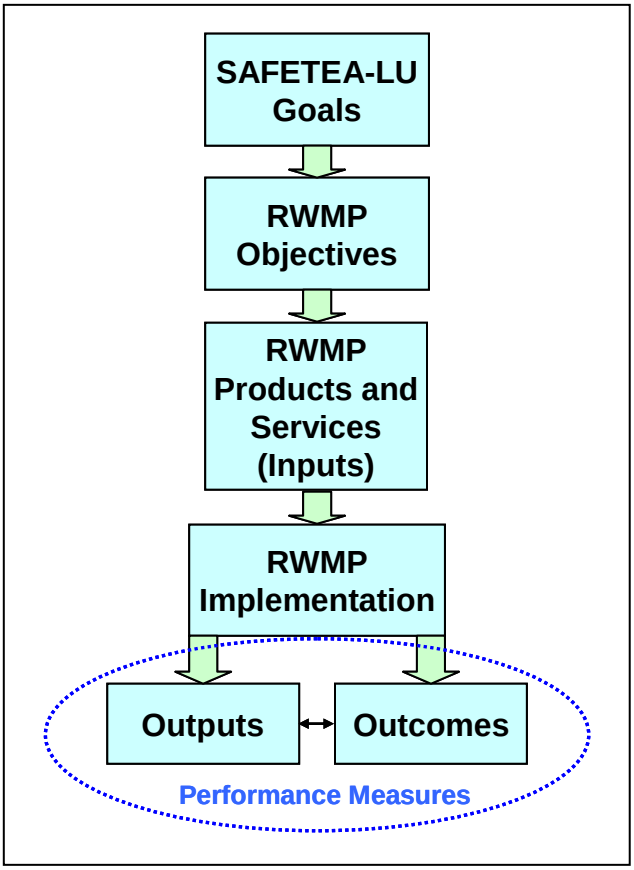

Figure 1. Link between goals, objectives, and performance measures.

The links between SAFETEA-LU goals, RWMP objectives and outputs and outcomes are illustrated in Figure 1. The identified performance measures will use indicators to describe the efficiency and effectiveness of products and services within the RWMP. Output measures tend to be quantitative indicators of operational efficiency, such as tons of materials applied to a freezing road surface or the miles of roadway plowed over a period of time. Outcome measures represent impacts or benefits achieved from program activities that tend to be more difficult to quantify, such as the reduction in travel time or travel costs that can be attributed to the use of a decision-support tool. Outputs link most directly back to the inputs, while outcomes relate more to the

programmatic goals. Both output and outcome metrics serve as valuable indicators of program performance.

1.5 Scope of Work

The performance measures study was initiated in late 2006 by FHWA using a contractor team. The study included the following elements that are described in more detail in this report:

- **Conduct literature review.** An extensive search and review was conducted of over 150 documents, focusing on those that address RWMP objectives associated with traveler safety, mobility, operational efficiency, information integration, and technology transfer for road weather management. While close attention was placed on surface transportation programs, performance measures were also examined in other weather programs of the federal government, such as those being used by the National Oceanic and Atmospheric Administration (NOAA) and the Federal Aviation Administration (FAA).
- **Identify hypotheses and associated measures of effectiveness (MOEs).** FHWA and its contractor team identified several objectives and hypotheses related to each of the three primary goals of the SAFETEA-LU Section 5308 program, and identified about 120 preliminary output and outcome measures that relate not only to those goals but also to the products and activities of the program.
- **Conduct stakeholder workshop.** All this information was organized in a matrix and presented to a representative group of stakeholders during a workshop sponsored by FHWA in April 2007.
- **Circulate Request for Information to stakeholders.** The performance measures were refined based on the recommendations from the workshop, and more than 60 outcome measures were distributed nationally for comments and recommendations through a Request for Information (RFI) survey sent out to 253 public and private sector stakeholders.
- **Recommend selected measures for implementation.** The measures were then reviewed and prioritized in terms of relevance to the RWMP, endorsement by the stakeholders, data availability, and ease of implementation.

2 Literature Review

The purpose of the literature review and synthesis is to gather and document examples of performance measures presently used by other agencies to evaluate outcomes associated with their program objectives. The information collected will assist in identifying relevant performance measures for the RWMP.

The synthesis was conducted in two parts. The first was a review concentrating on: 1) literature describing evaluations of traveler information, including Advanced Traveler Information Systems (ATIS) and 511 services as well as RWM systems and services, 2) literature describing methods of evaluating traveler information and RWM systems and services, 3) literature describing control and treatment strategies and the metrics appropriate to measuring performance associated with these RWMP activities, and 4) reports on the "valuation of information," as it applies to the economic benefits associated with RWM systems. Particular emphasis was placed on the outputs and outcomes of weather information on the following areas: traffic management (including traveler information), maintenance management, emergency management, transit management, transportation system performance, and driver performance.

The team examined selected literature on methods of developing performance metrics, as well as the use of performance methods in other subject areas, for applicability to surface transportation weather programs. This included performance metrics currently used for products and services that are similar to RWMP products and services. Specific emphasis was placed on NOAA since that agency has a long history of performance metrics development as part of its activity assessment efforts. Particular attention was placed on the NOAA National Weather Service's Assessment Program and NOAA Regional Integrated Sciences and Assessments Program (RISA).

The literature identified MOEs used by organizations and programs to test hypotheses associated with their organizations' goals. The relationship of performance measures from similar programs and organizations was used to determine best practices, and the effectiveness of the performance measurement across programs and organizations was used to identify lessons learned. The contractor team developed a review template to guide a consistent process for identifying the relevant information about metrics from the literature considered.

The second part of the synthesis was a comparative analysis of elements of performance metrics across the agencies and disciplines considered in the literature review. This analysis provided insight into similarities and differences employed for performance metrics development and application, and it highlighted accepted practices in related organizational and programmatic areas. Building upon the synthesis, the strengths and weaknesses of respective performance metrics were described. The literature review report[1] concluded with a brief summary of findings. These findings found crosscutting support for the goals of 1) customer satisfaction, 2) efficiency, 3) reduced energy and environmental impacts, 4) mobility, 5) productivity, and 6) safety. The review also revealed that while the use of performance measures has not become

[1] Battelle, Meridian Environmental Technology, Inc., and KMJ Consulting, Inc. 2007. *Road Weather Management Performance Metrics Development: Literature Review and Synthesis.* Draft Report. Prepared for the Federal Highway Administration, Office of Operations. Contract No.: DTFH61-D-00007. (March 21).

universally adopted, it is a well-established practice at both the State and Federal levels with continued expansion underway. The theme that pervaded the literature was the importance of performance metrics associated with safety, effectiveness, efficiency, and customer satisfaction. The detailed performance measures covered in the literature vary by the particular program or agency under consideration.

A common theme found in the literature is that the development of performance measures includes a process addressing clear goals supported by a solid commitment to seeing the process through to completion. In addition, the process of performance measurement addresses fundamental questions of conciseness, ease of data collection, ease of interpretation, cost effectiveness, and validity of findings. Consideration is given to ensure that the process developed aims to continually improve programs through constant examination of outcomes and avoiding the pitfall of examining outputs only for program evaluation.

It was found that the fundamental themes of program direction, program management, and customer acceptance are intertwined within the process of performance management. Goals, objectives, and outcomes tend to be connected by the measures utilized to determine the success of applying resources to meet the expected outcomes. Candidate performance measures shown in Table 1 were identified from the literature in the context of four general outcome categories:

- *Enhanced observation capabilities:* extended availability of weather observations through increased spatial coverage, number of observed weather elements and quality of observed data.
- *Advanced state-of-the-practice:* improvements in the implementation and operation of technologies and methods.
- *Coordinated research program:* enhanced management of research activities within agencies and across multiple agencies.
- *Training and outreach:* increased awareness of new knowledge or technology and methods for more effectively using technology through education.

Each of the publications, reports and articles reviewed for this study discussed efforts to assess performance in terms that could be classified into one or more of these categories. In Table 1 the performance measures discussed in the literature are arrayed into these four categories, reflecting how the activities of the various programs focused their performance assessment efforts. The reasons for synthesizing the literature in this way are 1) to identify candidate measures that may be consistent with the needs of the transportation and weather communities, and 2) to help assure that potentially useful measures for the RWMP are not overlooked. The next step is to use this information and these candidate measures as a starting point in refining metrics that are 1) applicable to the RWMP projects and activities and 2) linkable to the SAFETEA-LU goals.

The measures listed in Table 1 are extracted directly from the literature that was reviewed, and many of these measures are quite general or otherwise not immediately applicable to the RWMP as presented in the literature. They need to be refined further to apply appropriately to the RWMP's programmatic goals and activity components. The research team sought to map each of these measures from the literature to the four outcome categories as the first step in moving from the literature synthesis to the formulation of a set of metrics that could apply to the RWMP. The

checked boxes seek to represent how these measures are actually applied in the literature. Measures checked in multiple boxes are mostly those that are referenced in more than one source; hence, they are the more widely used measures. Many additional measures that were observed in the literature were so specifically aligned with a particular program that they were judged less applicable to the RWMP and were therefore not included in Table 1.

Table 1. Candidate performance measures from the literature review.

CANDIDATE PERFORMANCE MEASURES	Enhanced Observation Capabilities	Advanced State-of-the-Practice	Coordinated Research Program	Training and Outreach
Achievement of organization's key objectives	■	■	■	■
Estimated or perceived value of program	■	■	■	■
Change in quality of service provided	■	■	■	■
Level of acceptance	■	■	■	■
Customer satisfaction	■	■	■	■
Adjust subjective decisions into objective framework	■	■		■
Change in organizational structure	■	■		
Change in organizational procedures	■	■		
Impact of deployment in terms of customer satisfaction	■	■		
Specific modifications in human actions	■	■		
Weather forecast improvement	■	■		
On-time performance	■			
On-budget performance	■			
Attitude towards service provided	■			
Perceived convenience of service	■			
Operator performance		■		
Cost efficiency (procedural)		■		
Cost efficiency (operational)		■		
Benefit attributable to a given cost		■		
Benefit/cost ratio		■		
Financial feasibility		■		
Level of effort		■		
Accident reduction		■		
Perceived safety		■		
Planning time		■		
Extent of congestion – spatial		■		
Extent of congestion – temporal		■		
Average travel time		■		
Average travel rate		■		
Perceived travel time		■		
Weather delay (vehicle-hours)		■		
Accessibility of traveler information (by travelers)		■		

3 Hypotheses and Associated Measures

In this part of the study FHWA and the contractor team developed an initial set of measures that are aligned with Section 5308 goals and RWMP objectives for stakeholder review and refinement.

3.1 Matrix of Hypotheses and Measures

Using the literature review and synthesis as a starting point, a set of hypotheses and relevant MOEs associated with FHWA RWMP products and activities were developed. These hypotheses and MOEs, expressed in both qualitative and quantitative terms, were organized under each of the three SAFETEA-LU Section 5308 goals.

The hypotheses generally pertain to social, scientific, organizational, and economic benefits of the RWMP activities and are quantifiable through selected performance measures. In order to establish relevant and implementable measures, the matrix of measures included references to appropriate and available data sources.

Output and outcome measures were identified with enough detail and clarity so that the suppliers of transportation weather products and services and transportation system operators would understand how they could enhance their performance and improve their products and services.

3.2 Workshop with USDOT Personnel and other Stakeholders

The contractor team conducted a workshop at which the hypotheses and preliminary measures were presented and discussed with the United States Department of Transportation (USDOT) personnel and selected stakeholders to obtain feedback and refine the measures before distributing them more widely for additional comment. The workshop was held in the Washington, DC area on April 24, 2007 with members of the Road Weather Management team, representatives from other modes of the USDOT, NOAA, State Departments of Transportation (DOTs), Institute of Transportation Engineers and other stakeholders. An initial matrix with the draft measures was provided to the participants prior to the workshop.

The comments and changes made at the workshop are reflected in the revised matrix of performance measures shown in Appendix A. The matrix served as the basis for subsequent communication with the larger stakeholder community to request more detailed information on the performance metrics.

4 Request for Information

In order to refine and prioritize the metrics, a Request for Information (RFI) survey was developed and distributed to a large group of practitioners across the country. Hundreds of respondents were identified from State DOTs, weather and road weather working groups, NOAA, and other agencies and individuals known to have an interest or involvement in the RWMP. These respondents included providers and users of weather information, such as State DOT policy, maintenance, and operations personnel; transit (all modes) policy; maintenance and operations personnel; transportation and meteorological professional organizations; and other organizations cited in Section 4308(b) of SAFETEA-LU. The providers included both public agencies, who consume weather information for their internal use as well as for delivery to the public, and private sector weather service providers. The weather information users included both public and commercial travelers. More than 250 individuals were selected to receive the RFI survey and evaluate the recommended performance measures.

The refined matrix of output and outcome measures was initially distributed to the workshop participants for their final review and comments. The contractor team decided, instead of distributing a paper copy of the matrix for review and comment, to prepare an on-line RFI to facilitate distribution and receipt of survey materials. The RFI was structured as shown in Table 2 for each of 66 outcome metrics. Respondents were asked to indicate whether they thought each measure was "good" as is, "fair" and needed improvement, or "poor" and should be eliminated. They were asked to provide comments if they felt the metric needed improvement or should be dropped. They were also given the opportunity to add any new metrics that they thought were missing from the list.

Table 2. Example format for on-line Request for Information.

GOAL:	**1. Maximize use of available road weather information and technologies.**			
OBJECTIVE:	**1-1: Maximize access to and use of current road weather data and information.**			
HYPOTHESIS:	**Current road weather data are available, accessible from various sources, and used by agencies, and with proper quality control provide accurate and reliable road weather information to transportation agencies and the traveling public.**			
RWMP Outcome Measures:	**Good (Keep it)**	**Fair (Improve it)**	**Poor (Drop it)**	**Comments**
Number of agencies that have and use a decision protocol that includes consideration of road weather information.				
Other metrics:				

Only the outcome metrics were included in the RFI to simplify the survey and focus on the most important measures, making the process more manageable. The RFI contained 15 sets of road weather program objectives, associated hypotheses for assessing performance against each objective, and 66 outcome measures (metrics) for testing the hypotheses. The outcome measures were designed to assess whether the program's goals and objectives are being met in terms of

results and benefits, both short term and in the long run. Outcome metrics tend to be more qualitative and are often difficult to measure; therefore, they were included in the RFI to seek the help and guidance from knowledgeable stakeholders in reviewing the measures. The RFI respondents were asked to consider the following criteria in their metric evaluation:

- Does the metric address the Section 5308 goal?
- Is the metric relevant to the RWMP objective?
- Is the metric practical in terms of the effort and cost it would take to implement it?
- Will the metric allow comparison of performance across products and services?
- Are data available to support the metric?
- Are other critical metrics missing for each objective?

The draft RFI was sent to the workshop participants to pretest the form and content. Based on the feedback received from the pretest, the RFI was further modified and finalized. The 253 respondents were sent a letter inviting their participation and directing them to the on-line RFI. The contractor team monitored and compiled the results.

Figure 2 shows the distribution of 71 completed RFI surveys by organization type. The large majority of respondents were individuals who worked for State or local DOTs.

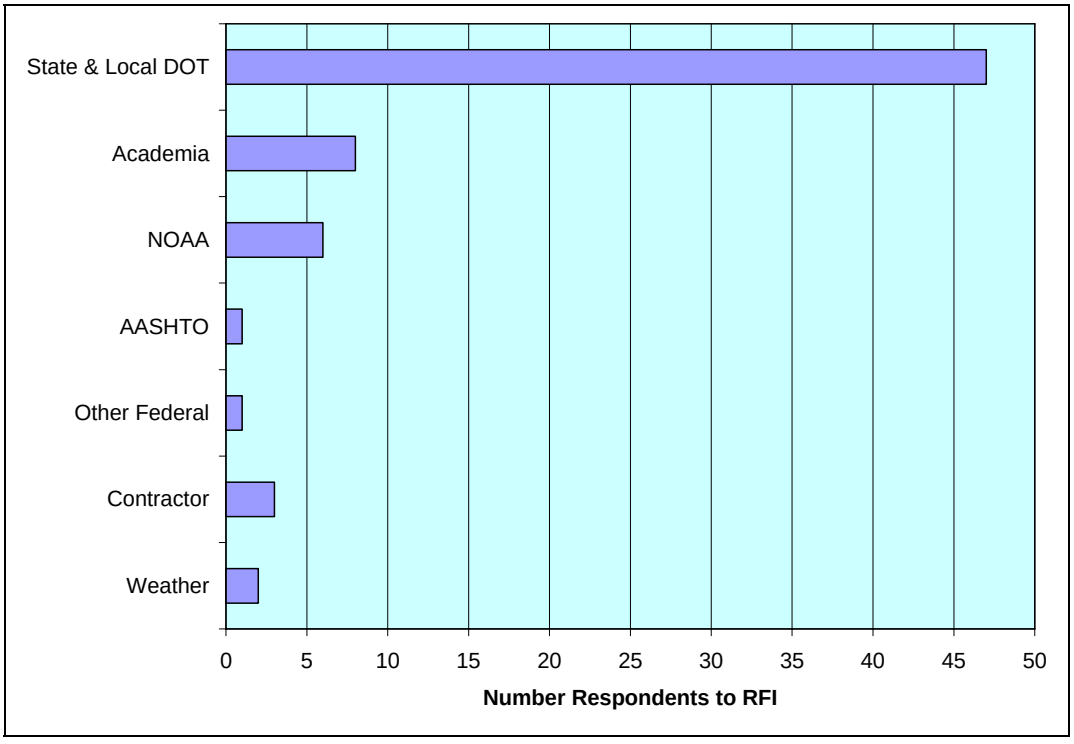

Figure 2. Distribution of respondents to the RFI by agency or organization.

Figure 3 shows graphically how the 71 respondents to the RFI rated the outcome metrics. For the 66 metrics that the respondents were asked to rate, the metric that received the fewest "good" ratings had about half (48.1%) of the respondents who said that metric was "good," and the

highest rated metric among all of them had 86.5% of the respondents rating it as "good." The average (median[2]) rating of "good" was 66.7% for all the metrics. Likewise, 24.3% of the respondents on average rated the metrics as "fair" and only 6.5% rated them as "poor." The highest percentage of respondents rating any of the metrics as "poor" was 30.9% and the highest proportion rating any metric as "fair" was 40.7%. For the most part, the respondents thought the metrics were good and, where they thought improvements were needed, they offered constructive suggestions.

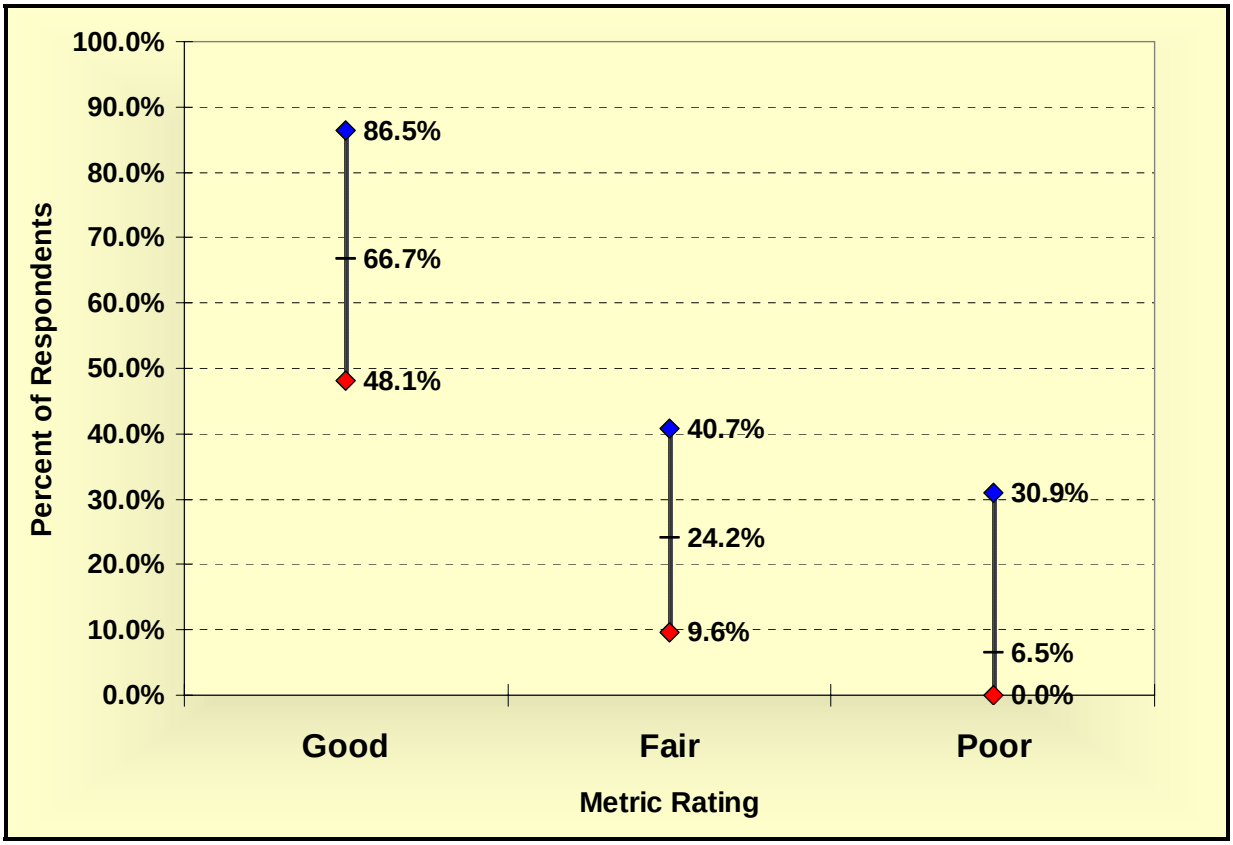

Figure 3. Distribution of ratings of metrics by RFI respondents: range and median values.

A total of 760 individual comments about the RFI were received from the respondents, though many of those comments were repeated over a number of proposed metrics. Table 3a, 3b and 3c present selected examples of comments organized under the three SAFETEA-LU goals and RWMP objectives. While the specific measure that elicited a comment is not shown in these tables, the comments convey a sense of the range of issues and concerns raised by road weather stakeholders regarding RWMP efforts to implement various performance metrics over the coming years.

[2] Median is a measure of central tendency (average) in which half the measures are above the median and half are below the median.

Table 3a. Examples of RFI respondent comments on proposed metrics.

Goal 1: Maximize use of available road weather information and technologies.	
RWMP Objective	**Selected RFI Respondent Comments on Proposed Metrics**
1. Maximize access to and use of current road weather data and information.	• It is available, just not widely used. • An agency may not consider road weather info because there isn't an efficient way of getting the info. • It's crucial to realize that travelers' use of weather information will vary by weather events, subpopulations (e.g., ethnicity, gender, income, age); this will require much time and investment to evaluate properly. • The fact that users simply "use" weather info for a decision is not good enough by itself; needs to include some measure of the effectiveness of the decisions. • Metric is relevant but hard to obtain data, quantify and accurately measure. • Determining causality and attributing crash reduction to weather information will be difficult due to multiple causes. Will require additional research.
2. Maximize use of road weather forecast information.	• Need to find out specific actions or decisions included within the term "using". • Data need to be reliable, accurate, and timely. • Data quality (accuracy and reliability) and usage are more important than a quantity measure. • Costs of such services to agencies are hampering use of these forecasts and there is rarely a performance-related requirement for accuracy.
3. Maximize use of integrated weather and traffic data.	• Those who have been doing maintenance for years haven't learned the benefits of using current technology to improve their jobs. We need to be able to show the benefits from integrating the RWIS with an MDSS program. • Sharing doesn't mean that it is used to increase the quality of the decision process.
4. Maximize adoption of fixed environmental sensor station technology, including atmospheric, roadside and pavement sensors).	• Define "extent" and how you can measure it.
5. Promote deployment and adoption of mobile environmental sensor station technology.	• Spatial and temporal needs vary among differing geographic areas. • Measures activity - not outcome. • Need to identify the usefulness, reliability, and accuracy – quality of data not quantity.
6. Maximize use of decision support systems for road weather management.	• Weather forecasts need to be more accurate for an MDSS to be useful. • Percent coverage is not the same as percent of real usage.

The first goal area shown in Table 3a covers six program objectives and includes numerous proposed individual performance metrics that elicited various responses from the RFI reviewers. Their range of concerns can be characterized as follows:

- Program elements are complex and metrics tend to be unidimensional, so it is important to think carefully about the application of a metric under different circumstances.

- Good use of road weather information is important to evaluate, but first we need to be sure agencies are aware of and have ready access to the information and systems.
- Implementing some of these metrics may take considerable effort and resources.
- Data to support the metrics may be difficult to obtain. We should be clear about where the data will come from and what it will cost to obtain those data. We need a way to assure data quality.
- Additional research needs are likely to be identified in connection with the implementation of many of these metrics.

Table 3b. Examples of RFI respondent comments on proposed metrics.

Goal 2: Expand road weather research and development efforts to enhance roadway safety, capacity, and efficiency while minimizing environmental impacts.	
RWMP Objective	**Selected RFI Respondent Comments on Proposed Metrics**
1. Expand R&D for maintenance decision support (winter and non-winter maintenance) and deploy best systems and practices.	• Important to be able to truly control for differences between untreated and treated roads. • Condition of roadway at time of accident and level of service for the specific route must be known to measure. • Uncomfortable with this because there are many co-dependent factors. • Good outcome, but investment in R&D doesn't necessarily mean these outcomes will be achieved. • Info is not likely available in most places. • This will provide misleading results on agency wide scale; need to relate it to specific highways vs. level of RWIS/ESS support to operations. • I am not sure what this means. • This opens a whole can of worms. How do you define an adverse impact? • Not sure of the relevance.
2. Expand R&D for Road Weather Observation and Forecasting (including data collection and modeling) and deploy best practices.	• Not sure this really measures the extent to which the objective is achieved. However, it is a valid metric for other objectives. • This is great in theory provided you can really measure this. • Leave the causality to the lawyers. I'd suggest you show reduction in crashes and show improvement in use of road weather info and let the numbers speak for themselves.
3. Expand R&D for Weather-Responsive Transportation Management (WRTM) and deploy best practices.	• Hard to quantify. • But do we have the baseline throughput and delay data to compare to after we implement WRTM? • Sometimes an increase in cost could result, because a better level of service is being delivered.
4. Conduct evaluations and benefit cost analyses of RWMP elements that enhance safety, capacity, and efficiency while reducing environmental impacts.	• These measures for RWMP duplicate measures for other aspects. It would seem to me to be very difficult in practice to differentiate outcomes. • The level of service improvement may lead to higher costs. • Not everyone is using this technology in the way it was meant to be used, and they don't know how to use it to save money, and they don't hold anyone accountable. • Very difficult to understand "what" is being measured much less "how" it would be measured. This one gets the "MUSHY METRIC" award.

The second and third goal areas shown in Table 3b and 3c cover additional program objectives. Some of the RFI reviewer comments were similar across the three goal areas and some were

unique to the goal and objectives related to that goal. Some additional general comments regarding metrics proposed for goal areas two and three include the following:

- The implementation of some metrics may require careful attention to research design and statistical rigor, particularly with regard to controlling exogenous program influences, or assuring appropriate baselines against which to measure performance.
- You need to use care when interpreting outcomes because R&D investments may not yield the anticipated results.
- Again, agencies may face unique conditions that make it very difficult to apply and interpret performance metrics used across the board.
- While the program overall may seek to achieve and measure cost reductions, service improvements and desirable performance may well imply cost increases.
- Metrics must be carefully specified and checked to be sure users share a common interpretation of what the metric and its application means.
- You can't assume that a road weather technology that has been transferred to the private sector will end up being successful or achieve its intended purpose.

Table 3c. Examples of RFI respondent comments on proposed metrics.

Goal 3: Promote technology transfer of effective road weather scientific and technological advances.	
RWMP Objective	**Selected RFI Respondent Comments on Proposed Metrics**
1. Conduct training and educational activities for the weather and transportation communities on RWM technologies and practices.	• Use pre-test and post-tests to determine training effectiveness. • Trainees usually don't have much influence on agency practices. • Include all workers, not just trainees.
2. Perform outreach (i.e., websites, informative materials, presentations) and consultation services on RWM technologies.	• Not sure what the results would mean. For example if tech transfer has been done perfectly and training has been done perfectly, the number of inquiries should hopefully be near zero. • Often awareness doesn't lead to use.
3. Expand public-private and public-public partnerships and collaboration in the U.S. to promote technology development and transfer.	• Since technologies vary dramatically in scope and cost, perhaps need to categorize them. • Effectiveness of the technologies is more important than the number generated. • Reaching the marketplace doesn't mean they are successful. • The number/rate treats all technology transfers as equal, which may not be true.
4. Expand partnership and collaboration with international agencies to promote technology transfer and deployment.	• Difficult to measure - depends on information from private companies. • This information is not communicated much - at least not to public agencies. • Number of technologies doesn't necessarily relate to quality of technologies and level of innovation.
5. Conduct conferences and workshops on RWM.	• Difficult to measure if the adoption can be tied to the information from the workshops.

5 Recommended Metrics for Program Implementation

The contractor team worked with FHWA to synthesize and refine the metrics based on the RFI responses and other RWM program considerations. It was important to identify a short list of measures that addressed performance across each of the RWMP's major products and services and within each of the three Section 5308 goal areas. Table 4 lists 11 outcome and output measures selected from among all the measures considered in this study as the best candidates for implementation over the next several years. For each measure, the RWM programs that are linked to the measures and the sources of data that could be used to verify or determine the measure's implementation are identified. These measures are distributed more or less evenly across the three Section 5308 goal areas, and they address all of the major RWMP products and services.

Table 4. Selected Road-Weather Management Program performance measures.

Goal 1: Maximize use of available road weather information and technologies.
Number or percentage of transportation agencies that use road weather information and decision support systems (based on current or forecast information) for making advisory, control and treatment decisions. *(Clarus, MDSS, MODSS, WRTM; Data sources: FHWA, state DOTs, local transportation authorities)*
Number or percentage of travelers who use road weather information for making travel decisions (both pre-trip and en-route). *(Clarus, WRTM, VII, TMC Weather Integration; Data sources: State 511/ATIS sites: private traffic vendors, cable TV weather services)*
Number of environmental sensor stations (ESS) deployed and used by transportation agencies to support decision-making (normalized by total area or length of road network). *(ESS Siting Guidelines, Clarus, MDSS; Data sources: FHWA consultants, State DOTs, local transportation authorities)*
Goal 2: Expand road weather research and development efforts to enhance roadway safety, capacity, and efficiency while minimizing environmental impacts.
Number of agencies participating in and benefiting from road weather R&D projects. *(All RWMP R&D projects; Data sources: FHWA, state DOTs, local transportation authorities)*
Percentage of time roadway meets safety and capacity level of service (LOS) standards (i.e. V/C ratio, etc.) during and after weather events (normalized by the frequency/intensity of winter events). *(All R&D, particularly MDSS, MODSS, WRTM; Data sources: state DOTs, local transportation authorities)*
Reduction in agency costs (i.e. labor, equipment, and materials) due to adoption of maintenance and operations decision-support systems for road weather management. *(All R&D, particularly MDSS, MODSS, WRT; Data sources: FHWA, state DOTs, local transportation authorities)*
Reduction in user costs (i.e. delay, crashes, vehicle operating costs, emissions, salt damage) due to improved road weather advisory, control and treatment strategies. *(All R&D, particularly MDSS, MODSS, WRTM; Data sources: state DOTs, National Highway Traffic Safety Administration (USDOT), insurance industry reports)*

Goal 3: Promote technology transfer of effective road weather scientific and technological advances.
Number of agencies/individuals visited or contacted through technology transfer, training, and outreach efforts. *(All tech transfer, training and outreach activities; Data sources: FHWA, AASHTO, AMS, ITSA, ITE)*
Rate of adoption of RWM technologies (e.g., decision-support systems) by agencies that participated in workshop or training activities. *(All tech transfer, training and outreach activities; Data sources: state DOTs, local transportation authorities)*
Number of RWM technology development, testing, and deployment activities initiated through public or private sector based on identified operational needs. *(All tech transfer, training and outreach activities; Data sources: FHWA, AMS, NWA, ITSA)*
Number of road weather technologies developed through public-private and/or public-public partnerships reaching operational deployment. *(All tech transfer, training and outreach activities; Data sources: FHWA, AMS, NWA, ITSA)*

This prioritized set of measures reflects some combinations of measures that are provided in the tables in Appendix A, and in several cases include output measures, though mostly they are outcome measures. When implemented in practice, each measure will need to be considered in terms of its intended use and the needs and characteristics of the circumstances and location of its use and, on the basis of that, it is likely to be appropriate to reword or modify parts of the measure to best fit those specific circumstances. Several of them as they stand in Table 4 combine elements from more than one of the original metrics.

6 Program Implementation Plan

An implementation plan will be developed that will guide the use of these measures for evaluating both success and performance of the RWMP over the next several years. This plan will address the collection and documentation of the data received from available or developed sources as well as applying quality checking procedures to the information. Further, the plan will address the dissemination of the information and how it will be used by recipients. Finally, the plan will provide a "score card" on the RWMP based on the information received from the implementation of the metrics. Challenges that will be faced in implementing the plan include variability in data format and normalization issues, reluctance to share data, and continued communications with public and instituting agencies to update information. Figure 4 graphically depicts the steps expected to be necessary to successfully implement each measure.

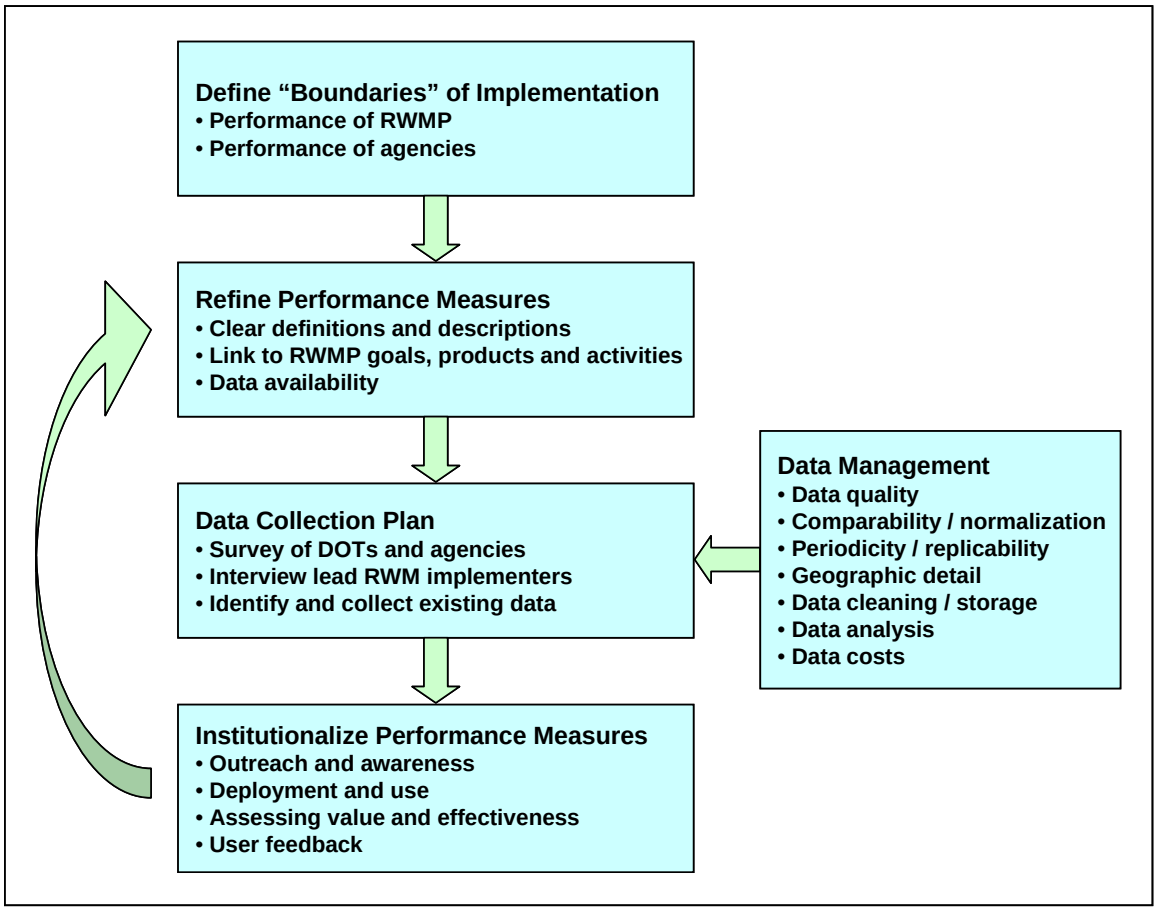

Figure 4. RWMP performance measure implementation process.

It is recommended that this performance measurement project be extended to take the metrics initially identified and recommended (Table 4) and refine and implement those that can be supported with available data and offer the greatest potential to support the performance evaluation of the RWMP products and activities, following the general steps shown in Figure 4

APPENDIX A

PERFORMANCE MEASURES

ROAD WEATHER MANAGEMENT PROGRAM
Federal Highway Administration

May 23, 2007

Goal 1 - Maximize use of available road weather information and technologies.

Objective 1-1	Hypothesis	Output Metrics[1]	Outcome Metrics[1]	RWMP Products and Initiatives	Comments[2]
Maximize access to and use of current road weather data and information	Current road weather data are available, accessible from various sources, and used by agencies, and with proper quality control provide accurate and reliable road weather information to transportation agencies and the traveling public	• Number of agencies using current road weather information to make advisory, control and treatment decisions (e.g. DMS, 511, MDSS, signal timing) • Number of agencies or providers contributing to or receiving information from road weather data networks (e.g., MADIS, *Clarus*) • Number of travelers having access to travel-related weather information • Number of advisory systems or services (e.g. ATIS, DMS, 511) that include road weather information	• Number of agencies that have and use a decision protocol that includes consideration of road weather information • Number of travelers using weather information for making trip decisions • Reduction in the number of weather-related crashes and incidents attributable to the use of road weather information technologies • Reduction in travel times and delays associated with the use of road weather information • User satisfaction with road weather information and technologies	ESS Siting Guidelines, *Clarus*, MDSS, MODSS	

[1] Many of the output and outcome metrics have to be normalized by VMT, size of area and other factors to allow relative evaluations across agencies, locations and operational environments.

[2] In evaluating the appropriateness of each metric in measuring performance against each objective, consider its **relevance** to the objective, its **practicality** in terms of the **effort** and **cost** to implement it, whether it will allow **comparison** of performance across products and services, and the **availability of data** to support the measure. Also indicate whether any critical metrics are missing.

Objective 1-2	Hypothesis	Output Metrics[1]	Outcome Metrics[1]	RWMP Products and Initiatives	Comments[2]
Maximize use of road weather forecast information	Road weather forecast data are available, accessible from various sources, and used by agencies, and with proper quality control provide accurate and reliable road weather information to transportation agencies and the traveling public.	• Number of agencies using road weather forecast information to make advisory, control and treatment decisions • Number of providers of forecast road weather information • Number of road weather forecast data items available to agencies and travelers • Number of travelers having access to forecast weather data. • Number of advisory/warning systems that provide forecast weather info.	• Number of transportation agencies that have and use a decision protocol that includes consideration of road weather forecasts • Percentage of travelers using road weather forecast information for making trip decisions • Reduction in weather-related crashes and incidents resulting from advanced warning system response • Reduction in system travel time and delay resulting from advanced warning system response	*Clarus*, MDSS, MODSS	

Objective 1-3	Hypotheses	Output Metrics[1]	Outcome Metrics[1]	RWMP Products and Initiatives	Comments[2]
Maximize use of integrated weather and traffic data	Integration of weather data into traffic operations will lead to improved traffic management operations decisions and practices that in turn will alleviate the impacts of adverse weather Policies, procedures, and technologies are in place to allow agencies to integrate weather and traffic data and use these data for transportation applications.	• Number of transportation agencies or TMC's having integrated road weather information available for decision making • Number and types of data elements available to support integration of weather and traffic data • Number of transportation agencies with developed weather-responsive management plans • Number and type of transportation operations enhanced by integration of weather information	• Number of transportation agencies that proactively and routinely use road weather data in making operational and maintenance decisions • Extent to which road weather data and information are shared within and among agencies (e.g., transportation, law enforcement, emergency services)	TMC Weather Integration, WRS, Weather Responsive Transportation Management (WRTM)	

Objective 1-4	Hypothesis	Output Metrics[1]	Outcome Metrics[1]	RWMP Products and Initiatives	Comments[2]
Maximize adoption of fixed and mobile environmental sensor station (ESS) technology, including atmospheric, vehicle-mounted, roadside, and pavement sensors)	Fixed and mobile atmospheric and road weather sensors provide accurate data to improve maintenance and traffic management decisions	• Number of ESSs deployed and used by transportation agencies • Number of ESSs included in RWIS or integrated road weather data networks • Number of agencies equipped with and using atmospheric and ESS data • Number of agencies coordinating ESS observations with other agencies • The number of ESS for which metadata are well documented and available	• Extent to which ESS data are used in support of maintenance decisions • Extent to which ESS data are used in support of traffic management decisions	ESS Siting Guidelines, *Clarus*	

Objective 1-5	Hypothesis	Output Metrics[1]	Outcome Metrics[1]	RWMP Products and Initiatives	Comments[2]
Promote deployment and adoption of mobile environmental sensor station technology	Mobile data collection systems including VII probe systems will supplement and enrich existing road weather data sources, and be widely available.	• Number of VII equipped vehicles capable of collecting road weather data • Type and quantity of VII road weather-related probe data available to forecast entities • Number of vehicles equipped with automatic vehicle location and road weather sensors • Number of transportation agencies collecting and using mobile data	• Percent of targeted geography and time period adequately covered by environmental sensors • Accuracy and resolution of road weather reporting and forecasting systems using mobile data • Percent of travelers and agencies that use data obtained from mobile sensors • Number and types of road weather management strategies that use mobile data	VII, AVL/MDC	

Objective 1-6	Hypothesis	Output Metrics[1]	Outcome Metrics[1]	RWMP Products and Initiatives	Comments[2]
Maximize use of decision support systems for road weather management	Maintenance and operations decision support systems that address weather are available, applicable to, and used by transportation agencies	• Number of agencies with decision support capabilities for road weather management • Number of agencies actively using decision support systems for road weather management • Number of vendors providing software or tools with road weather management decision support capabilities • Number of agencies participating in research, development, and training activities for road weather management decision support systems	• Number of weather-related maintenance activities using decision support systems • Number of weather-related operations activities using road weather decision support systems • Number of transportation agencies supporting the deployment and use of decision support systems for road weather management. • Percent of total road miles for which the decision support system is being applied	MDSS, MODSS, Weather Response System for Transportation, Weather Responsive Transportation Management	

Goal 2 - Expand road weather research and development efforts to enhance roadway safety, capacity and efficiency while minimizing environmental impacts.

Objective 2-1	Hypotheses	Output Metrics[1]	Outcome Metrics[1]	RWMP Products and Initiatives	Comments[2]
Expand R&D for maintenance decision support (winter and non-winter maintenance) and deploy best systems and practices	Maintenance decision support system will improve agency decision-making (ability to predict timing and type of weather event, resulting road condition; and optimal application of treatment materials) Maintenance R&D will ultimately lead to deployment of systems that help improve transportation system performance including safety, mobility, capacity, and environment	• Number of agencies participating in R&D activities for maintenance decision support tools and strategies • Number of agencies adopting and using maintenance decision support systems developed from R&D • Number of private sector entities participating in R&D related to maintenance decision support • Number of peer-reviewed publications on maintenance decision-support R&D	**SAFETY** • Number of weather-related incidents and crashes due to untreated roads • Percentage of time roadway meets safety level of service (LOS) standards during a storm event • Number and types of incidents involving snowplows and other maintenance vehicles **CAPACITY** • Average capacity, delay and throughput during weather events • Number of lanes/roads closed and time of closure during weather event **EFFICIENCY** • Type, quantity, cost and cost-effectiveness of labor, equipment and materials used for maintenance • Time to clear roads during weather event	MDSS, MODSS	

Objective 2-1	Hypothesis	Output Metrics[1]	Outcome Metrics[1]	RWMP Products and Initiatives	Comments[2]
			EFFICIENCY (Continued) • Lead time protocols to permit appropriate response times to anticipated and non-anticipated weather events • Ratio of time to clear roads to duration of storm **ENVIRONMENTAL IMPACTS** • Percent of materials out of total used (salt, chemicals) for road maintenance that have low adverse environmental impact • Amount of chemical sprays used for roadside maintenance • Percent of all material applications that violate local environmental standards		

Objective 2-2	Hypothesis	Output Metrics[1]	Outcome Metrics[1]	RWMP Products and Initiatives	Comments[2]
Expand R&D for Road Weather Observation and Forecasting (including data collection and modeling) and deploy best practices	R&D programs designed to improve the quality and usefulness of road weather data and models will lead to better information and decision making which ultimately will enhance highway mobility, safety, capacity and environment	• Number of agencies participating in R&D activities for road weather observation and forecasting • Number of private sector entities participating in R&D related to road weather observation and forecasting • Number of data elements and extent to which road weather data collection and modeling are improved by R&D • Number of peer-reviewed publications on road weather observation and forecasting R&D	**SAFETY** • Reduction in weather-related crash rates attributable to road weather observation and forecasting improvements **CAPACITY** • Percent of time maximum capacity is maintained during weather events due to improvements in road weather observation and forecasting **EFFICIENCY** • Reduction in agency maintenance and operating costs due to improved road weather observations and forecasts • Time savings to agency personnel and to motorists who avoid becoming stranded because of improved information **ENVIRONMENTAL IMPACTS** • Reduction in adverse environmental impacts of weather due to improved road weather observation and forecasting	*Clarus*, ESS Siting Guidelines, Study on Mesoscale Observing Systems, CCTV Visibility Research, Planetary Boundary Layer Concept Development	

Objective 2-3	Hypothesis	Output Metrics[1]	Outcome Metrics[1]	RWMP Products and Initiatives	Comments[2]
Expand R&D for Weather-Responsive Transportation Management (WRTM) and deploy best practices	Advances in R&D and deployment of resulting strategies and technologies for WRTM will help alleviate the mobility and safety effects of adverse weather and the potential environmental impacts of WRTM activities	• Number of agencies participating in R&D activities and implementing WRTM tools and strategies • Number of private sector entities engaged in R&D related to WRTM • Number of R&D projects related to WRTM practices (e.g. traffic signal control; advisory strategies such as DMS, HAR, 511) • Number and type of WRTM best practices deployed • Number of peer-reviewed publications on WRTM R&D	**SAFETY** • Reduction in weather-related crash rates attributable to WRTM strategies **CAPACITY** • Increase in average throughput and capacity, as well as reduction in travel time and delay under inclement weather attributable to WRTM strategies **EFFICIENCY** • Reduction in agency maintenance and operating costs due to implementation of WRTM Strategies **ENVIRONMENTAL IMPACTS** • Reduction in environmental impacts of weather due to implementation of WRTM strategies	Empirical Studies on Weather and Traffic, Weather Response System for Transportation, MODSS	

Objective 2-4	Hypothesis	Output Metrics[1]	Outcome Metrics[1]	RWMP Products and Initiatives	Comments[2]
Conduct evaluations and benefit cost analyses of RWMP elements that enhance safety, capacity and efficiency while reducing environmental impacts	Periodic program reviews and benefit-cost evaluations that address mobility, safety, economic and environmental impacts will improve RWMP products and services	• Number of RWMP product or service evaluations and cost/benefit analyses that incorporate safety, capacity, efficiency, and environmental impacts • Number of agencies evaluating RWMP products and services based on their impacts on safety, capacity, efficiency, and the environment.	**SAFETY** • Reduction in weather-related crash rates attributable to adoption of RWMP products and systems designed to improve highway safety **CAPACITY** • Increase in average throughput and capacity, as well as reduction in travel time and delay under inclement weather • Adoption of RWMP products and systems designed to optimize highway capacity **EFFICIENCY** • Reduction in agency maintenance and operating costs due to implementation of RWMP products and systems designed to improve efficiency **ENVIRONMENTAL IMPACTS** • Reduction in environmental impacts due to implementation of RWMP products and systems intended to mitigate adverse weather effects and preserve the environment	MDSS Cost-Benefit Analyses, ITS Deployment Evaluations	

Goal 3 - Promote technology transfer of effective road weather scientific and technological advances.

Objective 3-1	Hypothesis	Output Metrics[1]	Outcome Metrics[1]	RWMP Products and Initiatives	Comments[2]
Conduct training and educational activities for the weather and transportation communities on Road Weather Management (RWM) technologies and practices	Attendees will appreciate and make use of meteorological and road weather information learned in training	• Number of courses and other training activities conducted • Number of attendees receiving the training • Attendees' evaluations of the usefulness of the training • Number of inquiries for training materials (presentations, specific projects cited)	• Awareness and understanding of RWM programs and technologies • Change in use of RWM technologies in management and operational practice • Development and use of weather-responsive management and operational practices by trainees in their jobs	NHI Course, training CD, *Clarus* training program, MDSS Video, Webinars, MDSS RoadShows	

Objective 3-2	Hypothesis	Output Metrics[1]	Outcome Metrics[1]	RWMP Products and Initiatives	Comments[2]
Perform outreach (i.e., websites, informative materials, presentations) and consultation services on RWM technologies	Focused outreach activities will broaden understanding and promote awareness of RWM technologies and practices	• Number of brochures disseminated • Number of web access (sessions) to RWMP online resources (e.g., PDF reports downloaded) • Number of webinars conducted (and number of attendees) • Number of presentations (and number of attendees) • Number of state/local meetings/conferences with presentations by RWMP staff	• Number of agencies visited/contacted through outreach efforts • Number of inquiries regarding RWM resources and technologies • Number of transportation managers and decision-makers who are fully aware of and knowledgeable about RWMP activities and technologies • Number of citations and links to RWMP reports, websites and other products	RWMP website, tools, brochures, presentations, webinars, MDSS RoadShows	

Objective 3-3	Hypothesis	Output Metrics[1]	Outcome Metrics[1]	RWMP Products and Initiatives	Comments[2]
Expand public-private and public-public partnerships and collaboration in the U.S. to promote technology development and transfer	Federal facilitation will encourage private sector and research institutes to adapt the RWM technologies into practical systems for use by transportation agencies	• Number of vendors offering or improving RWM products (software, hardware, MDSS modules and updates) • Number of commercialized RWM technologies/products • Number of research institutes, consortiums, or stakeholder groups involved in RWM technology development • Number of inter-agency agreements focused on road weather management activities	• Number of road weather technologies developed through public-private and public-public partnerships reaching marketplace • Number and rate of road weather technology transfers per year reaching marketplace	Aurora, TRB, AASHTO, NOAA	
	The public sector will contribute to the identification of operational requirements of RWM in support of technology development	• Number of agencies that are using RWM technologies • Number of public agencies considering RWM technologies • Number of public agencies participating in the development and testing of RWM technologies	• Number of RWM technology testing/development activities initiated through public sector recommendations • Number of deployed RWM technologies that resulted from public sector identified operational needs		

Objective 3-4	Hypotheses	Output Metrics[1]	Outcome Metrics[1]	RWMP Products and Initiatives	Comments[2]
Expand partnership and collaboration with international agencies to promote technology transfer and deployment	International collaboration will benefit RWM in the U.S. by shortening the learning curve in technology development and improving operational practices	• Number of international events and scans attended designed to promote technology transfer • Number of relevant international RWM technologies considered for adoption in the US • Number of international operational doctrines examined • Memberships to international groups or organizations	• Length of the technology development cycle • Frequency of communication between national and international agencies • Number of new RWM technologies identified or adopted based on international partnerships	SIRWEC/PIARC WMTSP	
	International collaboration will provide incentives to US vendors to accelerate technology development	• Number of US RWM technologies adapted in foreign market	• Number of new technologies reaching the marketplace		

Objective 3-5	Hypotheses	Output Metrics[1]	Outcome Metrics[1]	RWMP Products and Initiatives	Comments[2]
Conduct conferences and workshops on RWM	Transportation agencies will learn from sharing operational challenges and potential RWM technology solutions at conferences and workshops	• Number of conferences, road weather sessions, and workshops conducted or sponsored by RWMP • Number of agency attendees in each event • Attendees' evaluations of the usefulness of conferences and sessions	• Awareness and understanding of managers and operators regarding available and applicable RWM solutions and technologies • Rate of adoption of RWM technologies by transportation agencies that participated in the conferences or workshops	Eastern Snow and Ice Expo, ITS America, TRB workshops	
	Developers and consultants will benefit from conferences and workshops through improved identification of operational needs	• Number of vendors and consultant attendees participating in conferences and workshops	• Private sector understanding of public sector operational needs		