Development of a Comprehensive Road Weather Safety Audit Program

Most weather responsive strategies, such as speed management and access control, are reactive. This paper introduces a program development that emphasizes weather influences on highway safety. The objective is to develop pragmatic road weather safety audit processes, procedures, and methodologies where weather-related safety issues can be addressed proactively.

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Introduction

Adverse weather—such as rain, snow, ice, and fog—affects user safety and mobility on the nation's roadways and substantially increases traffic accidents, speed reductions, and travel times. According to the Federal Highway Administration (FHWA), inclement weather is partially or fully responsible for more than 1.5 million highway crashes and more than 600,000 injuries and 7,000 fatalities on U.S. roads every year.[1] The toll from these crashes—important health concerns and economic losses—must be addressed.

The perception that there is little that can be done to mitigate adverse weather effects on transportation safety may linger among some transportation professionals. The fact that weather is rarely considered during project planning and design stages may not be uncommon, as indicated by a survey conducted by the University of Wisconsin–Madison, where it was found that none of 22 responding agencies conduct formal road weather safety audits (RWSA) or similar practices.[2] Because weather conditions are closely related to climate, geography, and terrain differences, crash patterns and trends are fairly random. This situation presents challenges to a reactive safety approach but offers opportunities for a proactive safety measurement—that is, evaluating the safety of roadways before crashes happen using a process such as RWSA. Through RWSA, transportation safety deficiencies can be identified and corrected in early project stages of planning, design, and pre-opening through the review of available and relevant historic crash data, local transportation impacts, and, more important, the possible change to safety conditions of transportation facilities in proximity (or overall network safety performance).[3] Weather-related crashes are a tremendous safety concern, so the same concept can be applied when reviewing highway projects that may be vulnerable to inclement weather.

RWSA is the logical extension of the conventional road safety audit (RSA), but with a particular emphasis on how weather impacts highway safety. It not only inherits all the merits of a typical RSA but also includes special concerns pertaining to such weather conditions as snow, rain, fog, ice, wind, and dust. In Australian RSAs, such environmental factors as rainfall, fog, and sun glare are being explicitly considered.[4] In the 2006 FHWA Road Safety Audit Guidelines, a number of questions about weather and sunlight are included as part of the environmental aspect in the prompt list, acknowledging the importance of weather issues.[5]

Implementing RWSAs would help mitigate potential safety problems. The improvements recommended by the audit can usually be implemented at a cost that is marginal compared to the benefits achieved from the resulting reduction in crashes. Successful stories and testimonies of incorporating RSAs into project development can be found online at FHWA's safety program under "Road Safety Audit."[6] Safety countermeasures on adverse weather impact (that is, icy curve warning system, pavement treatment, roadway delineation, etc.) are constantly being added to the crash modification factors clearinghouse.[7,8] Adding to the existing body of knowledge, this paper describes the development of tangible and pragmatic safety audit processes and procedures by which roadway and weather-related issues can be proactively addressed.

Processes and Procedures

RWSA is a type of RSA that focuses particularly on identifying weather-related road safety issues and concerns. When conducting a RWSA, it is critical to identify relevant stakeholders and their responsibilities; to streamline the audit process using existing facilities, manpower, and resources; and to guide engineers through the carefully designed audit process. The traffic safety program at a state's department of transportation (DOT) can have different roles, responsibilities, and functions, depending on its position in the DOT organizational structure. Regardless of where the safety program resides within a state DOT, it can serve as the administrator to oversee and coordinate all RWSA activities within project planning, development, and design divisions. Certain levels of institutional integration and coordination are needed in order to reach the full potential of a RWSA program within a state DOT or other transportation organization. For instance, it is recommended that the RWSA program be co-administered by the traffic engineering and winter maintenance sections; they benefit from the shared expertise between meteorologists and engineers as well as the relevant data from the Road Weather Information Systems (RWIS) and traffic accident database. Another powerful coalition can be established between the RWSA program and the DOT design unit, from which safety issues can be reviewed and addressed by the design team more efficiently. In this manner, feasible and economically justifiable design alternatives can be considered and evaluated. Subsequently, retrofit actions can be replaced by predictive designs through special provisions included in the DOT facility's development guidance.

A RWSA may be conducted several times during the course of a project, depending on the magnitude and complexity. In general, there are five defined audit stages:

- Feasibility;
- Preliminary Design (30 percent of design stage);
- Detailed Design (60 percent of design stage);
- Pre-Opening; and
- Existing Road Facilities.

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The safety audit program manager is responsible for identifying and selecting funded projects to be audited and for recommending new RWSA initiatives.

The RWSA procedure requires the professional judgment of those with road safety experience and must be conducted by individuals who have appropriate training and who are independent of the entities involved in the project. It is advantageous to have a team of two or more individuals rather than a single person because such diverse backgrounds and differing approaches are favorable, and the cross-fertilization of ideas resulting from a group of people is similarly valuable.[3] In addition to in-house resources, the DOT can use specialty master contracts to bring in external expertise. The master contracts can be serviced for two purposes: 1) for consultants with the experience and capability of conducting RSAs for projects with anticipated construction costs that exceed $25 million; and 2) for general safety purposes on smaller projects. The auditor is responsible for writing a report containing all the safety deficiencies and recommendations after the audit is conducted. The Institute of Transportation Engineers (ITE) RSA process is recommended where, under step 4, field reviews must be performed under various weather conditions if weather is likely to present a problem.[7,8] This is theoretically ideal but practically difficult given most project schedules. As a result, auditors may need to design "what-if" scenarios by referring to similar cases or lessons learned.

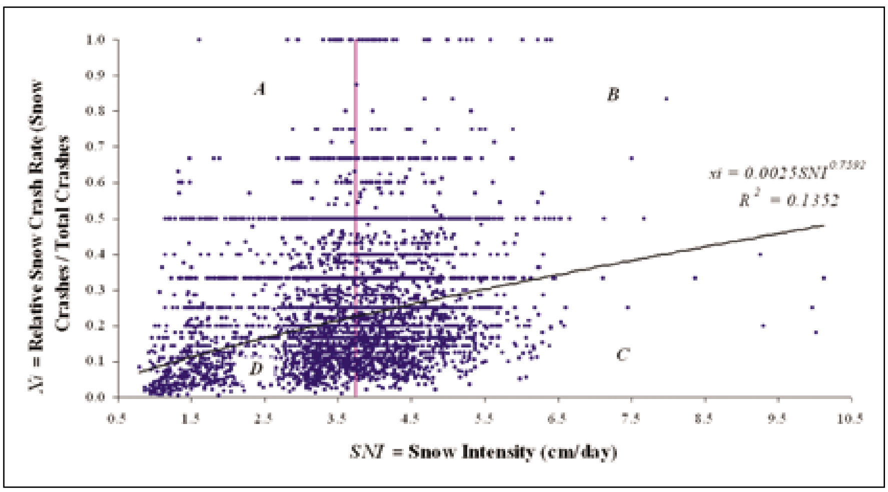

Figure 1. Snow-related crash prediction model.

Methodologies

RWSA can be performed at different scales, depending on the scope of the project. If the goal is to address safety concerns over a large geographic extent using low-cost, systematic safety treatments, then some types of screening methodologies must be implemented. If the purpose is to identify safety deficiencies for a predetermined project, then a project-specific audit is required with the assistance of prompt lists or checklists. Nevertheless, it is important to understand that prompt lists (even the most detailed ones) should be viewed as guidelines only: they are not a substitute for knowledge and experience, and are intended as an aid in the application of knowledge and experience.[5]

Systematic screening methods for identifying road weather safety issues need the rational connection between weather-related crashes and corresponding weather events on a tempo-spatial basis. Use snow-related crashes as an example in which a quantitative method was developed for analyzing snow-related crashes.[9] In Figure 1, the power function for snow crash rates ($x_i = 0.0025SNI^{0.759}$ where x_i is the proportion of snow-related crashes at location I, and SNI is the snow intensity measured by cm per day) and the measure of snow impact, such as median snow intensity, divide the space into four quadrants: A, B, C, and D. Priority is given to weather-vulnerable areas with high relative crash rates but less severe weather problems (Quadrant A) and especially to areas with both high crash rates and severe weather problems (Quadrant B). When using the screening tool, cautions are warranted for areas with a short crash history or very few crashes—for example, areas with 1.0 relative snow crash rate in Quadrant A and B. The areas with low crash rates but severe weather problems located in Quadrant C also deserve a proactive review because crashes are random events. Areas in Quadrant D where both snow intensity and crash risk are low do not demand as many resources as do areas in other quadrants. Identification of these locations—along with supplementary information, such as traffic conditions, highway geometric features, and detailed crash information—will give road safety auditors ample information to proceed with an effective RWSA and to propose appropriate countermeasures.

For ice-related crashes, a different methodology was employed because ice events are more location-specific.[10] Figure 2 displays the distribution of ice-related crash rates in the U.S. state of Wisconsin, where local Moran's I is a spatial autocorrelation metric. Larger Z-scores than +1.96 indicate positive statistically significant spatial autocorrelation—that is, similar values cluster together. Values below –1.96 indicate negative statistically significant spatial autocorrelation—that is, similar values are dispersed.[11] Hence, ice-related crash clusters can be conveniently identified. Integrating data based on geographic information system (GIS) with advanced spatial statistical techniques helped to identify patterns of ice-related crashes along highway bridges that are considered ice-prone locations.

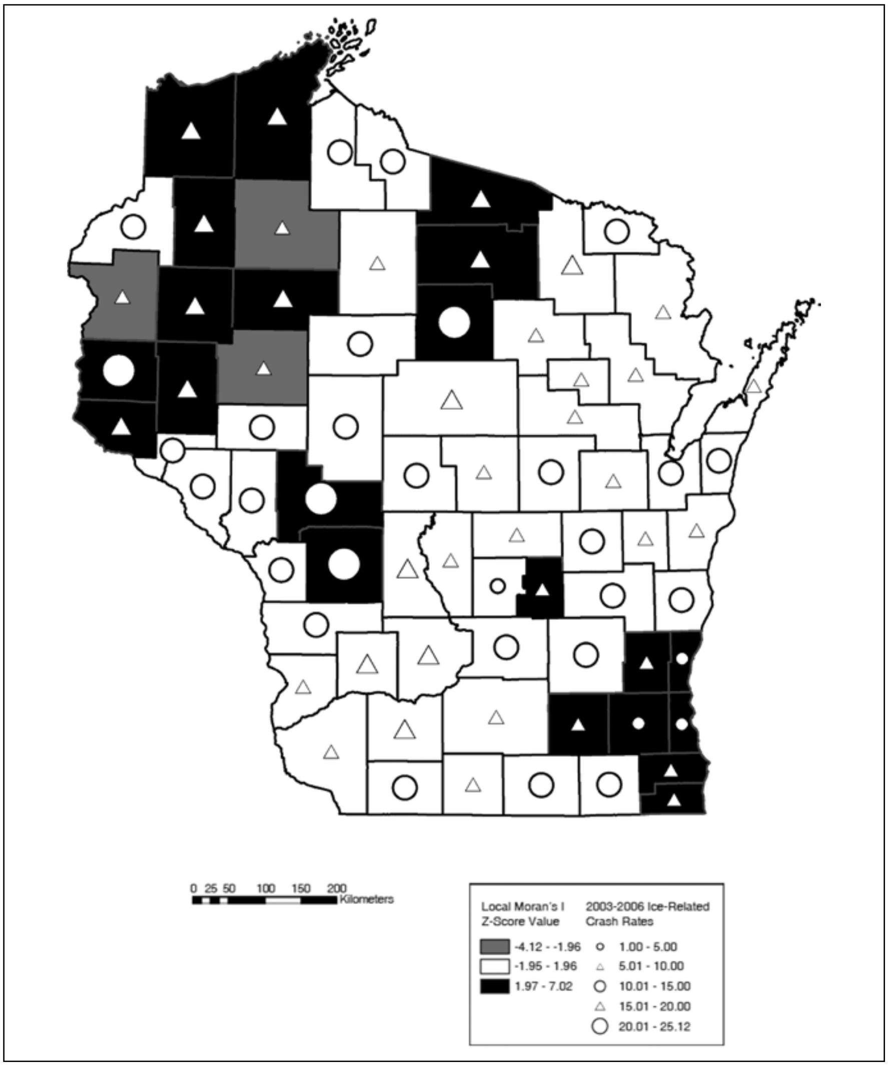

Figure 2. Ice-related crash rates for Wisconsin counties, 2003–2006.

County winter maintenance personnel can use these results to improve current anti-icing and de-icing policies and to implement proactive measures, such as anti-icing at bridges.

For a predetermined project, the primary element of a RWSA is the use of prompt lists to assist auditors in identifying potential safety concerns. The prompt list guides users to think of what can be done differently on the project as a result of an RWSA. In this study, prompt lists were created and crafted per general engineering practices and policies by combining information from various design manuals. The content of each prompt list depends on the type of project and stage to be performed—that is, any of the first four stages can be used with new projects, depending on the status or progress of the project. Additionally, a "Weather Constraints" section was developed and included in each stage. This weather section was created to evaluate and improve road weather-related safety issues caused by common weather events like snow, rain, ice, and fog. For example, Table 1 includes these issues in the "Weather Constraints" section of the feasibility stage. This weather-related prompt list, along with prompt lists pertaining to other project considerations, assists auditors in identifying design, operation, and weather-related safety concerns. By evaluating weather effects in the feasibility stage, other potential problems can be circumvented, such as the decision to install snow fencing along a route where drifting snow may occur or the application of new pavement materials like open-graded asphalt for effective drainage of rainwater. Advanced pavement marking materials, such as wet-reflective tape and signing,

Table 1. Weather constraints within feasibility stage.

Item	Issue	Actions and Comments
1. Route choice	Has the location of the route been checked for any potential weather issue?	
	Is the site or area selected for the project free of any weather related problem? (Consider snow, fog, rain or flood, ice, wind, others)	
	Can the route be modified in order to avoid or minimize any weather-related issue? Consider historical weather information. If YES, how can it be modified?	
2. Intersections	Is the area free of any weather-related issue that could disfavor the proposed intersection layout? Consider historical weather information.	
3. Other concerns	Is the area free of the potential of flooding? Consider historical weather information.	
	Were the effects of wind, rain, snow, ice, fog, and sun angles adequately considered in the design?	
	Does the general design approach fit in with the likely weather in the area?	
	Is the illumination sufficient for safe traveling at night or under low-visibility conditions?	

could be recommended during the preliminary design stage. Special design features related to drainage and pavement skid resistance could be forwarded during the detailed design stage. A spectrum of road weather safety applications could be considered via a proactive review, ranging from such infrastructure improvements as fog or ice warning systems to such operational enhancements as alternative signal timing plans and access control, or such maintenance advancements as fixed anti-icing systems.

Data Requirement

Without reliable and accurate data, the RWSA methodologies cannot work effectively. In fact, the difficulties of conducting RWSA are primarily due to the scarcity of road weather information and the limited accessibility of this information to engineers, planners, and designers. The task of interpreting and applying weather information may be intimidating to auditors; therefore, quantifiable, meaningful, and user-friendly weather data are critical to successful RWSAs. In this study, exemplary cases show how the weather and crash information was collected, processed, and analyzed.

Two major resources have been consulted: Road Weather Information System (RWIS) and National Weather Service (NWS). For example, the state of Wisconsin has more than 50 RWIS stations that employ specialized equipment and computer programs to monitor air and pavement temperatures. Typically, RWIS does not collect precipitation intensity or visibility information, and the data that is collected may be unreliable. As such, NWS data provides better and more complete coverage.[12]

Snowfall data was gathered from 151 NWS stations in Wisconsin, and snow intensity applied in the previous example was calculated by the ratio of total snow precipitation to snow days. The same approach was also used in calculating rainfall. Fog information was measured by the average number of fog events per month for each observing station. Weather data collected was for point locations and then interpolated into a continuous surface for the whole state. The universal kriging model was used to perform this interpolation, by which spatial trends and correlation of weather variables (with elevation) were included into the models to improve the predictive power.[13]

Weather-related crash data were retrieved from the state accident database using the FHWA definition—that is, any crash occurring during adverse weather conditions (snow, fog, sleet, or rain), slick pavement conditions (snowy, icy, slushy, or wet pavement), or both.[14]

An important piece of information that is usually not effectively captured in the audit procedure is the knowledge of local officials and those who routinely provide maintenance of the designated roadway section. An example of this was found during the STH 69 audit in Wisconsin. On the north end of the project near the Dane/Green County line is a low point in the roadway profile at the bottom of a long downgrade, which is surrounded by a large area of wetlands and small ponds. Because of being a topographic low point with an abundant supply of moisture, this section of roadway is a frequent location of wet pavement, black ice, and/or fog during various times of the year. In most cases, the roadway segments north and south of this segment do not experience these conditions. The problem is that no current Wisconsin Department of Transportation database is designed to identify such locations. The use of a RWSA procedure providing a prompt-list item is critical to ensure that appropriate people are contacted and that they contribute to the audit so that this safety problem location is appropriately addressed.

Conclusions

The weather component of the RSA procedure is unique; currently, few agencies have developed a weather-related procedure. This research has shown that weather can be effectively utilized in the audit process and should be an active component of any safety audit procedure. Auditors are encouraged to combine information with their own experiences and local knowledge to make determinations.

This study introduces the development of the RWSA program and demonstrated a protocol of utilizing weather and crash information to address complex interactions of different aspects of road, weather, and traffic safety. Institutional support ensures the sustainability and accountability of an RWSA program. The data-driven approach proactively assesses the weather impact and mitigates its effects on public safety. The practice can readily be applied by other agencies in combination with their own processes, available funding, and staffing resources.

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References

1. Alfelor, Roemer and C. Y. David Yang. "Managing Traffic Operations during Adverse Weather Events." *Public Roads,* Vol. 74, No. 4 (2011): FHWA-HRT-11-002.

2. Qin, Xiao, David Noyce, Ghazan Khan, and Zylkia Martin. *RWSA Plan Development and Initial Implementation—Final Report.* Madison, WI: Department of Civil and Environmental Engineering, University of Wisconsin–Madison, 2006.

3. Transportation Research Board (TRB). NCHRP Synthesis 336: *Road Safety Audits, A Synthesis of Highway Practice.* Washington, DC: National Cooperative Highway Research Program, 2004.

4. AUSTROADS. *Road Safety Audit,* Second Edition 2002. Sydney, Australia: Austroads Incorporated, 2002.

5. Federal Highway Administration. *FHWA Road Safety Audit Guidelines.* Accessed June 2012. http://safety.fhwa.dot.gov/rsa/guidelines/documents/FHWA_SA_06_06.pdf.

6. FHWA. *Road Safety Audit* (RSA). Accessed December 2012. http://safety.fhwa.dot.gov/rsa/.

7. FHWA. Crash Modification Factors Clearinghouse. Accessed December 2012. www.cmfclearinghouse.org/results.cfm.

8. Institute of Transportation Engineers (ITE) in cooperation with the Federal Highway Administration (FHWA). *Road Safety Audits & Road Safety Audit Reviews, Executive Summary.* Accessed June 2012. http://safety.fhwa.dot.gov/rsa/.

9. Qin, Xiao, Ghazan Khan, and David A. Noyce. "A Spatial Statistical Approach to Identifying Snow Crash-prone Locations." Paper presented at the 87th Transportation Research Board Annual Meeting, Washington, DC, 2007.

10. Khan, Ghazan, Kelvin R. Chaparro, Xiao Qin, and David A. Noyce. "Application and Integration of Lattice Data Analysis, Network K-functions, and GIS to Study Ice-Related Crashes." *Transportation Research Record* 2136 (2009): 67–76.

11. Fotheringham, A. S., C. Brunsdon, and M. Charlton. *Quantitative Geography: Perspectives on Spatial Data Analysis.* Sage Publications, 2000.

12. Surface Weather Observation Stations (ASOS/AWOS) Web site. Accessed June 2012. www.faa.gov/air_traffic/weather/asos/?state=CA.

13. Ormsby, Tim and Alvi Jonell. *Extending ArcView GIS.* Environmental Systems Research Institute, Inc., 1999.

14. FHWA. *Road Weather Management Program.* Accessed July 2012. http://ops.fhwa.dot.gov/weather/.

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