Application of Road Weather Safety Audit to the Wisconsin Highway System

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Abstract. There is a perception that transportation professionals can do little about adverse weather effects because it is “Mother Nature”. Accordingly, most of the weather responsive strategies are reactive such as speed management, access control and other operational practices. In fact, particular weather factors should be considered during the design, perhaps even the project planning stages, to avoid large remedial costs. The objective of this study is to develop a pragmatic safety audit process and procedure in which roadway and weather-related issues can be addressed proactively.

The paper introduces the development of the road safety checklist with the emphasis on potential weather influence on highway safety. A total of five road safety audit checklists were developed for a series of stages from the project development to the project completion: Feasibility Stage; Preliminary Stage; Detailed Design Stage and Pre-Opening Stage. Consistency and usability were key elements in the checklists development. A quantitative method is also provided to assist auditors in evaluating the severity of road weather safety problems. Meanwhile, this paper proposes an approach to institutionalizing the road weather safety audit by incorporating the road safety audit procedure as part of the Facilities Development Manual (FDM) which is the departmental procedure guidance for the development of road projects in Wisconsin.

BACKGROUND

Every year, transportation professionals face the increasing demand of enhancing traffic safety on the U.S. highways. Various strategies have been employed with this regard to reducing traffic conflicts, injuries and fatalities. Among these, hot-spot management is the one applied widely by state Department of Transportation (DOT) and other highway safety agencies. Hot-spot is a colloquial term for road segments or junctions in the highway network that show a higher density or frequency of fatalities and severe injuries or overall crashes than others within a region. Due to many statistical anomalies, the clusters of crashes are usually chance effects. In fact, hot-spots generally account for less than 20 percent of crashes with remaining crashes dispersed through the highway network. Even though a hot-spot has been identified through a clear crash pattern, the specific countermeasure may act only as a ‘band aide’ solution to part of the problem and not address the broader safety issue. Therefore, it is necessary to migrate from the reactive hot-spot management to a more proactive approach – evaluating the safety of roadways before crashes happen – called road safety audit or road safety assessment (RSA). It is indeed a “a formal examination of a future road or traffic project or an existing road, in which an independent, qualified team reports on the project’s crash potential and safety performance” (I).
The RSAs have been accepted in many counties and some states in the U.S. In addition to Australia, New Zealand and the United Kingdom, countries such as Canada, Denmark, India, Ireland, Italy, Malaysia, Norway and Singapore, are currently conducting some form of road safety audits (2). Within the United States, Pennsylvania, Iowa, New York, Minnesota, South Carolina, South Dakota and Wisconsin are among the states presently conducting some form of road safety audits (2, 3, 4, 5). However, the development and the condition of RSA vary from county to county, state to state. Some have developed manuals to guide practices and carried out RSAs for years, while others are initiating programs for the first time. In light of this global interest, efforts are underway to develop a formalized safety audit program in Wisconsin.

Transportation safety deficiencies can be identified and corrected in early stages such as planning, design and pre-opening by reviewing historic crash data, local transportation impact and, more importantly, the possible change of safety condition of adjacent transportation facilities or overall network safety performance through RSAs. The same concept can be applied to review the highway projects that may be vulnerable to inclement weather because weather related crashes are a tremendous concern particularly in Wisconsin. Wisconsin is a land of vivid extremes – from winter snowdrifts to sweltering heat, from crisp autumn afternoons to wet, blustery days. Not surprisingly, the transportation system of Wisconsin is no exception to the effects of adverse weather. According to the Wisconsin Department of Transportation (WisDOT), during adverse weather conditions approximately 1,430 persons were killed on Wisconsin roads from 1999 to 2002 and 116,790 were injured in crashes. Approximately 304,115 weather-related crashes were reported during this four-year period. Occasionally, the impact of inclement weather to the transportation system can be taken to an extreme: on October 11, 2002 Wisconsin witnessed the deadliest crash in its history involving 50 motor vehicles, a total of 10 fatalities and 39 injuries as the result of a fog-related crash on highway I-43 in Sheboygan County along Lake Michigan. This type of tragedy could have been avoided if a fog warning system had been in place.

Despite the repeat detriment to the Wisconsin highways by weather, there is a perception that transportation professionals can do little about it because weather is “Mother Nature”. Accordingly, most of the weather responsive strategies are reactive such as speed management, access control and other operational practices. Weather effect is not or rarely considered during project planning and design stages. This situation is not unique in Wisconsin but fairly common across the country, as indicated by the national information request conducted by the University of Wisconsin-Madison. The objective of this request was to obtain information regarding practices and use of RSAs or Road Weather Safety Audits (RWSA) which was defined as an extension of the RSA, differing from traditional assessments by addressing specifically road weather related issues. None of the 22 responding states are conducting road weather type safety audits or RSAs with the incorporation of weather as defined previously. One of the questions asked what agencies are doing regarding road weather safety. Only Illinois, Iowa, New Jersey, and Washington responded to this question. Illinois performs skid testing and uses Road Weather Information Systems (RWIS) to know when they need maintenance forces out to address road weather conditions. Iowa monitors friction numbers and performs crash analyses on low friction roads. New Jersey has a wet weather/skid crash reduction program and merges crash data with their pavement management systems skid coefficient number for appropriate pavement correction measures. Washington is installing weather sensor stations and
Environmental Sensor Stations are used to improve snow and ice control and operational decisions. Needless to say, these technology enhancements improve road weather safety but confine themselves to the limited information obtained through tested locations and RWIS stations. To be more proactive, the road weather safety issue should be addressed from spots to areas by a systematic and programmatic strategy.

Current RSA procedures, unfortunately, place little emphasis on weather issues; focusing more on road geometrics and operations using night time as the worst case scenario for road performance evaluation. This practice leaves little consideration for the effects of snow, ice, fog, rain, winds and other weather conditions commonly experienced by Wisconsin drivers. This study was designed to develop a pragmatic safety audit process and procedure in which roadway and weather-related issues can be addressed proactively.

**ROAD WEATHER SAFETY AUDIT (RWSA) FRAMEWORK**

RWSA is the logical extension of conventional RSA with particular emphasis on the weather impact to highway safety. It not only inherits all the merits of regular safety audit, but also includes special concerns pertaining to weather under a series of conditions such as snow, ice, rain, wind, etc. The purpose for the road weather safety audit framework is to identify the relevant stakeholders and their responsibilities, to streamline the audit process using existing facilities, manpower and resources, to guide engineers through the carefully designed audit checklists and to ensure the successful implementation of the RWSA program in Wisconsin.

**Organizational Structure for RSA/RWSA**

Improving highway safety and reducing number of crashes and crash severities are primary goals for WisDOT. Different divisions within WisDOT have different engagement and commitment to incorporating safety into their daily operations. Hence, selecting the most appropriate division or agency in WisDOT to manage RSA/RWSA is the key to success. An overview of the existing organizational structure helps identify the best area for the RSA/RWSA requirements. The traffic safety engineering program in WisDOT is a cross-division function that primarily involves the Bureau of Highway Operations (BHO) and Bureau of Project Development (BPD) in the Division of Transportation System Development (DTSD). BHO develops policies, standards and manuals related to the use and preservation of highway facilities; consults with transportation districts on roadways and roadside facilities; provides specialized help on traffic engineering, signs, markings, traffic signals/controls and lighting systems; and links safety management with highway operations. BPD develops policies, standards and manuals related to safe highway design; creates state and county maps; and provides training, support and expertise on specialized design services and quality management for transportation facilities and programs.

Highway safety is also an important component in the WisDOT programming and planning process managed by Bureau of State Highway Program (BSHP) including Hazard Elimination Program (HES), now replaced by Highway Safety Improvement Program (HSIP). In addition to engineering, enforcement and education programs are administered by Bureau of Transportation Safety (BOTS) in the Division of State Patrol (DSP). In general, safety can be, more or less,
presented in the areas involved with programming, planning, design, operations and maintenance processes in WisDOT.

After deliberate consideration, we chose BHO over other bureaus to house the RSA/RWSA program for three major reasons. First, the nature and the functions of BHO secure the necessary resources and eligible personnel for managing highway safety, including road weather safety. BHO regularly conducts highway safety analysis in WisDOT and positions a state highway safety engineer or his/her counterpart. Moreover, the BHO winter maintenance group consists of contracted meteorologists who make BHO advantageous to others in monitoring, collecting, synthesizing and analyzing weather information that is indispensable to RWSA. Second, BHO has an excellent relationship with regions and local jurisdictions in Wisconsin. BHO formed the Traffic Safety Engineering Workgroup which tightens the bond between the central office and the regional and local traffic engineers. BHO has successfully reached out to other safety coalitions such as the Wisconsin County Highway Association and local municipalities. Third, BHO has been actively cooperating with other WisDOT divisions such as BHD and BHSP. For example, BHO works closely with BPD to design safer highways and establish new traffic operations and management strategies for such new requirements as roundabouts and work zones. BHO is involved in the process of safety programming and planning by reviewing HES/HSIP applications for BHIP. Considering all stakeholders’ current roles and responsibilities in WisDOT highway safety program, the existing interagency relationship and the available resources and staffing, BHO is recommended to lead the RSA/RWSA program in WisDOT. The institutional arrangements may need to be adjusted to accommodate the changing needs and level of cooperation of the stakeholders. In Figure 1, solid line represents subordinate relationship; dashed line indicates coordination and cooperation; solid box symbolizes current agencies and programs and dash box stands for proposed program.

![WisDOT Institutional Arrangement Chart](image-url)

**Figure 1** — WisDOT Institutional Arrangement Chart
RSA/RWSA Processes and Procedures

An institutional layer that supports road weather safety audits demands complete institutional integration and coordination to realize the complete benefits of a fully-developed and integrated safety audit program and infrastructure in the state of Wisconsin. It is recommended that the RSA/RWSA program administrated by BHO and led by the state traffic safety engineer or his/her counterpart. Within the program, the road weather safety part will be headed by BHO winter maintenance section, a mixture of meteorologists and engineers. BHO should continue to work closely with BPD who develops and maintains DOT’s facilities development guidance to keep the safety audit related documents updated. BHO should also work with BHIP to fulfill the safety audits in the project planning and design stages following the RSA/RWSA program requirements. The program should adopt both top-down and bottom-up management strategies: top-down mandates the audit for projects meeting such criteria as project magnitude, cost, safety impact and duration; bottom up gives regions or local agencies flexibility to conduct safety audits based on request.

A RSA/RWSA can be conducted several times during the course of a project, depending on its magnitude and complexity. In Wisconsin, there are five defined stages: feasibility, preliminary design (30 percent of design stage), detailed design (60 percent of design stage) and pre-opening (or soon after the project is complete), the existing road stage. Usually, safety audits are not conducted in each stage for every project because of limited resources. Although benefits are obtained on all stages, larger benefits are produced on the early stages. Some projects have had estimated benefits/savings of up to several million dollars as a result of the audits. The safety audit program manager is responsible for selecting the projects to be audited with BHIP and urging project managers to submit the safety audit request at the proper time, phase, or stage of the project.

The RSA/RWSA procedure requires professional judgment by people with road safety engineering experience. It must be also conducted by people who have appropriate training and independence of the organizations that are involved in the project. It is advantageous to have a team of individuals of two or more people rather than a single person because diverse backgrounds and different approaches of different people are favorable, and the cross-fertilization of ideas resulting from a group of people is valuable as well (1). The safety audit program manager is responsible for forming an audit team, coordinating with the team members and choosing the available and appropriate auditors for specific projects. The auditor or team of auditors is also responsible for writing a report containing all the safety deficiencies after the audit is conducted. This report may contain recommendations for mitigating the deficiencies found, but not a detailed description of them. We recommended the Institute of Transportation Engineers (ITE) RSA flowchart in Figure 2 as an overview of this process (6).
RSA/RWSA Checklists

The primary element of a RSA is the use of checklist to lead auditors to potential safety issues when auditing a road or project as mentioned earlier. There is no formal or procedural way to create a RSA checklist. Therefore, the development of a RSA checklist requires an in-depth understanding of the project delivery process and the potential road safety issues throughout. An effective RSA checklist will lead auditors to a detailed analysis of all possible safety concerns rather than only checking common design standards. In addition, the audit procedure must be user friendly and easily managed during office and field audits.

Checklists were created and adapted to Wisconsin practices and weather patterns by combining information obtained from the Wisconsin Facilities Development Manual (FDM), the Manual on Uniform Traffic Control Devices (MUTCD), and common weather conditions in Wisconsin.

Repeatability of items or issues was a common factor from one stage to another in each checklist. However, it is important to notice that this repeatability is necessary since not all stages are audited. Consistency was another significant element to consider while preparing the new checklists. Making consistent checklists for the different stages of the audit process facilitates and simplifies the work of auditors. In other words, auditors will become familiar with the series of questions to consider and have an idea of what to expect while using the checklists. Consistency will also help when documenting the information or findings gathered into the audit report.

Five stages of checklists were developed for the Wisconsin procedure. These are:

- Feasibility Stage;
- Preliminary Stage (30 percent of design stage);
- Detailed Design Stage (60 percent of design stage);
- Pre-Opening Stage; and
- Existing Roads Stage audit.

A number of topics were included into each of the road safety audit stages. Consistency is omnipresent in the checklists content. The content of each checklist is dependent on the type of project and stage to be performed. For example, any of the first four stages can be used with new projects depending on the status or progress of the project. For existing facilities, only one safety audit stage can be conducted (existing road stage). It is important to mention that these checklists are expected to be a “living document” meaning that changes can be made to adapt to different types of projects.

As cited, the first audit stage, near the beginning of a project, is the feasibility stage audit. This stage includes topics such as the appropriateness of the proposed design to accommodate different types of vehicles; the appropriateness of the number of accesses to developments; route choice; sight distances concerns; intersecting angle; number and spacing of intersections; and the appropriateness of the design speed with the function of the road.

The preliminary stage audit is the second stage in the audit process and is completed when 30 percent of the design is finished. The preliminary stage audit includes general topics like drainage, landscaping, accesses to developments, accommodation for maintenance and emergency vehicles, and parking provision. It also includes design issues such as cross section elements, alignment, sight distances and intersection layout. Special road user (pedestrians, bicyclists, public transport) issues are also included. Some other issues covered are lighting, signage and pavement markings.

The third potential audit stage within the road safety audit process is the detailed design stage. This stage is conducted as soon as approximately 60 percent of the design is finalized. In this way, unnecessary remedial construction costs can be avoided. The detailed design stage covers design features related to drainage, pavement skid resistance, geometry, medians, shoulders, barriers and guardrails, readability, traffic signals, signs, markings, special road users and parking provisions, depending on the type of roadway.

Particularly, a “Weather Constraints” section was developed. This weather section is aimed to evaluate and improve road weather related safety issues due to common weather conditions like snow, rain, ice and fog. As an example, Table 1 includes the issues in the feasibility stage “Weather Constraints” section. A “Weather Constraints” section was included in each stage of the Wisconsin road safety audit checklists. Note that the “Weather Constraints” sections were developed by gathering road weather safety aspects from road weather safety experiences through the review of literature. This weather-related checklist, along with the checklists pertaining to the other project considerations, is expected to assist the auditors in identifying design, operation and weather-related safety concerns in Wisconsin.
<table>
<thead>
<tr>
<th>ITEM</th>
<th>ISSUE</th>
<th>ACTIONS AND COMMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Route choice</td>
<td>Has the location of the route been checked for any potential weather issue?</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Is the site or area selected for the project free of any weather related problem? (Consider snow, fog, rain or flood, ice, wind, others)</td>
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<td></td>
<td>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?</td>
<td></td>
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<tr>
<td>2. Intersections</td>
<td>Is the area free of any weather related issue that could disfavor the proposed intersection layout? Consider historical weather information.</td>
<td></td>
</tr>
<tr>
<td>3. Other concerns</td>
<td>Is the area free of the potential of flooding? Consider historical weather information.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Were the effects of wind, rain, snow, ice, fog, and sun angles adequately considered in the design?</td>
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<td>Does the general design approach fit in with the likely weather in the area?</td>
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<td></td>
<td>Is the illumination sufficient for safe traveling at night or under low visibility conditions?</td>
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Table 1 — Weather Constraints within Feasibility Stage

**RSA/RWSA INTEGRATION WITH CURRENT DOT POLICY**

In order to better institutionalize the RSA/RWSA practice, the RSA/RWSA has to be incorporated into the existing departmental policy, guidelines, processes and procedures. The Wisconsin Facilities Development Manual (FDM), composed of a total of 27 chapters (two more chapters are being planned), offer policy, procedural requirements and guidance for the facilities development process inside DTSD. This manual is utilized for all types of highway improvements on the State Trunk Highway System, streets or highway systems for which federal funds may be utilized and state facilities road systems funded with state funds administered by WisDOT. To become an effectively used component of traffic safety in Wisconsin, the RSA/RWSA procedure must be included in the FDM to provide detailed guidance and procedural requirements (as intended by the FDM).

As depicted in Figure 2, the RSA/RWSA procedure comprises a total of eight steps. These steps are:

- Identify project to be audited;
- Select Audit Team;
- Pre-audit meeting;
- Perform field reviews or inspections;
- Conduct audit analysis and prepare report of findings;
- Present audit findings to project owner/design team;
- Prepare formal response; and
- Incorporate findings into the project when appropriate.
According to the FDM, the Facilities Development Process (FDP) is a series of activities which lead to the development of a highway improvement project. Thus, the RSA/RWSA procedure needs to be incorporated as part of the FDP, as part of the activities performed for the development of highway improvement projects.

Chapter 3 (Facilities Development Process) in the FDM is divided in six sections and it is intended to provide a uniform and consistent approach that is applicable to all types of projects. Thus, in order to keep that consistency and uniformity through all the projects, the RSA/RWSA procedure will be incorporated initially within the six sections included in this chapter. The six sections in Chapter 3 are:

- Section 1 – Process Overview;
- Section 5 – Concept Definition;
- Section 10 – Investigation;
- Section 15 – Determination;
- Section 20 – Final Design; and
- Section 25 – Pre-contract Administration.

According to the FDM, sections 5 to 25 are at the same time the major developmental phases of the FDP.

In section 5 of Chapter 3 (Concept Definition), a Concept Definition Report (CDR) is prepared with the objective of establish an agreement between the District Project Development (PD), System Planning and Operations (SPO), Technical Services (TS) and other sections as to the timing and scope of the project. The CDR is prepared by SPO and it needs to answer essentially three questions:

- Where is the project location? (a map should be provided in the CDR)
- Why the project needs to be established?; and
- What are the project concepts that the district is proposing?

A feasibility stage safety audit concentrates on the general concept of the project including aspects such as route choice, general layout and the number of intersections. As shown, there is definitely a relation between these two stages, thus a good opportunity for conducting a feasibility stage audit is after the completion of the Concept Definition of the project.

As an example in Figure 3, the first three steps of the road safety audit procedure (Identification of project to be audited, Selection of audit team, and Pre-audit meeting) can be included into the Concept Definition phase of the FDM, while the fourth step (Perform field reviews or inspections) can be performed right after the completion of the Concept Definition. The audit team selection (step 2) needs to occur parallel to the concept definition after knowing if the project is to be audited, so that the feasibility stage audit can be conducted right when the CDR is completed. After the audit team is selected, the first pre-audit meeting needs to be organized to make sure that all the audit team members understand the audit process and that all the necessary information is provided to them. After an audit stage is conducted, all the remaining steps of the audit process can be conducted. In other words, once the feasibility audit is completed, the audit
The preliminary stage is the second stage within the road safety audit process and it focuses on horizontal and vertical alignment, intersection layouts, suitability of standards, and access locations. This stage audit can be conducted during section 15 (Determination) in Chapter 3 of the FDM in which a Design Study Report (DSR) needs to be prepared in addition to other reports such as a Location Study Report, and an Exception to Standards Report. The DSR report includes sections describing the location, present facility, traffic, need for project, proposed improvement and recommended design of the proposed project. The recommended design section includes a “geometrics” part in which preliminary plan sheets are required to be attached illustrating the proposed geometrics of the project which is essentially what a preliminary stage audit focuses on.

The detailed design stage audit is the third within the road safety audit process. This particular stage focuses on the inspection of the plans that will be subsequently used for the construction of the project. At this stage, the team of auditors should be provided with the drawings or plans which contain all the design details. The detailed design stage allows finding deficiencies if audits have not been performed at previous stages, and to find anything missed in the previous stages if these have been conducted. In terms of the FDP, the detailed design stage would be conducted during section 20 of the FDM (Final Design), right after the detailed engineering (subject 10 in the FDM).

The pre-opening audit focuses on the detailed inspection of the project before it is open to the public. Although, the chances to correct any problem are not the same as in previous stages, it is important to make sure at this point that everything is correctly implemented. A ‘post-opening’ audit can also be conducted to evaluate the performance of the project. The pre-opening audit
will also verify that the project is constructed as it was designed. In terms of the FDP, the pre-opening audit will be conducted after the completion of the construction work of the project.

AUDIT INFORMATION PREPARATION

The difficulties of conducting RWSA lie in the scarcity of road weather information and the limited accessibility to traffic engineers and operators. Another important fact shunning auditors away from the road weather safety issues is the interpretation and the usability of weather information. For a successful RWSA, weather should be quantified and described in a meaningful way so that engineers, planners and designers can understand, interpret and then address corresponding countermeasures or adapt to the challenging weather situation. A data-driven RWSA approach depends on what kind of weather and crash data are available. In this study, weather and crash information was collected, processed and analyzed to provide a quantitative method for auditors to evaluate the severity of road weather safety problems.

Weather Data Collection and Processing

An exhaustive review has been conducted for available weather information and the decision for choosing these data sources was based primarily on the extent of Environmental Sensor Station coverage in Wisconsin and the availability of a number of different kinds of weather parameters. Two major resources have been interviewed: Wisconsin RWIS and National Weather Service. To date, there are 58 RWIS stations across the state, providing weather forecast for 72 counties. The RWIS uses specialized equipment and computer programs to monitor air and pavement temperatures and predict whether precipitation will freeze on the pavement. However, typically RWIS does not collect any precipitation intensity information or visibility. We have also found RWIS to be unreliable. Later, it was decided to obtain the National Weather Service Cooperative Observing Network (COOP) data from National Climatic Data Center (NCDC). Moreover, data from the Automated Weather Observing System (AWOS) were also used where necessary to supplement the COOP data. Automated Weather Observing System (AWOS) is a suite of sensors, which measures, collects and broadcasts weather data to help meteorologists, pilots and flight dispatchers prepare and monitor weather forecasts, plan flight routes and provide necessary information for correct takeoffs and landings (8). Its primary function is to provide real time data and forecasts for aviation purposes; therefore, most of these sites are located at airports.

The NCDC is the world’s largest active archive of weather data. It collects data from just about any possible source of weather data present and provides a comprehensive, detailed platform with processed data products that can be used in different meteorological studies. Snow, rain and fog data have been collected through the available sensor stations. Snowfall data for 151 COOP stations were used. The units for precipitation and snowfall are inches, and degrees Fahrenheit for temperature data. The amount of snowfall for each day was added for each station by year to calculate the total amount of snowfall for each station per year in Wisconsin. The same approach was used in calculating rainfall for all the available stations in Wisconsin. Fog information was a very difficult one because of lack of observing stations collecting fog data throughout Wisconsin. For the convenience of data collection, it was decided to calculate the average number of fog events per month for each station. Since all the data collected for various
weather types were for point locations, this required that point data be interpolated into a continuous surface so that it would cover the whole state of Wisconsin.

After selecting the appropriate weather sources and processing of weather data, the next step was to establish a methodology which would render the use of weather data for several purposes. The weather data as shown in previous sections were available at point locations throughout the state of Wisconsin. In order to use the data effectively, all areas of the state have to be covered. Therefore, this data had to be modeled and interpolated to create a continuous prediction surface covering the whole state. It was decided to model weather data using a kriging process, and thereby the continuous weather maps were generated for various weather parameters (9, 10). Figure 4 shows the continuous snow prediction surface using 2000 to 2002 snow precipitation data collected through the weather stations in Wisconsin. The same method has been applied for rain and fog.

![Figure 4 — Snow Prediction Surface from 2000-2002 Data](image)
Crash Data Collection and Processing

Compared with weather data, crash data were rather easier to collect due to its familiarity and mature format. Crash data were received from WisDOT in flat files for the year 2000 to 2002. This dataset contained all the crashes occurring in the state of Wisconsin for the three-year analysis period on all roads. A GIS map (point shapefile format) was also received for crashes occurring on the State Trunk Highway Network system. An extensive literature review was conducted to search for the correct definition of weather-related crashes (11-16). According to FHWA, a weather-related crash was defined as any crash that happened during adverse weather conditions (snow, fog, sleet or rain), slick pavement conditions (snowy, icy, slushy, or wet pavement) or both (17). In Wisconsin, Wisconsin Motor Vehicle Accident Report (MV4000 form) has two sections regarding weather conditions at the time of the crash when investigated by the officer. A “weather condition” column that has weather-related information and a “road condition” column which has information about the road conditions at the time of the crash. Crash records with snow, rain, fog and sleet as “weather conditions” or wet, ice or snowy as “road conditions” have been included in this analysis. Based on the weather-related information entered into the crash forms and the above-mentioned definition of weather-related crashes, the following four categories of crashes were identified:

1. Fog (crashes reported in foggy weather conditions),
2. Snow (crashes reported in snowy weather conditions and snowy road conditions),
3. Rain (crashes reported in rainy weather conditions and wet road conditions), and
4. Ice (crashes reported in sleet weather conditions and icy road conditions).

Other types of data such as wind or cross wind crashes were excluded from the analysis because of small sample sizes (fewer than 150 crashes/year). Crashes with dry, other or unknown weather conditions were treated as non-weather-related crashes. Once the weather-related crashes had been categorized by type of weather, two datasets were created: a set of all crashes occurring in Wisconsin (both local and state trunk network roads) and a set of crashes occurring only on the state trunk network system. The state trunk network crashes were mapped in GIS point shapefile format whereas the local crashes were not. The state trunk network system includes all the Interstate Highway, the US highways and State Highways in Wisconsin. Due to the lack of traffic exposure data, the ratio of the number of weather-related crashes to the total number of crashes was used as the safety indicator for the locations to be audited.

Given the weather and weather-related crash information, a quantitative method is available to assist auditors in assessing the severity of road weather safety problems. For example, the priorities will be given to the weather vulnerable areas with high relative crash rates but less severe weather problems, then the areas with both high crash rates and severe weather problems. The areas with low crash rates but severe weather problems will also deserve a careful review because crashes are random events, especially where only a short crash history is available. The locations with low crash rates and gentle weather will be regarded as safe from the weather influence. Along with the audit information, several models and relevant statistics have been applied to establish the weather-crash relationship, which are not within the scope of this paper and omitted for brevity. An important piece of information 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. Police, EMS personnel and county highway workers have first hand knowledge on where potential weather related issues or “weather-related hot spots” are that may not show up in weather-crash evaluation methods. An example of this was found during the Wisconsin STH 69 audit. 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. This low spot is a swampy area where fog and black ice routinely form. No current WisDOT databases are currently able to identify such locations. A checklist item should be added to assure that these people are contacted and contribute to the audit.

CONCLUSIONS AND RECOMMENDATIONS

The weather component of the road safety audit procedure is unique as no other agency currently has developed a weather related procedure. This research showed 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 the information with their own experience and local knowledge to make the judgment. Given Wisconsin’s active involvement in weather-related engineering, many proactive safety features can be incorporated into future projects to improve the safety of Wisconsin roadways during all seasons.

The key to the success of implementing a RSA or RWSA program is to find the appropriate agency to manage the program, to integrate the RSA/RWSA processes and procedures with the existing departmental policies and guidelines and to design implementable and workable audit checklists. The institutional support ensures the sustainability and accountability of a RSA/RWSA program which will be independent of individuals. This study elaborated on the reasons and criteria to choose a program manager and explored the opportunities to integrate the RSA/RWSA processes and procedures into the WisDOT FDM. Considerable effort has been taken to develop the checklists with the inclusion of weather. Consistency, repeatability and usability were key elements of the checklists. Nevertheless, the checklists should be maintained as “living documents” to accommodate any new situation in the future.

The study recommended that local engineers, police and highway workers should be contacted for new information that may be neglected through the regular RWSA checklists. Maintenance personnel are also faced with some decisions directly linked to road weather safety such as snow storage. During a discussion with WisDOT staff, they talked about the problems they face when trying to find strategic places for snow storage in such a way that it does not disrupt traffic, obstruct views or cause any inconvenience to road users both while stored and during the melting phase. This is rarely considered by planners or designers when designing a highway segment. As a result of this discussion, it is recommended that consideration of snow storage be included as a checklist item as part of the developed “weather constraints” section.

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