Safety and Mobility Impacts of Winter Weather – Phase I

Center for Weather Impacts on Mobility and Safety

Final Report
August 2011

MTC
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Institute for Transportation

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About CWIMS

The Center for Weather Impacts on Mobility and Safety (CWIMS) focuses on research to find better and safer ways to travel whenever weather is a problem. CWIMS is an Iowa State University Center administered by the Institute for Transportation.

About the MTC

The Midwest Transportation Consortium (MTC) is a Tier 1 University Transportation Center (UTC) that includes Iowa State University, the University of Iowa, and the University of Northern Iowa. The mission of the UTC program is to advance U.S. technology and expertise in the many disciplines comprising transportation through the mechanisms of education, research, and technology transfer at university-based centers of excellence. Iowa State University, through its Institute for Transportation (InTrans), is the MTC's lead institution.

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The primary objective was to develop several preliminary means for the Iowa Department of Transportation (DOT) to identify locations of possible interest systematically with respect to winter weather-related safety performance based on crash history.

Specifically, metrics were developed to assist in identifying possible habitual, winter weather-related crash sites on state-maintained rural highways in Iowa. In addition, the current state of practice, for both domestic and international highway agency practices, regarding integration of traffic safety- and mobility-related data in winter maintenance activities and performance measures were investigated. This investigation also included previous research efforts.

Finally, a preliminary work plan, focusing on systematic use of safety-related data in support of winter maintenance activities and site evaluation, was prepared.

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SAFETY AND MOBILITY IMPACTS OF WINTER WEATHER – PHASE I

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August 2011

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EXECUTIVE SUMMARY

Highway agencies spend millions of dollars to ensure safe and efficient winter travel. However, the effectiveness of winter weather maintenance practices on safety and mobility are somewhat difficult to quantify.

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The primary objective was to develop several preliminary means for the Iowa Department of Transportation (DOT) to identify locations of possible interest systematically with respect to winter weather-related safety performance based on crash history.

Specifically, metrics were developed to assist in identifying possible habitual, winter weather-related crash sites on state-maintained rural highways in Iowa. In addition, the current state of practice, for both domestic and international highway agency practices, regarding integration of traffic safety- and mobility-related data in winter maintenance activities and performance measures were investigated. This investigation also included previous research efforts.

The analysis results do not absolutely convey site rankings, present problem locations, or represent locations where action is needed. However, the results may be used as a foundation for additional site evaluation and review. A preliminary work plan, focusing on systematic use of safety-related data in support of winter maintenance activities and site evaluation, was prepared.

BACKGROUND

Winter weather and its corresponding surface conditions have an impact on the safety and mobility of thousands of drivers annually. During the winters of 1995/6 to 2004/5, approximately one-third of all crashes occurring on rural, state-maintained highways in Iowa were winter weather-related. Moreover, approximately half of the rural Interstate crashes were winter weather-related. These crashes were generally found to be more severe than other winter crashes.

Highway agencies spend millions of dollars (in resources and personnel) in an effort to ensure safe and efficient travel. However, the effectiveness of these practices on safety and mobility are somewhat difficult to quantify. In addition, establishing the most cost-effective, need-based strategies for application of these limited resources can be equally challenging.

OVERVIEW

The primary objective of this project was to develop several preliminary means for the Iowa Department of Transportation (DOT) to identify locations of possible interest systematically with respect to winter weather-related safety performance based on crash history.

Specifically, metrics were developed to assist in identifying possible habitual, winter weather-related crash sites on state-maintained rural highways in Iowa. In addition, the current state of practice, for both domestic and international highway agency practices, regarding integration of traffic safety- and mobility-related data in winter maintenance activities and performance measures were investigated. This investigation also included previous research efforts.

Finally, a preliminary work plan, focusing on systematic use of safety-related data in support of winter maintenance activities and site evaluation, was prepared.

LITERATURE REVIEW

Performance Assessment

Winter weather maintenance and safety have been a recurring topic within transportation engineering for decades, as evidenced by studies as early as the 1940s that investigate the use of road surface treatments and their effects on highway safety (Donnelly 1947). For decades, engineers have realized that the key to increase roadway safety, especially during adverse weather conditions, such as snowstorms, is to keep the roadway free of ice and snow. Unfortunately, due to the technological limitations of weather forecasting systems, this approach has more often been reactionary, which can strain the resources of state and local agencies and may increase the likelihood that some locations with poor roadway conditions will persist.

With the advent of modern technology, and increasingly reliable weather forecasts, these problems have largely been abated from their historic levels. The use of Road Weather

Information Systems (RWIS) have enabled researchers to more closely detail the precise weather conditions that contribute to most accidents in a given area, and also allow traffic engineers and maintenance officials to specifically target winter maintenance practices where they will be the most effective (Blomquist and Carson 2001).

RWIS uses various monitoring stations and sensors across the state, or along a specific roadway, to measure environmental data during various weather situations. Readings can include metrics like air temperature, wind speed, and visibility, as well as pavement temperature, roadway surface condition (wet, dry, etc.), and the freezing point of the roadway surface. These systems have become an ubiquitous feature within many state DOTs across the country, from the Washington State DOT (WSDOT) on the west coast to the Maine DOT on the east coast (Senn 2005) (Cluett and Jenq 2007).

Furthermore, by combining RWIS data with the framework of a Maintenance Decision Support System (MDSS), many state DOTs, such as the Indiana DOT (INDOT) and the Colorado DOT (CDOT), have been able to further improve the safety and mobility of their roadways during winter weather events, as well as mitigate the environmental impacts of winter maintenance activities (Anderle and McClellan 2009).

An MDSS utilizes weather data and roadway conditions (often obtained using RWIS), along with a standard set of maintenance guidelines and roadways priorities, to formulate a cohesive maintenance plan during winter weather events and minimize the use of excess labor and materials. This plan is presented in a single platform that is easily accessible and able to be interpreted by agencies ranging from county maintenance engineers to state highway patrol officers (McClellan, et al. 2009).

While technologically-enhanced winter maintenance systems (such as RWIS and an MDSS) are clearly beneficial to the casual observer, it is important that researchers and state transportation officials be able to quantify the benefits of these systems. In addition, while technological advances have significantly improved the efficiency and performance of winter weather maintenance activities, room for improvement exists, and certain metrics can be adopted to measure the performance levels of activities and allow for a standard level at which these activities are considered completed.

Numerous studies have been conducted to determine the correlation between roadway surface condition and crash reduction. These studies typically return statistical evidence that a certain level of improvement in the roadway surface conditions will correspond to a certain level of reduction in crash frequency along a roadway.

A recent Canadian study did just this, and developed a road surface condition index (RSI), based on the commonly-used friction measure for a roadway. The study found that a 10 percent improvement in the road surface condition (as measured by the RSI) would lead to a nearly 11 percent reduction in the expected number of crashes (Usman, Fu and Miranda-Moreno 2010).

Similar to the safety benefits of roadway maintenance, another Canadian study aimed to quantify the mobility benefits of maintaining bare pavement conditions during winter storm events, using average travel time along the roadway as a metric for the level of mobility. The study found that winter road maintenance aimed at achieving bare pavement conditions during heavy snowfall could reduce the total traffic delay of the highway by five to 36 percent, depending on the volume to capacity ratio of the highway (Shahdah and Fu 2010).

In addition to metrics aimed at quantifying the improvements to safety and mobility from winter weather maintenance, additional metrics can be used to measure the performance level of the maintenance activities, as well as identify areas to be improved.

A University of Iowa study found that crash rates can increase by up to 84 percent in winter weather conditions, and that speed reductions of up to 24 mph can occur, depending on the storm severity and roadway type. This study identified a target speed reduction metric for the purpose of evaluating winter weather maintenance activities, such that the activities were considered to be successful if the average speed of traffic did not drop below the target reduction speed. Furthermore, the study made use of a storm severity index to more specifically tailor the reduction speeds to specific weather events, which will result in a more realistic goal for winter weather maintenance (Qiu and Nixon 2009).

Other studies have attempted to gauge the performance metrics currently in use by state DOTs for their winter weather maintenance activities. These studies have found that several states, such as the Minnesota DOT (Mn/DOT), are using innovative performance metrics to gauge the efficiency of their maintenance activities, including "time to bare pavement," which measures how quickly a roadway can be returned to its normal-weather condition. However, these studies also confirmed that many state DOTs are still using more traditional performance metrics with limited success, such as lane-miles plowed, tons of salt used, and cost per lane-mile of maintenance activities (Maze, et al. 2007).

Risk Management and Site Identification

While performance assessment is a crucial part of any winter maintenance plan and ensures that available resources are being maximized in terms of overall usage, it only forms one component of a comprehensive maintenance system. The other segment involves establishing a methodology to identify those roadways that are at a higher risk for winter weather-related crashes—and, more specifically, to identify individual road segments, known colloquially as black spots or hot spots. These areas are typically represented by such characteristics as a steep grade, locations on or near structures, or other unique features that may contribute to a loss of traction and/or visibility during winter weather.

There are numerous methods available for identifying roadways that are at particularly high risk for winter weather-related crashes. To understand why certain roadways are at a higher risk than others, the periods during which vehicles are most susceptible to be involved in a weather-related accident need to be understood.

A 2006 Wisconsin study analyzed the relative crash risk over the time period of a storm to help local and state maintenance departments better assess their maintenance activities. The study found that, somewhat intuitively, more severe snowstorms (in terms of duration, intensity, and wind speed) increase traffic crashes and fatalities, with a simultaneous increase in the consumption of deicing materials and labor hours.

However, the study was also able to conclude that proactive winter road maintenance significantly improves safety. The researchers determined that a large percentage of weather-related crashes occurred at the start of a storm, before maintenance activities were in full effect. The study also found that, as the storm progressed, there were an increasingly high percentage of crashes on local roads, which reflects more intense maintenance activities on freeways and interstates (Qin, et al. 2006).

The Ministry of Transportation in Alberta, Canada has recently completed a study in which crash data and RWIS were combined to rank public roadways, in terms of risk, for the purpose of better targeting winter maintenance activities. This study used the following metrics as a means of assessing each road for crash risk:

- Five-year major injury collision frequency and severity
- Five-year fatal collision frequency and severity
- Proximity to bodies of water
- Degree of grade and curvature on roads and bridge approaches
- Combinations of the above criteria

Furthermore, the Ministry makes use of deicing systems in several high-risk crash locations around the province and, with the use of RWIS, is able to apply deicing materials to these roadways before major winter weather events (Pinet, McDonald and Bielkiewicz 2009).

A recent Italian study went further to determine which methods should be used to identify roadway segments with unusually high numbers of crashes. According to the study, seven methods of "hot spot" identification were tested:

- Crash frequency (CF)
- Equivalent property damage only crash frequency (EPDO)
- Crash rate (CR)
- Proportion method (P)
- Empirical Bayes estimate of total crash frequency (EB)
- Empirical Bayes estimate of severe crash frequency (EBs)
- Potential for improvement (PFI)

The study looked at crashes from five years on one Italian roadway. Overall, the results indicated that the EB method was the most consistent and accurate method of identification, such that every hot spot identified with this method could be corrected with engineering countermeasures.

More significantly, however, was that the study indicated that the CR method is a rather poor indicator of hot spots as compared to other methods. CR is the de facto method of hot spot identification for many state DOTs (Montella 2010).

Similarly, an Oregon study made use of some of the same metrics for identifying winter-related crash locations, while, at the same time, incorporating some elements of climate variation in the analysis. The following metrics were considered in the ranking of crash locations within the state of Oregon:

- Critical rate (by functional class)
- Critical rate (by functional class and climate zone)
- Potential for crash reduction
- Expected frequency (adjusted by Empirical-Bayes)
- Frequency

Like the Italian study, this analysis identified the Empirical-Bayes method as being highly reliable and consistent, and many of the high-crash locations identified with this method were the same as crash locations identified with the more traditional frequency method (Monsere, Bosa and Bertini 2008).

Another recent American study looked to identify high-risk crash locations in the context of mobility. The study investigated the use of travel time as a means of identifying locations with consistently high accident rates. The study found that travel time reliability (measured as the average variation in travel times along a stretch of roadway) was a good predictor of the overall number of accidents in a given location, with more accident-prone locations seeing a greater variation in reliability (Saberi and Bertini 2010).

Several studies have also used more innovative tools to identify high crash locations, such as geographic information systems (GIS). A 2009 study used advanced statistical GIS-based crash analysis, along with a K-function, to identify ice-related crash clusters around Wisconsin DOT (WisDOT)-maintained bridges. Based on the perceived accuracy of the analysis, this study provides good support for focusing additional winter weather maintenance efforts, such as more frequent deicing, around these bridges (Khan, et al. 2009).

Another study used a Bayesian Hierarchical Modeling approach to combine crash rates with weather patterns on a microscopic level. The study's authors propose the use of a Poisson model with a log-link function, including a spatial random effect within a Bayesian hierarchical modeling framework, to predict the number of crashes as a function of local weather conditions. This methodology may prove to be useful in the development of more advanced systems for road weather safety and planning rankings on a county-wide level (Qin, Han and Zhu 2009).

Finally, in an effort to establish a more objective baseline for ranking roads by weather-related crash risk, a joint Montana State University-University of Hawaii study developed an index to quantify the crash risks on a roadway based on individual storms. The study used data from

California, Montana, and Oregon to develop a roadway weather severity index, which correlates the crash risks along the roadway with the parameters of an individual winter storm. This results in a more precise ranking of roadways for risk assessment and the information can be used in a wide variety of manners, from traveler notification to planning and maintenance activities (Strong, Shvetsov and Sharp 2005).

Current DOT Efforts

Based on personal interviews with 15 representatives from various state DOTs, the following describes their current states of practice with regards to integrating safety with winter weather road maintenance. The majority of the interviewed DOT representatives referred to their state's use of RWIS and/or a MDSS with regards to their winter weather maintenance activities. Because these tools are used primarily for monitoring weather conditions and winter maintenance progress, rather than identifying hot spots based on crash history, these tools were not addressed in the summary statements below.

Alaska DOT

As a matter of practice, certain segments of roadway receive more frequent applications of deicer and other snow removal methods in response to "higher-than-expected" crash rates. In addition, other safety concerns that arise with individual segments of roadways are sometimes considered in the winter maintenance decision process, though this affects a very small percentage of the state's roadways (Coffey 2010).

Colorado DOT (CDOT)

Winter maintenance activity prioritization is based primarily on traffic volume and roadway functional class (Wieder 2010).

Connecticut DOT (ConnDOT)

ConnDOT makes use of RWIS, but the system is used to monitor road temperatures only during snow and ice events. Furthermore, ConnDOT does not have a system in place for tracking winter weather-related crashes based on the location of the crash (Micali 2010).

Illinois DOT (IDOT)

Winter maintenance activity prioritization is based primarily on traffic volume and roadway functional class (Johnson 2010). However, IDOT is in the process of developing a tool that may soon be able to be used for the purpose of identifying winter weather hot spots. This software-based crash analysis tool uses a binomial distribution function to identify crash types that are overrepresented on a particular roadway segment. This tool is currently being used in an experimental stage to analyze individual intersections for safety remediation. However, once the development of the tool is more substantially completed, it may be used on a systematic level to identify snow and ice-related crash trends (Piper 2010).

Maryland DOT (MDOT)

Priorities for winter maintenance activities are based primarily on traffic volume and roadway functional class. However, other factors, such as roadway characteristics, rush hour impact, and past crash information, are sometimes used to help determine the timing of operations, materials employed, and application rates of treatment materials. These same factors are also used in setting priorities for anti-icing operations prior to winter events and in post-storm patrols. In general, MDOT felt that their State Highway Administration (SHA) shops already know about and address trouble spots, which crash analysis may only confirm. (Yurek 2010).

Massachusetts DOT (MassDOT)

General safety measures are sometimes used for evaluating the performance levels of certain highways during winter weather events (Brown 2010).

Michigan DOT (MDOT)

Priorities for winter maintenance activities are based primarily on traffic volume and roadway functional class (Felt 2010).

Montana DOT (MDT)

Priorities for winter maintenance activities are based primarily on traffic volume and roadway functional class (Roberts 2010).

Nebraska Department of Roads (NDOR)

Priorities for winter maintenance activities are based primarily on traffic volume and roadway functional class. However, NDOR does take safety into consideration with the use of automated bridge de-icing systems. When funding for a new de-icing system is made available, NDOR reviews bridges with the highest crash rates and, along with other factors such as roadway functional class, determines whether a de-icing system is appropriate for the bridge (Sands 2010).

New Hampshire (NHDOT)

Priorities for winter maintenance activities are based primarily on traffic volume, traffic speed, and, in some cases, the grade of the highway. However, NHDOT does make use of a subjective system for identifying problem areas along individual highways for higher-priority maintenance.

This system relies on the state's highway patrol officers to report unsafe conditions or especially problematic circumstances on individual roadways (Boynton 2010).

New York State DOT (NYSDOT)

Priorities for winter maintenance activities are based primarily on traffic volume and roadway functional class. There is some special priority given to treating areas of frequent black ice formation, as identified by historic crash rates in these areas. In addition, bridges are given special priority in the after-storm cleanup process to minimize the risk of severe vaulting accidents (Lashmet 2010).

Oregon DOT (ODOT)

Priorities for winter maintenance activities are based primarily on traffic volume and roadway functional class (Morrison 2010).

Pennsylvania DOT (PennDOT)

PennDOT tracks winter weather-related crashes to identify "crash clusters," which can then be used to apply more-frequent maintenance to the associated roadway segments. Furthermore, PennDOT has extensively used alternate means to improving highway safety during winter weather events, such as forcibly lowering the speed limit based on the severity of the event, as well as restricting certain types of large truck traffic during the worst parts of the storm. The DOT's own research has shown these methods to be highly effective in reducing crash rates (St.Clair 2010).

Rhode Island DOT (RIDOT)

Priorities for winter maintenance activities are based primarily on traffic volume and roadway functional class (Annarummo 2010).

Vermont DOT

Priorities for winter maintenance activities are based primarily on traffic volume and roadway functional class. Some special treatment is given to "areas of extreme curvature and problem grades" (Sargent 2010), but additional information about how these road segments are identified is not available at this time.

Washington State (WSDOT)

Priorities for winter maintenance activities are based primarily on traffic volume and roadway functional class. Certain localized weather patterns are given special consideration when prioritizing winter road maintenance, but, overall, the highway system in the state is not ranked by risk level associated with winter weather, partly due to liability considerations. (Mills 2010).

West Virginia DOT (WVDOT)

Priorities for winter maintenance activities are based primarily on traffic volume and roadway functional class. Within this framework, there are four key categories of road:

- Priority 1: Interstates, expressways, US routes, state routes, and high-traffic county routes, which are plowed and treated in that order
- Priority 2: All other paved county routes
- Priority 3: Unpaved county routes
- Priority 4: Home Access Road Program routes (Hughes 2010)

Wyoming DOT (WYDOT)

Priorities for winter maintenance activities are based primarily on traffic volume and roadway functional class. However, there is some ongoing research being done in Wyoming's Winter Research department to identify the most frequently occurring winter weather-related crash types on state highways and the most effective means to reduce or eliminate them (Shultz 2010).

METHODOLOGY

The primary objective of this project was to identify locations of possible interest systematically with respect to winter weather-related safety performance. Three critical components were necessary to support this objective:

- Define the appropriate extent and segmentation of the reference roadway network
- Assimilate winter crash history
- Develop safety-related evaluation metrics

Each component is discussed in this section.

Data Assimilation

Road Network

The scope of this project is the rural, primary (state) highways in Iowa. The initial road network is based on a network created in a 2005 research project. At the request of the project sponsor (the Iowa DOT), this network represented the primary highway system at one-mile intervals. In other words, analysis segments were approximately one-mile long and would serve as the basis for crash assignment and safety metric comparison.

In the 2005 project, Iowa DOT staff advised that consistent, discreet, fixed-length analysis sections best served their needs with respect to evaluation of possible maintenance and operations mitigation strategies for locations of interest (rather than longer or variable-length sections).

To account for changes in the state highway system since the 2005 study, the most-recent version of the Iowa DOT's geographic information management system (GIMS) roadway database was used to evaluate network consistency. Within the GIMS, road segments that experienced change due to administrative, geometric, or new construction since 2005 were adjusted. New alignments and construction, such as bypasses, were added to the network as one-mile segments. Roadway segments with a change in jurisdiction, from state to local agency, were removed from the network.

All of the road segments in the analysis road network are one-mile in length with exceptions near county borders and route termini.

Winter Crash Data

The Iowa DOT defines winter as the time period between October 15th and April 15th. Two winter crash data sets were used in this project. All winter crashes were included in these data sets and winter weather-related crashes were identified (explicitly).

The first data set represented the crash database (a subset of the Iowa DOT's comprehensive crash database) that was created as part of the original project. This database included crashes from the winters beginning in October 1995 and ending in April 2005. During this timeframe (in January 2001), the Iowa DOT implemented a new field crash report form, so the data set included two distinct formats and attribute sets, and, therefore, two diverse winter-related crash definitions.

Before 2001, winter weather-related crashes were defined as those in which any of the following were reported for the crash event or for any driver/vehicle involved in the crash:

- Weather conditions: Snow or Sleet/hail
- Surface conditions: Ice or Snow
- Roadway environment: Frost-covered bridge floor

Based on the 2001 report form, the Iowa DOT established a winter weather-related crash definition in 2009 that was slightly broader than the one employed in 2005. Winter weather-related crashes were defined as those in which any of the following were reported for the crash event or for any driver/vehicle involved in the crash:

- Weather conditions: Sleet/hail/freezing rain or Snow or Blowing sand/soil/dirt/snow
- Surface conditions: Ice or Snow or Slush
- Vision obscurement: Blowing sand/soil/dirt/snow

Given this new definition in 2009, the research team replaced the post-2000 crashes used in the 2005 study with a second crash data set, employing the new definition. This data set was provided by the Iowa DOT Office of Traffic and Safety and included crashes occurring on primary roads for the winters beginning in October 2001 and ending April 2009. It was later limited to only state-maintained rural roads.

With GIS, crashes were attributed (assigned) to roadway segments based on spatial proximity. Assignment accuracy was assessed and refined through both visual inspection and comparison of the crash literal description and the spatially-assigned route.

Crashes located at intersections or interchanges, particularly highway on and off ramps, were assigned to the higher system route – Interstate, US, and Iowa. If intersecting roads were of the same system, the crash was assigned to the lower-numbered route, as per standard DOT practice. For example, if a crash occurred at the interchange of I-35 and US 30, the crash was assigned to I-35. If the crash was located at the interchange of US 30 and US 65, it was assigned to US 30.

Special consideration was given to road segments experiencing geometric changes during an analysis period (but retaining the same route), such as expansion from a two-lane to a multi-lane divided facility. Crashes occurring prior to the year of modification were removed from consideration for two of the evaluation metrics (to be discussed later). The affected roadway segments were identified using a variety of online resources.

Upon final review, a comprehensive crash database, including appropriate crashes from all winters, was created. This database primarily included base-level attributes, common to both crash forms, such as crash severity and case number. Inclusion of crash case number would facilitate future integration of any crash data of interest. Several supplemental attributes were added, such as weather-related indicator, ramp indicator, winter of occurrence, and roadway segment of occurrence. Limited attributes from the 2001 form only were also included.

Ultimately, several attributes facilitating computation of evaluation metrics (to be discussed later) were computed and summarized for each road segment for each winter. The following attributes were included:

- Frequency of winter weather-related crashes by severity
- Frequency of non-winter weather-related crashes by severity
- Frequency of winter weather-related injuries by severity
- Frequency of non-winter weather-related crashes by severity

ANALYSIS

Analysis Periods

The Iowa DOT identified two primary analysis periods of interest:

- Winters beginning in October 1995 and ending in April 2009, encompassing 14 winters
- Winters beginning in October 2001 and ending in April 2009, encompassing eight winters

The first analysis period built on the previous research efforts, which included the winters of 1995/1996 to 2004/2005, and facilitated a comparison of prior results, through the inclusion of additional winters. In addition, given the unpredictable nature of winter weather (both within a single winter and among winters), randomness of crashes and potentially-limited winter weather crash frequency, the 14 winter analysis period provided a more extensive data set to review, potentially minimizing these impacts. However, this analysis period included crashes from two distinct crash forms, where winter weather-related crashes had been defined in different manners. The second, eight-year analysis period represented a consistent crash form and winter weather-related crash definition.

Winter Weather-Related Safety Metrics

Overview

To assess the possible safety-related impacts of winter weather on state-maintained rural highway segments in Iowa, several crash-based metrics were developed. Based on a review of previous studies and related, earlier research activities at Iowa State University (ISU), winter weather-related crash density and winter weather crash proportion (the proportion of all winter crashes that are winter weather-related) were identified as primary metrics of interest.

An additional metric, based on person-level injury severity (injuries on each roadway segment by frequency and severity), was also considered in the evaluation of the roadway segments. Finally, in a preliminary effort to combine the three metrics into one overall rating, a simple equal weighting of the three metrics was applied, and the resulting values were aggregated to determine a composite score for each roadway segment. These metrics will be discussed in more detail in subsequent sections.

The following attributes were computed for each roadway segment:

- Winter weather-related crash density, winter 1995/1996 to winter 2008/2009
- Winter weather-related crash density, winter 2001/2002 to winter 2008/2009
- Winter weather-related crash proportion, winter 1995/1996 to winter 2008/2009
- Winter weather-related crash proportion, winter 2001/2002 to winter 2008/2009
- Winter weather-related crash severity, winter 1995/1996 to winter 2008/2009
- Winter weather-related crash severity, winter 2001/2002 to winter 2008/2009
- Composite winter weather-related crash score, winter 1995/1996 to winter 2008/2009
- Composite winter weather-related crash score, winter 2001/2002 to winter 2008/2009

Each of the metrics were evaluated within a common road type—freeway, expressway or two-lane highway—and categorized based on their relative magnitude within the appropriate road type and analysis period. Specifically, the total mileage of a given road type was computed and categories were created based on percentage of mileage ranges. The evaluation was performed among common road types because of their generally similar characteristics, such as speed, geometric design, access control, median presence, and traffic volume. This is consistent with the US Road Assessment Program (usRAP) risk-mapping protocol. The derived ranges included the five categories shown in Table 1.

Table 1. Mileage category ranges (for each road type) by relative magnitude

Category	Metric value is among percentage of system mileage
1	Lowest 40 percent
2	Next 25 percent
3	Next 20 percent
4	Next 10 percent
5	Highest 5 percent

A combination of manual and automated methods was employed to establish these category ranges and assign them to corresponding road segments. Ranges differed among each metric and road type.

Winter Weather-Related Crash Density

This metric primarily conveys crash frequency. It represents the frequency of winter weather-related crashes on a given road segment, on a per-mile basis. This metric was computed by summing the total frequency of winter weather-related crashes occurring along a road segment (within an analysis period) and dividing the total by the length of the road segment (in miles) and the number of years in the analysis period.

Sites possessing high density values typically experience the most winter weather-related crashes. However, the metric does not take into consideration traffic volume, which may be important when evaluating sites based on density. Roads with high traffic volumes typically experience more crashes anyway, and, therefore, have a higher crash density. Site assessment within common road types partially lessens the impacts of traffic volume differences. Rate-based metrics, where traffic volume is taken into consideration, were not derived for this project due to limited availability of actual traffic volumes during winter weather conditions. Only average annual daily traffic (AADT) was comprehensively available, which may misrepresent conditions during winter weather events.

The impact of short analysis sections is also a consideration when using this metric. Short roadway segments, with a large number of weather-related crashes, can result in a very high density value when extrapolated for an entire mile of roadway.

Winter Weather-Related Crash Proportion

This metric represents the total proportion of winter crashes on a road segment that are weather-related. A high proportion of winter weather-related crashes may suggest that the safety of a site is impacted more by winter weather conditions. This metric was computed by summing the total number of winter weather-related crashes over an analysis period and then dividing by the total number of winter crashes in the analysis period.

This metric should not necessarily be used independently. Roads with low traffic volumes or very few crashes may tend to fall at either end of the rating spectrum. For example, if a road segment had one crash during an analysis period that was weather-related, the segment would have a weather-related crash proportion of 1, or 100 percent. Another road segment, with many weather-related crashes (or high density), and a proportion of 0.75, would likely be of more interest.

Both this metric and the density metric include all weather-related crashes and do not convey the severity of these crashes. In other words, fatal crashes and property damage only (PDO) crashes receive the same weight.

Severity

This metric attempts to take severity into consideration. The severity metric presents a total score assigned to each road segment based on the total frequency and severity of injuries experienced in winter weather-related crashes. This metric was created by computing the total frequency of injuries by severity over an analysis period and assigning each injury severity a certain number of points, based on the standard Iowa DOT scale shown in Table 2 (Iowa Department of Transportation n.d.).

Table 2. Standard Iowa DOT scale for assigning points by injury severity

Injury severity	**Points each occurrence**
Fatality	200, with the first fatality at a site treated as a major injury
Major	100
Minor	10
Possible/Unknown	1

These points were then aggregated for each road segment to produce an overall severity score. The post-2000 crash database contained an attribute table in which the personal-level injury severity data were aggregated to the crash-level. A similar summary table did not exist for the pre-2001 database, so the data were derived from the personal-level injury table, based on the crash case number.

As with the density metric, the severity metric does not account for the changes in total injuries resulting naturally from different traffic volumes. Therefore, the severity metric should be used in conjunction with the other metrics to provide a more comprehensive representation of winter weather-related crash experience along roadway segments.

Composite Score

In an effort to take into consideration all metrics and potentially limit the influence of any single metric, a composite score was computed. Several techniques were evaluated to combine the metrics. Ultimately, the values for each crash metric were "normalized" with respect to all road segments, and the normalized scores each given a one-third (1/3) weighting in computing the total score.

To normalize the scores, each individual metric for a specific road segment was divided by the maximum value of that metric for the common road type and analysis period. As a result, all of the road segment metrics were indexed against a maximum value of 1.0. Given the proportion metric was already constructed in this manner (the maximum possible observable proportion for any road segment was 1.0), further normalization was not necessary.

The final result of this analysis was a composite total of normalized density, proportion, and severity scores. The benefit of this method is that it was unlikely that all three metrics would potentially misrepresent winter weather-related crash experience for a single road segment. Any possible misrepresentations would be balanced out for different metrics in other road segments.

While the methodology for this is sound, it may be preferred to weight the three metrics differently. For example, in the Iowa DOT safety improvement candidate location list (SICL), severity receives a three-fifths (3/5) weighting compared to crash density and crash frequency, which each receive a one-fifth (1/5) weighting. In the future, at the discretion of the Iowa DOT, the normalized density, proportion, and severity metrics may be used to recompute composite road segment scores based on alternate weighting.

Visual Representation of Analysis Results

A critical component of this project was to effectively convey the analysis results in various forms. Effective visual presentation allows users to quickly identify possible locations of interest as well as compare locations on a system-wide basis—both within the same metric and among all metrics. The underlying crash data, in conjunction with other pertinent data sets, may then be used to further assess the site. The different visualization forms employed are described below.

GIS-Based Hard Copy Maps

Because both the crash and roadway data used in this project exist geospatially, these data sets, as well as the analysis results, were integrated and managed within a GIS environment, specifically Environmental Systems Research Institute, Inc. (ESRI™) ArcGIS™. This tool was also used to create hard copy maps presenting analysis results for the four metrics (density, proportion, severity, composite) for three road types (freeway, expressway, two-lane road) for the two analysis periods (winter 1995/96 to winter 2008/09 and winter 2001/02 to winter 2008/09). Each map presented four basic layers to aid in visualization:

- Road segments, color coded by final category
- Primary roads in Iowa
- Iowa county boundaries
- Iowa urban areas

Keyhole Markup Language (KML) Maps

To expand the availability of the analysis metrics to a wider audience, the GIS-based data sets were converted to keyhole markup language (KMZ/KML) files for use in an Earth browser such as the Google Earth™ mapping service or Google Maps™ mapping service (Figure 1, Figure 2, and Figure 3).

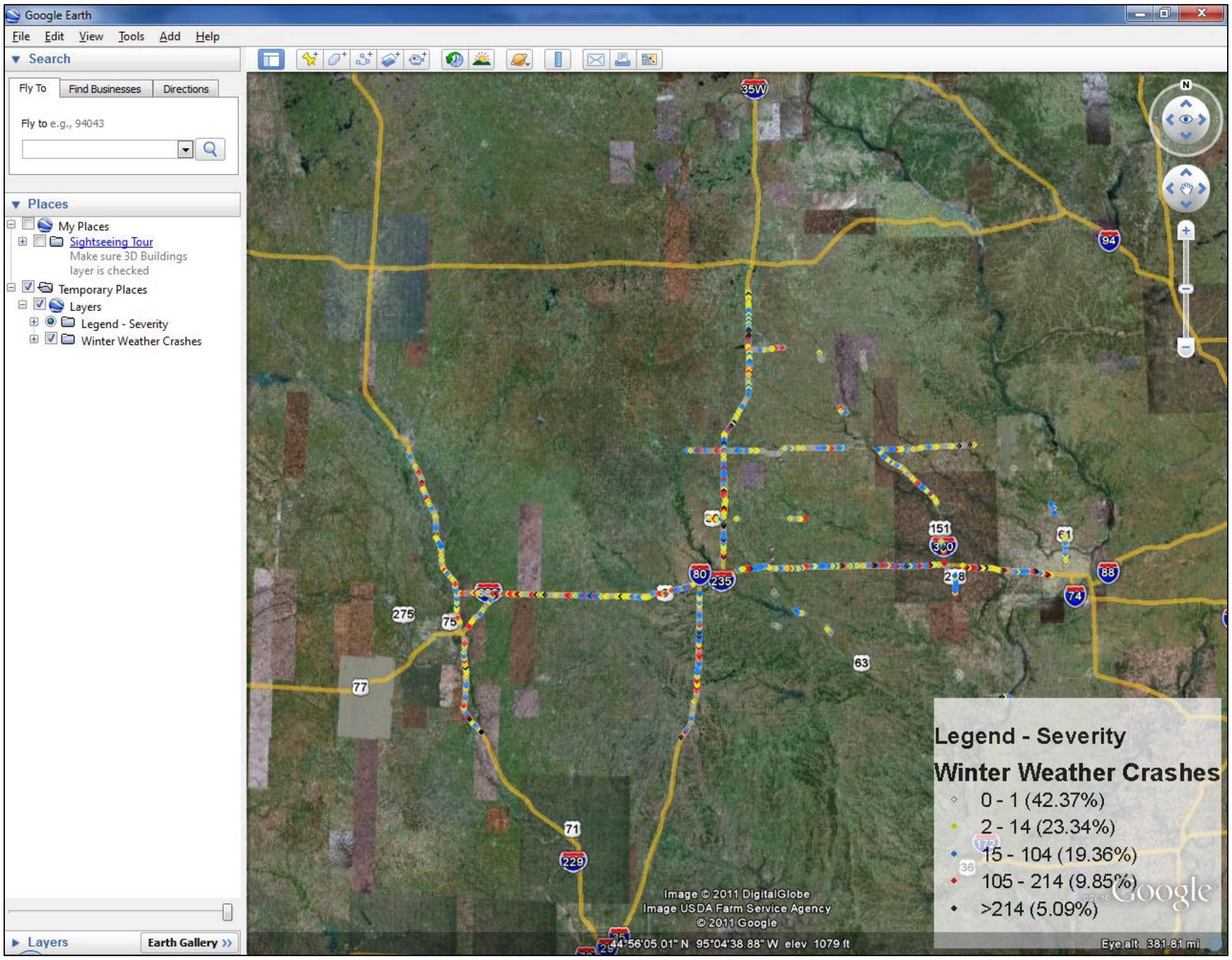

Figure 1. Sample Google Earth interface showing the freeways

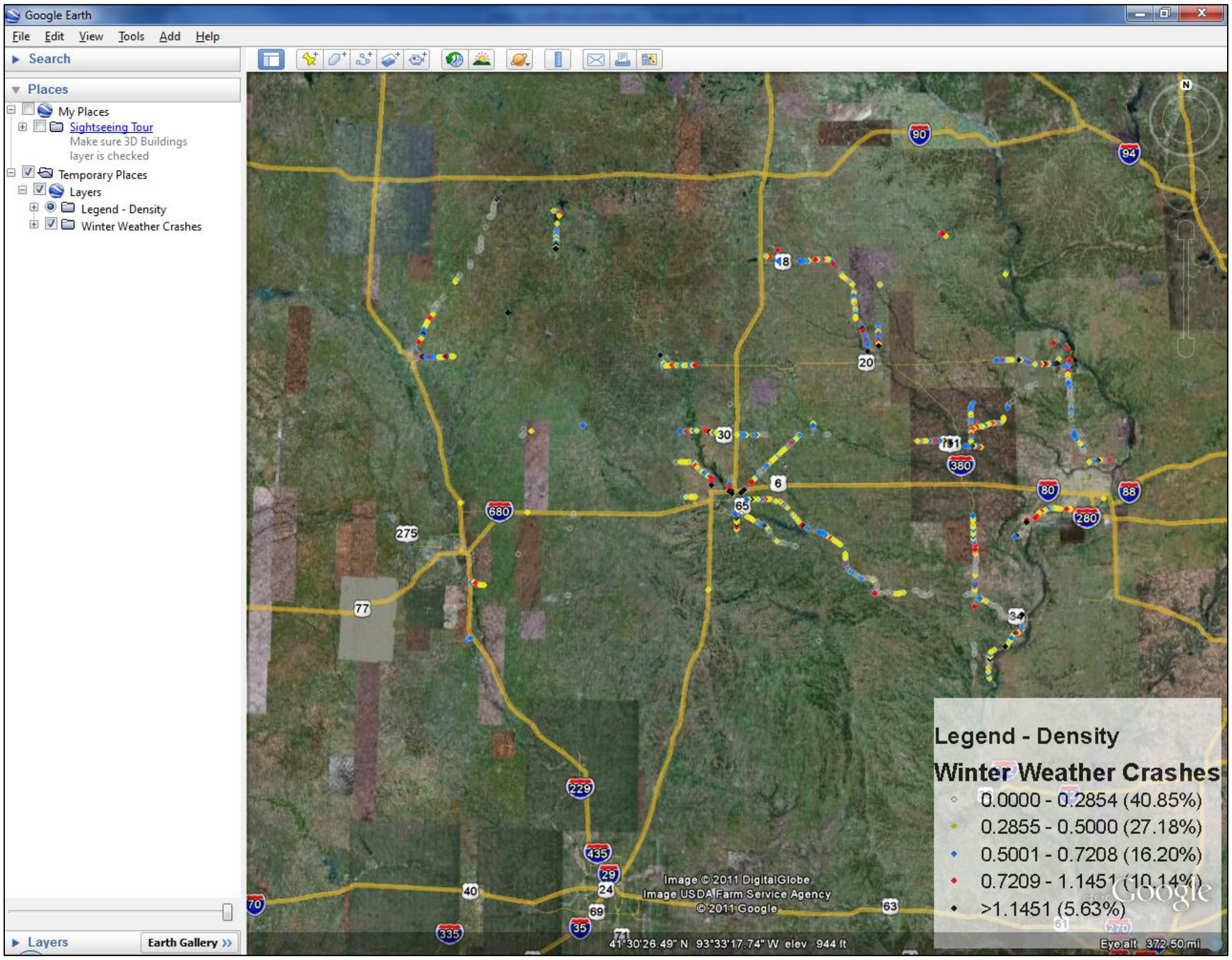

Figure 2. Sample Google Earth interface showing the expressways

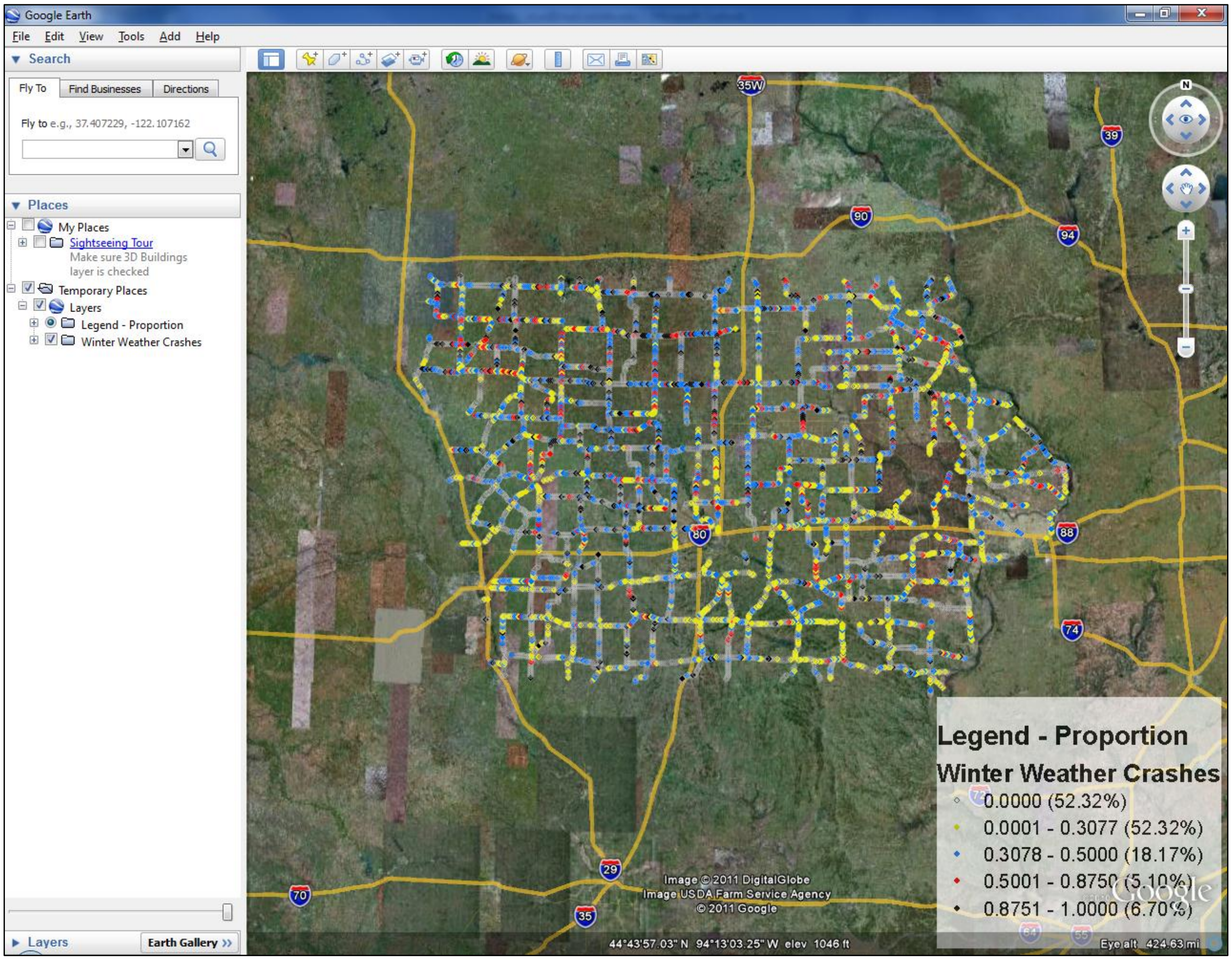

Figure 3. Sample Google Earth interface showing the two lane roads

Use of an Earth browser provides additional flexibility, and depth, in review. For example, some basic underlying data, such as total winter weather-related crashes, crash density, and category, were associated with each road segment, allowing general users access to more data (Figure 4).

Figure 4. Sample site attributes

In addition, aerial images, street-level views, and any other information available through these browsers may be viewed interactively. And, full documentation for use and interpretation of the data within an Earth browser was provided to the Iowa DOT.

Analysis Period Comparison

As was discussed previously, two different analysis periods were evaluated; and, each possessed unique strengths and weaknesses. However, the impact of this on these analysis periods was not immediately clear (e.g., whether significant differences exist between the metric values).

To determine whether the crash metrics from the 1995–2009 analysis period were significantly different from the same metrics for the same road segments from the 2001–2009 period, a z-test was applied. The z-test was applicable because the sample data consisted of the entire population—that is, all freeways and two-lane primary highways in Iowa. Given the data for both analysis periods came from the same population, a paired z-test was used to determine if significant differences exist between the data sets. Following are the steps employed for the freeway crash proportion metric.

1. Let µd denote the true average difference between crash density from 1995–2009 and crash density from 2001–2009.

2. Null Hypothesis = H0: $\mu d = 0$

3. Alternative Hypothesis =: $\mu d \neq 0$

4. Test Statistic: $z = \frac{\bar{d}-0}{\sigma_d}$

5. $\sum d_i = 25.8$, $\sum d_i^2 = 665.64$, from which $\bar{d} = 0.02854,\ \ \sigma_d = 0.10253$, and

6. $z = \frac{0.02854-0}{0.10253} = 0.278 \approx 0.3$

7. A set of z-tables showed that the area to the right of 0.3 under the z curve was 0.382. The inequality in Ha implies that a two-tailed test is appropriate, so the P-value is approximately 2(0.382) = 0.764.

8. Because 0.764 > 0.1, the null hypothesis was not rejected at all reasonable significance levels. It appeared that the true average difference in winter weather-related crash proportions from 1995–2009 and 2001–2009 was zero. There was no evidence to suggest that the crash proportions from 1995–2009 were significantly different than from 2001–2009.

Similar hypothesis tests were conducted for the remaining data sets, with sample results presented in Table 3. Figures presenting the distribution of the differences for identical road segments from the two analysis periods were also created (see example in Figure 5).

Table 3. Hypothesis test results

Data set	$\bar{d}$	σ_d	z	P-value	Result
Freeway proportion	0.02854	0.10253	0.3	0.76	Fail to Reject H0
Freeway density	0.02766	0.22625	0.1	0.92	Fail to Reject H0
Two-lane proportion	-0.01004	0.205191	-0.1	0.92	Fail to Reject H0
Two-lane density	0.05277	0.17869	0.3	0.76	Fail to Reject H0

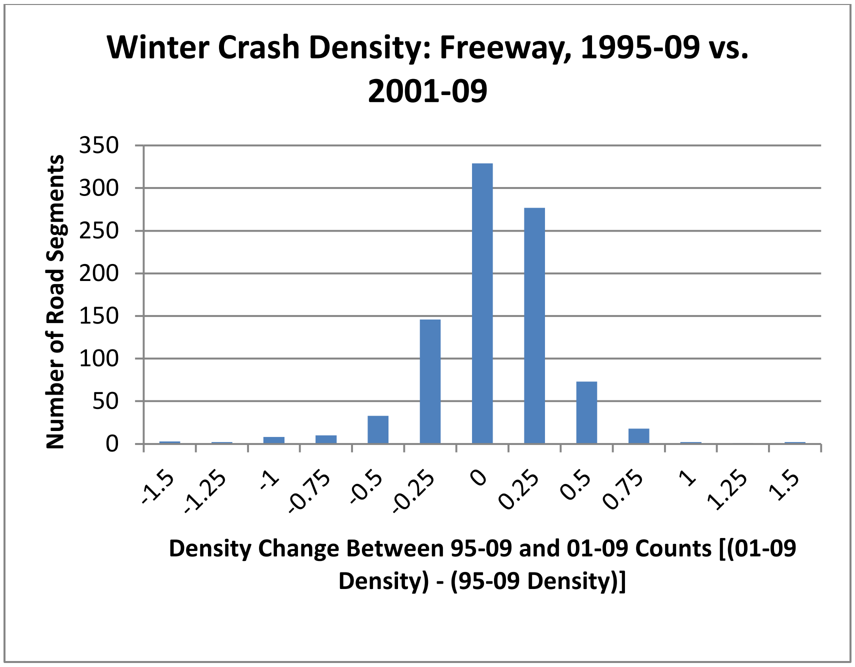

Figure 5. Sample winter weather-related crash density comparison

Based on a simple hypothesis test, the differences in freeway densities can be rejected as statistically significant at the α= 0.05 level. Tests conducted for the other three metrics yielded identical results. There is no evidence to suggest that the crash metrics for 1995–2009 are significantly different than 2001–2009. As a result, the 1995/96–2008/09 analysis period may be preferable for consideration, simply due to the fact that more crash data is available.

Sample Site Investigations

The two primary objectives of sample site evaluations were to demonstrate how discrete crash data could be used to further investigate the history of a road segment and how disparate data sets could be used in conjunction with the metrics developed as part of this project. These sample investigations were not intended to represent a comprehensive, in-depth analysis but rather to introduce concepts for future consideration.

Sample Site 1

Beginning in 2007, as part of the Iowa Light Detection and Ranging (LiDAR) Project, location and elevation data (X, Y, Z) were collected for the entire state of Iowa. Average horizontal spacing was 1.4 meters, with one meter root mean squared error (RMSE). Vertical accuracy was +/- 18 cm (The Iowa LiDAR Project - LAS and ASCII Files n.d.). These data sets are readily downloadable from the Iowa LiDAR Mapping Project website at http://geotree2.geog.uni.edu/lidar/.

Based on preliminary density and proportion evaluation, a three-mile section of Interstate of possible interest was identified and the crash frequency was assessed (Figure 6).

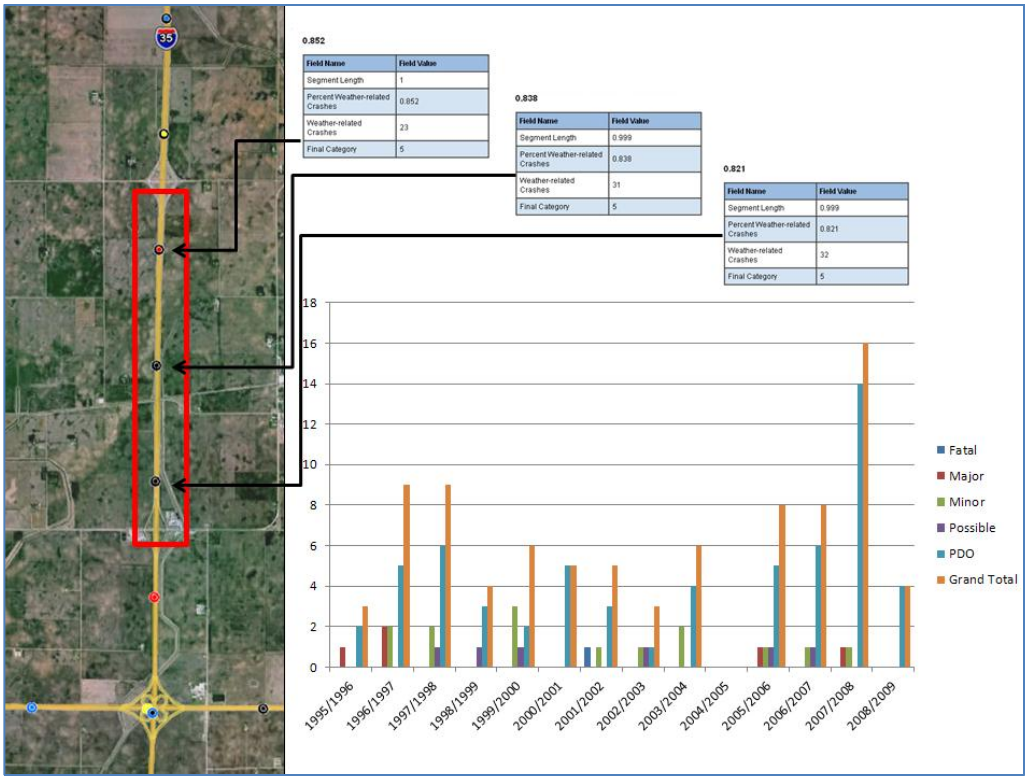

Figure 6. Sample site 1 crash frequency distribution

A total of 86 winter weather-related crashes occurred along this section of roadway from the winters of 1995/1996 to 2008/2009. In general, the crashes appeared to occur fairly consistently throughout the analysis period, with most of the crashes being of low severity. However, the winter of 2007/2008 experienced nearly twice as many winter weather-related crashes than the next highest winter.

LiDAR data for the site was then acquired and, within GIS, assimilated and a terrain was model created. Crash locations along the site were overlayed within GIS (Figure 7) and roadway/roadside cross-sections and the longitudinal profile were approximated (Figure 8).

The terrain model indicated that a vertical curve was located along the roadway and a portion of the western roadside (and, to a lesser degree, the eastern roadside) was at a higher elevation than the roadway. This was confirmed through road-level evaluation (Google Maps Street View). Crashes appeared to be localized around this location.

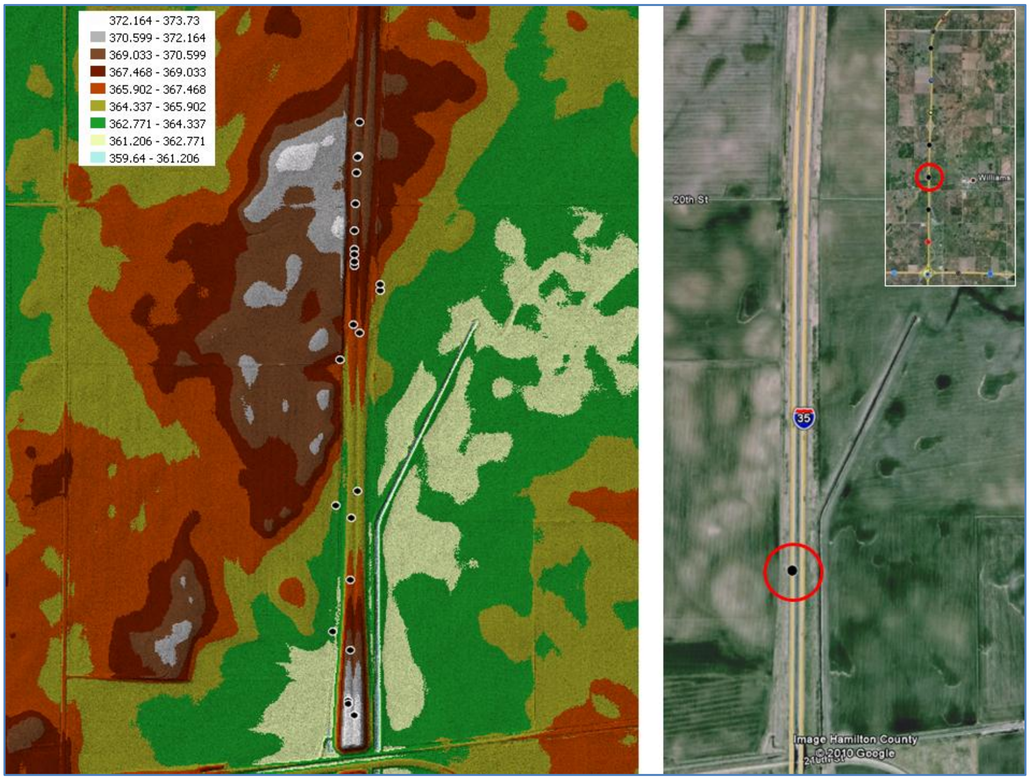

Figure 7. Sample site 1 terrain and crash distribution

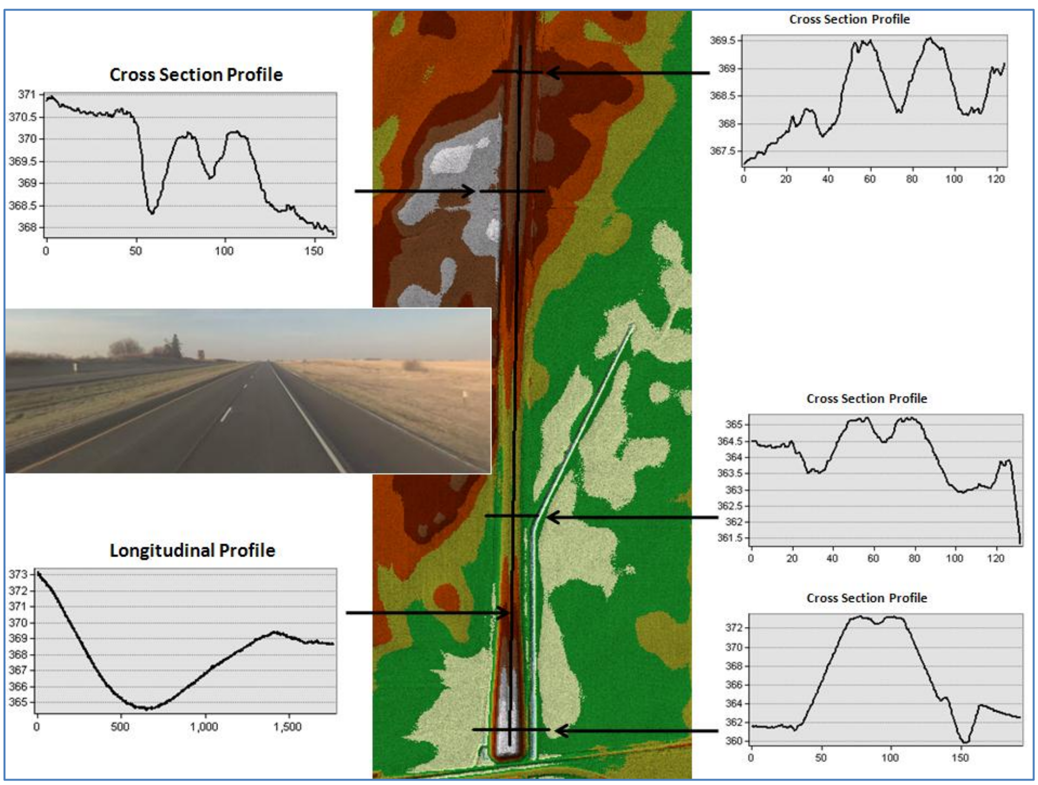

Figure 8. Sample site 1 roadway cross-sections and longitudinal profile

Lastly, the Street View interface of Google Earth and Google Maps was utilized to provide additional visual information about the site character (Figure 9). As mentioned previously, this confirmed what was apparent from the terrain model. It also indicated that living snow fences were located along a portion of the site.

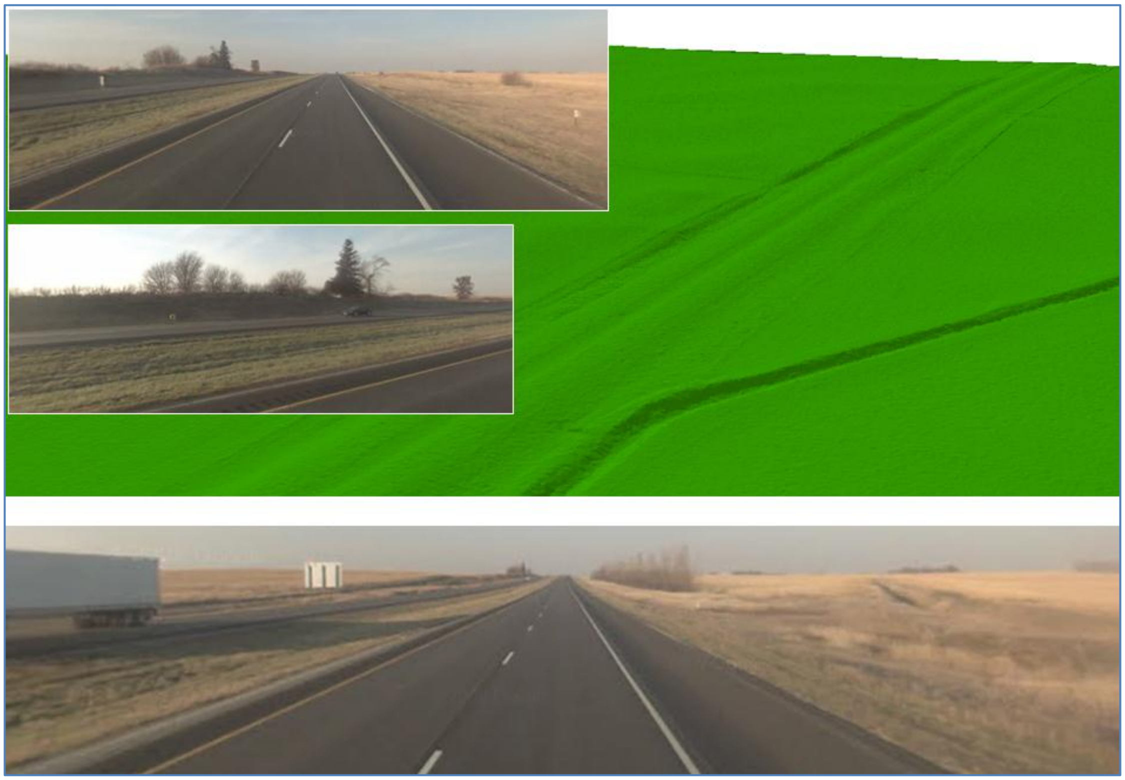

Figure 9. Sample site 1 street view

No additional investigation was conducted at this site, such as specific crash history. Generally, the investigation demonstrated that LiDAR data may effectively and quantitatively present information about possible sites of interest.

Sample Site 2

Sample Site 2 Overview

A second, preliminary site investigation was conducted at a one-mile site with the crash metrics shown in Table 4 for the winters or 2001/2002 to 2008/2009.

Table 4. Sample site 2 2001–2009 winter weather-related crash metrics

Metric	Value	Category
Density	3.122 crashes per year	5
Proportion	0.81	4
Severity	Raw Score 483, Normalized 0.249	5

This site experienced approximately three winter weather-related crashes annually and 81 percent of all crashes occurring in the winter were winter weather-related. While the severity score was only approximately 25 percent of the maximum statewide score, it still was within the top five percent of freeway segments in Iowa (the definition of a Category 5 ranking).

An aerial image of the site under investigation is provided in Figure 10.

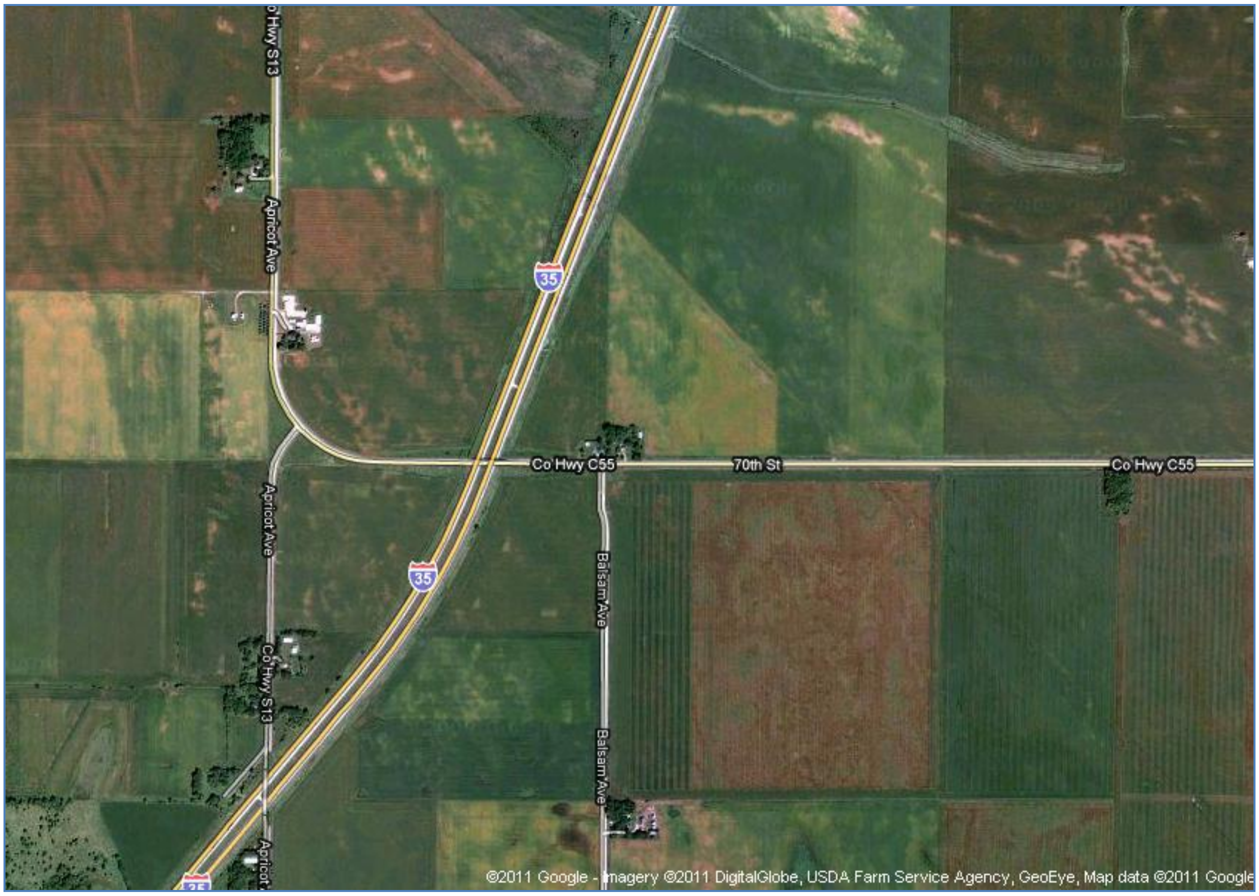

Figure 10. Sample site 2 aerial view

Sample Site 2 Visual Site Inspection

A visual inspection of the site was conducted using the Google Street View application. This allowed for a ground-level review of any unique site features with these key findings:

- A living snow fence is currently in place on the western side of the highway in areas adjacent to the overpass
- Rumble strips are located on the inside and outside shoulders of both directions of roadway
- The terrain at the site is level, with the exception of the vertical grades proximate to bridge approaches

Sample Site 2 Crash Analysis

As a demonstration, the crash investigation included all crashes occurring in the 2001 portion of the 2000/2001 winter and all subsequent winters through the 2008/2009 winter. However, in the future, it may be more appropriate to segregate the weather-related and non-weather-related crashes.

Sample Site 2 Direction of Travel

A little more than half (51 percent) of the crashes on this segment of roadway involved vehicles traveling in the southbound direction. This included all recorded crashes where snow was listed as a road surface factor at the time of the crash. Thirty-one percent of the crashes were reported as traveling northbound, while the direction was not recorded for 18 percent of the crashes.

Sample Site 2 Coincident Crash Occurrence

Coincident crashes may be broadly considered chain-reaction crashes. In some cases, many vehicles may be involved in a chain-reaction crash, resulting in high winter weather-related crash metrics but limited incidents throughout an analysis period. Sites experiencing many coincident crashes may be evaluated differently from a site with more isolated crashes. Approximately five crashes appeared to be related to each other. In one case, a passenger car sideswiped a guardrail and an SUV swerved to miss the car and ended up in the ditch. With the other occurrence, three vehicles simultaneously lost control; however, the initial cause of these three crashes was not clear (e.g., if one or more vehicles caused the others to lose control).

Sample Site 2 Crash Severity

Of the 35 winter crashes that were recorded at this site, seven included at least one minor injury. Furthermore, the total injury and fatality count among all of these crashes was:

- 1 crash with fatalities (1 fatality total)
- 2 crashes with major injuries (3 major injuries total)
- 6 crashes with minor injuries (9 minor injuries total)
- 13 possible/unknown injuries

Sample Site 2 Crash Location and Fixed Objects

An overpass is located on the roadway segment of interest, approximately one-half mile from its southern terminus. This overpass was referenced in 34 percent of all winter crashes, meaning that the crashes occurred at or near the overpass. A collision with a fixed object, such as the overpass, was reported as the first harmful event in only 14 percent of the crashes.

Sample Site 2 Weather as a Contributing Circumstance

The road surface itself was a contributing circumstance in 71 percent of the crashes. Furthermore, weather was reported as a contributing factor in 74 percent of these crashes. For the crashes that did list weather as a direct contributing factor, 80 percent listed ice as the specific road surface condition, 16 percent listed snow as the road surface condition, and 4 percent listed some unspecified road surface condition at the time of the event.

As for the crashes where weather was not listed as a contributing factor, 12 percent were the result of a previous collision, while the remaining 88 percent listed a contributing factor of "other." This can be interpreted in a variety of ways, but does not denote a non-weather related cause explicitly.

Sample Site 2 Crash Cause and Collision Manner

Driving too fast for conditions was the major cause of 37 percent of all winter crashes, while running off the road was attributable to 29 percent of crashes. Losing control of the vehicle represented the major cause in 6 percent of the crashes, with the remainder being denoted as "other." In addition, more than 77 percent of the crashes were reported as non-collision, which indicates they were single vehicle crashes.

Sample Site 2 Lighting at the Time of Crash

Forty-nine percent of all crashes occurred in conditions of total darkness, while 51 percent occurred in daylight or partial-light (e.g., twilight) conditions. Average hourly traffic distribution and time of weather event occurrence are also a consideration when evaluating lighting. For example, the typical percentage of travel by hour may suggest whether dark condition crashes are over- or under-represented.

Sample Site 2 Vehicle Type

The vehicle types involved in the crashes were evenly split between passenger cars, light trucks, tractor/semi-trailers, and other vehicles, with each category representing between 24 and 26 percent of vehicles involved. Of possible interest is the incidence of semi-tractor trailers, at over one quarter (26 percent) of all vehicles. Given the same percentage of first harmful events (26 percent) involving the jackknifing of the vehicle, further investigation of typical, system-wide vehicle type involvement may be warranted.

CONCLUSIONS AND RECOMMENDATIONS

Several research projects have investigated possible use of historic crash data for planning winter maintenance and operations strategies. However, while some informal practices exist, most state DOTs do not have formal mechanisms in place to utilize such data in their maintenance activities.

In this project, four winter weather-related crash metrics, and associated databases, were developed to facilitate system-wide, preliminary evaluation of the rural, primary highways:

- Winter weather-related crash density
- Winter weather-related crash proportion
- Winter weather-related crash severity
- Composite winter weather-related crash score

Categorization of these metrics was completed for three different road types (freeway, expressway and two-lane) and two different analysis periods (winters of 1995/1996 to 2008/2009 and winters of 2001/2002 to 2008/2009). Statistical analysis suggested that the differences in metrics for the two analysis periods were not statistically significant. Therefore, use of the longer period in additional analysis may be beneficial, providing more crash data for evaluation.

Analysis results may be reviewed through either use of GIS- or Google Earth-based data sets. These metrics and their corresponding categories should not necessarily be evaluated independently, as anomalies may occur. They are best evaluated in parallel.

The analysis results do not absolutely convey site rankings, present problem locations, or represent locations where action is needed. However, the results may be used as a foundation for additional site evaluation and review. This is discussed, in part, in a preliminary work plan developed for the Iowa DOT.

This work plan focused on outlining possible systematic use of these data in support of winter maintenance activities and site evaluation. The plan was considered a working document, intended to initiate discussion regarding use of the products of this project. The preliminary work plan is provided in Appendix A.

REFERENCES

Anderle, Phillip, and Anthony McClellan. Modernising Maintenance Operations Using a Maintenance Decision Support System. *Journal of Public Works & Infrastructure*, August 2009: 15-24.

Annarummo, Paul R., interview by Steven M. Lavrenz. *Winter Weather Safety Information* (September 2010).

Blomquist, D. T., and J. Carson. Utilizing Road Weather Information System (RWIS) Data to Improve Responses to Adverse Weather Conditions. *International Conference: Traffic Safety on Three Continents.* Moscow: PTRC Education and Research Services Limited, 2001. 14p.

Boynton, interview by Steven M. Lavrenz. *Winter Weather Safety Information* (August 2010).

Brown, Paul, interview by Steven M. Lavrenz. *Winter Weather Safety Information* (August 2010).

Cluett, Chris, and Jeffery Jenq. *A Case Study of the Maintenance Decision Support System (MDSS) in Maine.* Washington, DC: Federal Highway Administration, 2007.

Coffey, Michael J., interview by Steven M. Lavrenz. *Winter Weather Safety Information* (August 2010).

Donnelly, A. L. Safety in Surface Maintenance. *Traffic Quarterly*, October 1947: 383-388.

Felt, interview by Steven M. Lavrenz. *Winter Weather Safety Information* (August 2010).

Hughes, Sasha, interview by Steve M. Lavrenz. *Winter Weather Safety Information* (August 2010).

Iowa Department of Transportation, Office of Traffic and Safety. Crash Analysis Resources. *Iowa DOT top 200 safety improvement candidate locations (SICL).* n.d. http://www.iowadot.gov/crashanalysis/pdfs/iowa_safetyimprovementcandidatelocation_method_20070220.pdf (accessed 2010).

Johnson, David B., interview by Steven M. Lavrenz. *Winter Weather Safety Information* (August 2010).

Khan, Ghazan, Kelvin Santiago-Chaparro, Xia Qin, and David Noyce. Application and Integration of Lattice Data Analysis, Network K-functions, and GIS to. *Transportation Research Record 2136*, 2009.

Lashmet, interview by Steven M. Lavrenz. *Winter Weather Safety Information* (August 2010).

Maze, Thomas H., Chris Albrecht, Dennis A. Kroeger, and Jonathan Wiegand. Peformance Measures for Snow and Ice Control Operations. *NCHRP Web Document*, December 2007: 133p.

McClellan, Tony, Melody Coleman, Paul Boone, and Kirk Carpenter. Research Pays Off: Implementing a Winter Maintenance Decision Support System: Indiana Department of Transportation's Process, Success, and Savings. *TR News*, November 2009: 35-37.

Micali, Vincent A., interview by Steven M. Lavrenz. *Winter Weather Safety Information* (August 2010).

Mills, interview by Steven M. Lavrenz. *Winter Weather Safety Information* (August 2010).

Monsere, Christopher M., Peter G. Bosa, and Robert Lawrence Bertini. Combining Climate, Crash, and Highway Data for Improved Ranking of Speed and Winter-Weather Related Crash Locations in Oregon. *Journal of Transportation Engineering*, July 2008: 287-296.

Montella, Alfonso. A Comparative Analysis of Hotspot Identification Methods. *Accident Analysis & Prevention*, March 2010: 571-581.

Morrison, interview by Steven M. Lavrenz. *Winter Weather Safety Information* (August 2010).

Pinet, M., S. McDonald, and B. Bielkiewicz. Alberta Road Weather Information Systems Network Expansion, Winter Risk Assessment and Priority List for Advanced Winter Maintenance Strategies. *2009 Annual Conference and Exhibition of the Transportation Association of Canada - Transportation in a Climate of Change.* Ottawa: Transportation Association of Canada, 2009. 12p.

Piper, Dave L., interview by Steven M. Lavrenz. *Winter Weather Safety Information* (August 2010).

Qin, X., J. Han, and J. Zhu. Spatial Analysis of Road Weather Safety Data Using a Bayesian Hierarchical Modeling Approach. *Advances in Transportation Studies*, July 2009: 69-84.

Qin, Xiao, David A. Noyce, Chanyoung Lee, and John Kinar. Snowstorm Event-based Crash Analysis. *Transportation Research Record 1948*, 2006: 135-141.

Qiu, Lin, and Wilfrid A. Nixon. *Performance Measurement for Highway Winter Maintenance Operations.* Ames: Iowa Department of Transportation, 2009.

Roberts, Thomas, interview by Steven M. Lavrenz. *Winter Weather Safety Information* (August 2010).

Saberi, Meead, and Robert Lawrence Bertini. Beyond Corridor Reliability Measures: Analysis of Freeway Travel Time Reliability at the Segment Level for Hot Spot Identification. *TRB 89th Annual Meeting Compendium of Papers DVD.* Washington, DC: Transportation Research Board, 2010. 13p.

Sands, interview by Steven M. Lavrenz. *Winter Weather Safety Information* (August 2010).

Sargent, William, interview by Steven M. Lavrenz. *Winter Weather Safety Information* (August 2010).

Senn, Larry. *Summary Report: Washington State Road Weather Information Systems.* Springfield: National Technical Information Service, 2005.

Shahdah, Usama, and Liping Fu. Quantifying the Mobility Benefits of Winter Road Maintenance -- A Simulation-Based Analysis. *TRB 89th Annual Meeting Compendium of Papers DVD.* Washington, DC: Transportation Research Board, 2010. 16p.

Shultz, interview by Steven M. Lavrenz. *Winter Weather Safety Information* (August 2010).

St.Clair, interview by Steven M. Lavrenz. *Winter Weather Safety Information* (August 2010).

Strong, Christopher K., Yurii Shvetsov, and Julia Sharp. *Development of a Roadway Weather Severity Index.* Washington, DC: Research and Innovative Technology Administration, 2005.

The Iowa LiDAR Project - LAS and ASCII Files. *Iowa Lidar Mapping Project.* n.d. ttp://geotree2.geog.uni.edu/Lidar/iowa_lidar_metadata.html (accessed June 27, 2011).

Usman, Taimur, Liping Fu, and Luis Fernando Miranda-Moreno. Accident Prediction Models for Quantifying Safety Benefit of Winter Road Maintenance. *TRB 89th Annual Meeting Compendium of Papers DVD.* Washington, DC: Transportation Research Board, 2010. 23p.

Wieder, David, interview by Steven M. Lavrenz. *Winter Weather Safety Information* (August 2010).

Yurek, Russell A., interview by Steve M. Lavrenz. *Winter Weather Safety Information* (August 2010).

APPENDIX A. WINTER SAFETY AND MOBILITY WORK PLAN

Overview

The Safety and Mobility Impacts of Winter Weather Phase I report will serve as documentation for Phase I activities (Task 1, 2, and 3), which outlined international winter safety-related efforts and combined crash data and analysis tools to identify routine winter weather-related crash sites on state-maintained rural highways in Iowa. Task 4 includes the development of a work plan for future (Phase II) project tasks, which will focus on site specific analyses and mitigation strategy selection. In Phase II, the research team would work with Iowa DOT staff to:

- Identify candidate locations based on the three metrics developed for Phase I
- Conduct candidate site-level analysis, taking multiple factors into consideration, such as crash history and weather history, wind conditions, terrain, roadside characteristics, and traffic
- Identify specific mitigation strategies (such as targeted/reprioritized maintenance activities, roadway/roadside improvements, and application of ITS technologies) for use in Iowa
- Investigate the effectiveness of existing roadway/roadside improvements
- Outline a plan for implementation, measurement, and monitoring of these strategies across the Iowa DOT transportation network.

Work Plan

The objectives of this work plan are to outline standardized procedures for candidate site selection, (based on crash experience during winter weather conditions), propose an approach to evaluate these sites, and identify possible mitigation strategies to improve mobility and safety during adverse winter weather conditions.

Candidate Site Selection

While several factors may be considered in preliminary candidate site selection, roadway type and crash history will be the focal points.

Type of Roadway

The Iowa DOT, with assistance from the research team, will identify the types of roadways to be initially evaluated. Rural freeways and/or expressways may provide the most opportunity, as they typically possess an adequate number of incidents for evaluation and a return on investment. Additionally, traffic on these roadways may be less significantly impacted by adverse weather conditions, compared to rural two-lane highways. If the methodology employed in this initial work plan is deemed successful, it may be extended to roadways with lower traffic volumes.

Crash History

Evaluation of crash history may be multi-tiered and iterative in nature. It may also require more expansive analysis of the rural highway system as a whole.

First, the Iowa DOT, with assistance from the research team, will establish a site prioritization protocol. This protocol may be based on many factors or considerations, such as:

- A combined weighting of the three metrics (winter weather-related crash density, proportion and severity) developed in Phase I of this project or their standing within the network as a whole, e.g. top five percent of the mileage.
- Identification of the most critical metric, e.g. winter weather-related crash density.
- Establishment of threshold values with respect to one or more metrics.

Once established, additional criteria may be applied to further refine the locations of interest. For example, are one-mile analysis sections sufficient, or is it more desirable to analyze sections of longer extents? If the latter, proximate one-mile sites satisfying pre-defined criteria may be grouped for consideration, e.g. an analysis section must include at least two “high priority” one-mile segments within two miles of each other. This would allow some flexibility in that “high priority” sections would not necessarily need to be adjacent to each other. Practical analysis section extent may, in part, be dictated by available mitigation strategies, to be discussed later.

The Iowa DOT will propose a preliminary number of sites for potential investigation.

Site Evaluation

The Iowa DOT, with assistance from the research team, will develop a list of factors potentially impacting roadway safety during adverse winter weather conditions. Emphasis will be on factors that the Iowa DOT may have some success in mitigating or improving. Factors may include surface conditions, roadside safety features (guardrail), roadside environment (ditch shape, foreslope, backslope), roadside obstructions, snow fences and vegetation, etc. These factors will then be evaluated with respect to the following:

- Crash history
- Field experience and observations
- Traffic and weather history
- Roadway and roadside character

Crash History

In depth, site specific crash experience with then be performed. Analysis will include evaluation of common characteristics and temporal variation (distributed throughout analysis period or limited to a few years or events) among the crashes. To further facilitate this analysis, the Iowa

DOT will identify a set of crash characteristics of interest (including vehicles and drivers) for the entire rural highway system, and statewide averages will be developed for comparison purposes. For example, the percentage of rollover crashes at a given location may be compared to the statewide average to determine if this type of crash is overrepresented at the candidate site. In this example, a high percentage of rollover crashes may represent the presence of a steep or unforgiving roadside.

Field Experience and Observations

Pertinent Iowa DOT field maintenance operators and law enforcement officials will be engaged to obtain anecdotal information about their observations and experiences, if any, at these candidate sites during adverse winter weather conditions. A list of factors to be considered will be provided as guidance.

Given that the information will be anecdotal, it may be appropriate to provide both sites of high and low priority, without distinguishing them, in an attempt to limit possible unintentional bias in responses. Additionally, responses may be solicited without providing the site crash history.

Traffic and Weather History

Where available, information regarding historic weather events and event traffic conditions will be evaluated. Weather event data may be used to assess if traffic safety appears more impacted during/after certain types of winter weather events, e.g. heavy precipitation, high winds, blowing snow, low friction road surface, long duration, etc. Historic traffic data, ideally from proximate ATR locations or RWIS sites, may aide in assessing how traffic is impacted by weather events. Some sites may experience much more significant reductions in traffic compared to others. Sites with consistently high traffic volumes throughout weather events may warrant more attention.

Roadway and Roadside Character

Roadway and roadside character will be assessed through both in-office review of relevant data sets, e.g. LiDAR, aerial imagery, video log, and a site visit. Characteristics of interest may include the roadway cross-section (including ditch shape, foreslope, and backslope), grade, horizontal and vertical curvature, structures, roadside obstructions and safety features. In-office review will be completed in advance of site visits so that the review team may identify features of interest to further review in the field.

Mitigation Strategies

The Iowa DOT, with assistance from the research team, will develop of standard set of possible mitigation strategies that the DOT may employ in an attempt to improve safety during winter weather conditions. These strategies may range from maintenance practices to physical changes to the roadway or roadside. Estimated unit costs for each of these strategies will also be developed.

Based on the site evaluation(s), strategies will be identified that may be best suited, or most applicable, for each site. In some cases, no appropriate strategies may be readily apparent. If available and applicable, crash reduction factors may be utilized to perform a benefit-cost analysis for the strategy or strategies identified.

The research team will also work with the Iowa DOT to identify locations of previous mitigation strategy implementation. The effectiveness of these mitigation strategies, for sites with sufficient crash history, will be evaluated. The effectiveness of existing strategies may serve as additional considerations in strategy selection.

Sites will be prioritized based on both their crash history and estimated impact of the selected mitigation strategies. The sites and associated strategies will be proposed for consideration for implementation.

Implementation Work Plan

A work plan will be developed, outlining a plan for implementation, measurement, and monitoring of all applied strategies across the Iowa DOT transportation network.