The Mobility and Safety Impacts of Winter Storm Events in a Freeway Environment

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This paper describes how data from several Iowa information management systems were used to analyze the mobility and safety impacts of winter storm events. Roadway and weather data were acquired from the roadway weather information system (RWIS), hourly traffic volumes from automatic traffic recorders (ATRs), and crash information from the accident location and analysis system (ALAS). Daily snowfalls were acquired from state and national agencies. Storm and non-storm data for seven interstate roadway segments were considered. Only winter storm events with a duration of four or more hours and a snowfall of 0.51 centimeters per hour (0.20 inches per hour) or more were evaluated. Analysis of the data revealed the impacts of winter weather on freeway traffic. Winter storm events decrease traffic volumes, but the impact is highly variable. The average winter storm volume reduction was approximately 29 percent, but ranged from approximately 16 to 47 percent. A positive relationship was found between percent volume reduction, total snowfall, and the square of maximum gust wind speed. Crash rates also significantly increase during winter storm events, possibly the result of a large decrease in traffic volumes and higher crash reporting rates during winter weather. After controlling for exposure, an increase in snowfall intensity and snowstorm duration also increased winter storm event crash frequency. The results of this research can help determine the potential impacts of winter weather, support the eventual development of a dynamic winter weather driveability level of service system, and assist with planning preventive and emergency operations. Key words: winter weather, mobility, safety, volume.

INTRODUCTION

Traffic volume and safety along a roadway segment is a function of a number of factors (e.g., heavy vehicle percentages, lane widths, etc.). One of these factors is weather. Engineering designs and maintenance attempt to minimize the impacts of weather on traffic, but each year winter storm events impact mobility and safety. This research used data from several Iowa information management systems to evaluate winter weather impacts on traffic volume and safety.

LITERATURE REVIEW

Weather and Volume/Travel Decisions

Hanbali and Kuemmel have investigated winter storm volume reductions (*1*), using traffic volume and weather data from at least the first three months of 1991 at 11 locations in four states. Traffic volume reductions were calculated for different ranges of total snowfall, average daily traffic, roadway type, time of day, and day of the week (*1*). Overall, the reductions ranged from 7 to 56 percent (*1*). The researchers concluded that volume reductions increased with total snowfall, but that the reductions were smaller during peak travel hours and on weekdays (*1*). A 1977 Federal Highway Administration (FHWA) study had similar findings (*2*).

Weather and Safety

Several researchers have explored the relationship between adverse weather and safety (*3, 4, 5, 6, 7, 8*). For example, Hanbali found a significant decrease in crash rates before and after deicing maintenance activity (*3*), and the results of several Swedish studies have supported these findings (*4, 5, 6*). The Swedish studies also indicate that severe injury rates on roads with snow and ice can be several times greater than non-winter roadways (*4, 5, 6*). Perry and Symons also found that total injuries and fatalities increased by 25 percent on snowy days, and the rate of injuries and fatalities increased by 100 percent (*7*). A Canadian study, on the other hand, reported that winter months (December to March, inclusive), when compared to summer months, had higher minor and material damage accident rates but lower severe and fatal crash rates (*4*). A 1977 FHWA study had similar findings but found increased severe injury crash rates in snowbelt states when compared to the non-snowbelt states during winter months (*8*).

DATA COLLECTION

This project used data from the roadway weather information system (RWIS), automatic traffic recorders (ATRs), the accident location and analysis system (ALAS), and the Iowa Department of Agriculture and Land Stewardship (IDALS)/National Weather Service (NWS). Roadway and/or weather data from Iowa RWIS stations and the IDALS/NWS, crash data from ALAS, and hourly traffic volumes from Iowa interstate ATRs were linked. The data were acquired for winter storm event and comparable non-storm event time periods.

Seven RWIS sites along the interstate in Iowa were analyzed. All the RWIS stations had a nearby ATR, and the hourly volumes collected at these ATRs were used to approximate storm and non-storm event traffic volumes adjacent to the RWIS station. The location of the seven RWIS/ATR pairs are shown in Figure 1. Bi-directional ATR hourly traffic volumes were acquired for 1995, 1996, 1997, and 1998. The volume data was not used in this research if it was

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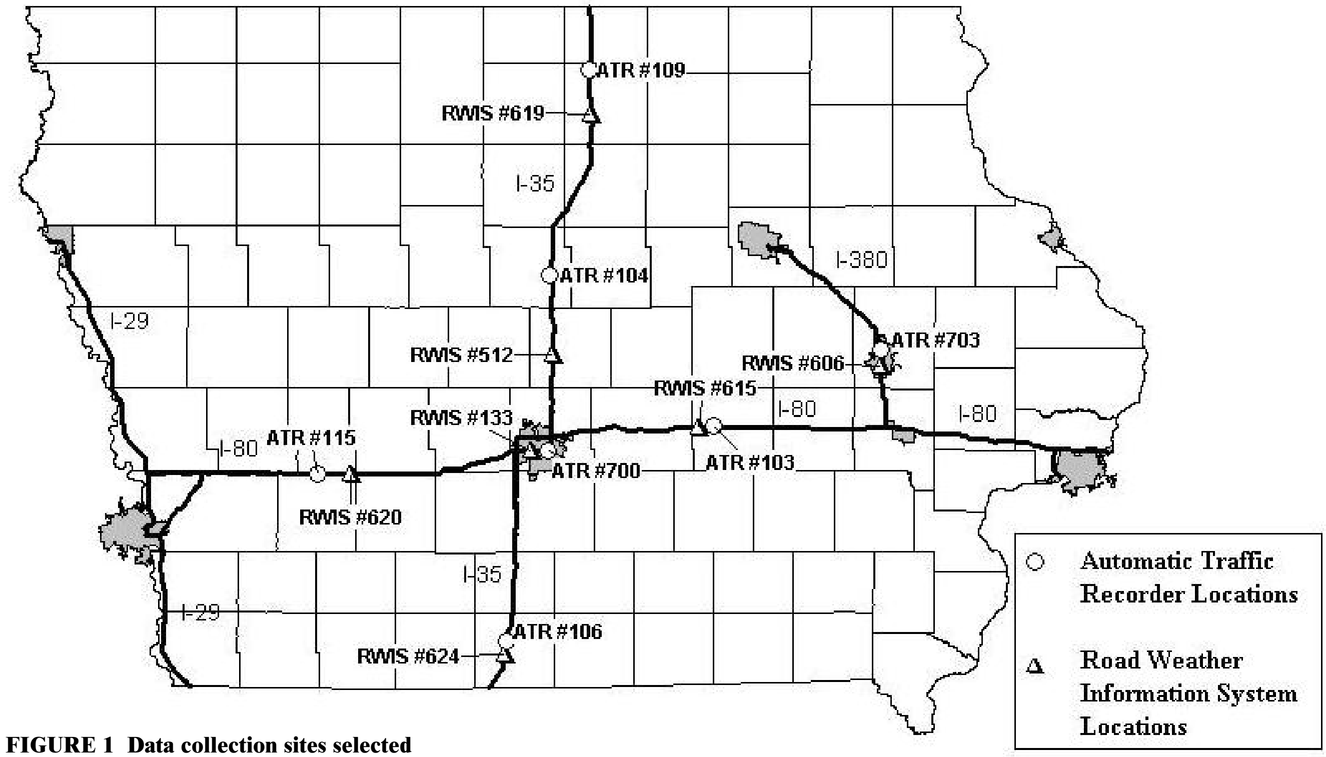

FIGURE 1 Data collection sites selected

estimated (due to an ATR malfunction) or was measured on a day near a holiday (i.e., a non-typical travel day).

Weather and roadway data from the RWIS stations (See Figure 1) and daily snowfall information from IDALS/NWS observer sites were used to define, identify, and determine the time periods when winter storm events most likely occurred. RWIS and IDALS/NWS data from all or part of the 1995/1996, 1996/1997, and 1997/1998 winter seasons were acquired. In general, winter storm event time periods were defined by those hours when the RWIS stations recorded all the following: 1) precipitation occurring, 2) air temperature below freezing, 3) wet pavement surface (indicated at any of the pavement sensors at the site), and 4) a pavement temperature below freezing (indicated at all of the pavement sensors at the site). Any two winter storm events separated by only one "non-storm" hour were combined. In addition, this research only considered those winter storm event time periods that had a duration of at least four hours and an estimated snowfall intensity (from nearby IDALS/NWS information) of 0.51 centimeters per hour (0.20 inches per hour). The goal was to limit the research analysis to relatively significant winter storm events.

This research compared and statistically analyzed volume and crash data from winter storm and non-storm event time periods. For example, Figure 2 shows the hourly traffic volumes observed at the Jewell, Iowa ATR during a winter storm event on Saturday, April 12, 1997. Figure 2 also shows the average Saturday daily traffic flow profile for April 1997. As expected, the average volume during the winter storm event is at or below the average volume of the non-storm traffic flow profile. If possible, this type of comparison was completed, along with a similar storm/non-storm crash comparison, for each of the winter storm events defined.

WINTER STORM EVENT IMPACT ANALYSIS

Volume Analysis

Overall, 64 winter storm events, encompassing 618 hours, were defined for the traffic volume analysis. Some descriptive statistics of the winter storm event percent volume reductions are shown in Table 1.

Table 1 shows large variability in winter storm event traffic volume impacts. The average storm event volume reduction (by location) ranges from approximately 16 (n = 10) to 47 percent (n=6), and the overall average volume reduction is approximately 29 percent. The variability is shown by the fact that the standard deviation of the percent volume reduction at each RWIS location is close to the average percent volume reduction. The 95 percent confidence interval for the overall average percent volume reduction is 22.3 to 35.8 percent.

Regression analysis (assuming a normal distribution of the data) was used to investigate the relationships between percent volume reduction (the dependant variable) and storm event duration, snowfall intensity and total snowfall, minimum and maximum average (during a one-minute period) wind speed, and maximum gust wind speed (maximum four-second wind speed during a one-minute time period). The regression analysis indicated that percent volume reduction has a statistically significant relationship with total snowfall and the square of maximum gust wind speed. The other variables were either correlated with these two variables or were not found to have a statistically significant relationship with percent volume reduction. The results of this regression analysis are shown in Table 2. The model coefficients indicate that percent volume reduction in-

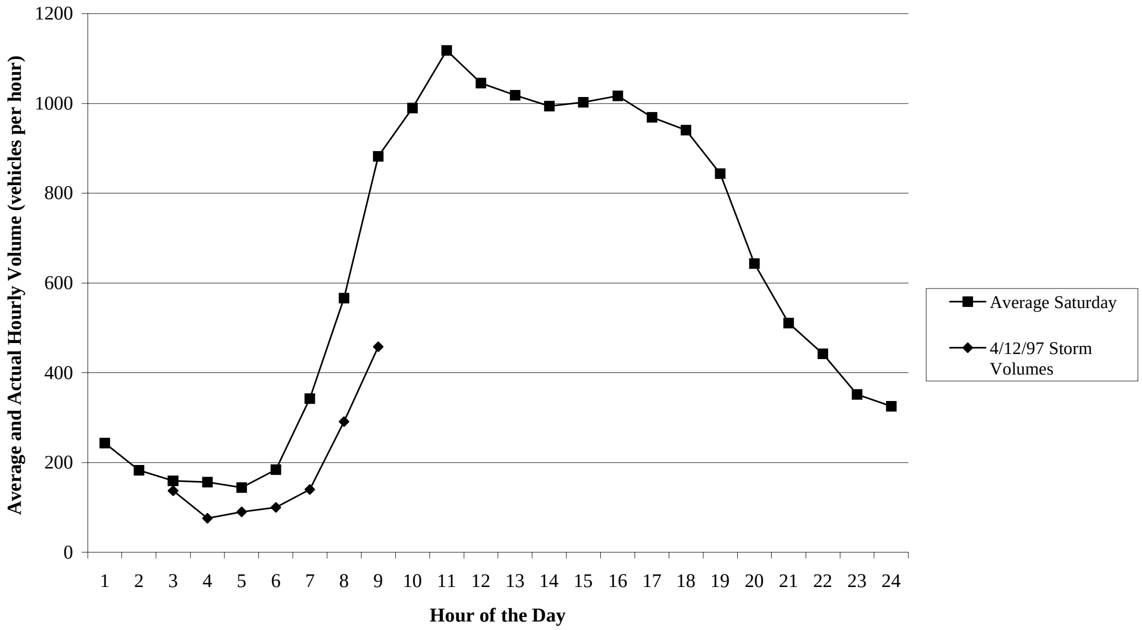

FIGURE 2 Average Saturday traffic flow profile (April 1997) and winter storm event (April 12, 1997) volumes

TABLE 1 Winter Storm Event Traffic Volume Summary[1]

Interstate RWIS Location	Number of Storm Events	Storm Event Hours	Average Storm Event Volume Reduction (Percent)	Std. Dev. Storm Event Volume Reduction (Percent)	Min. Storm Event Volume Reduction (Percent)	Max. Storm Event Volume Reduction (Percent)
#133 – I-235, Des Moines	8	83	36.4	30.5	13.0	86.5
#512 – I-35, Ames	10	82	15.5	13.7	1.4	46.9
#606 – I-380, Cedar Rapids	4	70	23.7	18.9	0.8	40.0
#615 – I-80, Grinnell	6	71	46.9	46.2	-42.1	84.3
#619 – I-35, Mason City	12	79	19.1	20.1	-1.9	71.6
#620 – I-80, Adair	10	107	35.3	30.8	-8.0	91.5
#624 – I-35, Leon	14	126	32.5	23.1	5.5	80.8
Overall	64	618	29.1	26.7	-42.1	91.5

[1] Negative volume reductions indicate an increase in volumes. Overall, three of the storm events defined had negative volume reductions.

Table 2 Regression Analysis Results
(Dependant Variable: Percent Winter Storm Event Volume Reduction)[1]

Explanatory Variable	Coefficient	T-Statistic	P-Value	Mean of Variable	Std. Dev. of Variable	Range of Variable
Total Snowfall (centimeters)	0.9010	2.16	0.035	9.562	6.038	2.67 to 27.51
Max. Gust Wind Speed[2] (kph^2)	0.01143	6.87	0.000	1925.08	1513.93	93.32 to 7558.56
Constant	-1.582	-1.34	0.730	-	-	-

[1]kph = kilometers per hour, 1 centimeter = 0.39 inches, 1 kilometer = 0.62 miles
Model Summary Statistics: Number of Observations = 64 Mean Square Error = 332 F-Value = 38.65 Coefficient of Multiple Determination = R-Squared = 0.559 P-Value = 0.000 R-Square (Adjusted) = 0.544

Table 3 Summary of Snowstorm Data[1]

Sample Statistic	Crash Frequency (crashes/storm)	Storm Duration (hrs)	Traffic Volume (veh)	Snow Intensity (cms/hr)	Max Wind Gust Speed (kmph)	Min Avg. Wind Speed (kmph)	Max Avg. Wind Speed (kmph)
Mean	2.00	9.09	7063.70	1.07	37.54	12.52	28.92
Std. Error	0.47	0.53	1502.06	0.07	1.98	1.27	1.56
Std. Deviation	3.43	3.89	11037.86	0.53	14.58	9.36	11.43
Variance	11.74	15.14	121834416.51	0.28	212.53	87.61	130.68
Minimum	0.00	4.00	231.00	0.51	9.66	0.00	9.66
Maximum	17.00	19.00	61910.00	2.54	66.01	33.81	54.74
Sum	108.00	491.00	381440.00	57.68	2026.99	676.20	1561.70
Count	54.00	54.00	54.00	54.00	54.00	54.00	54.00

[1]Conversions: 1 centimeter = 0.39 inches and 1 kilometer = 0.62 miles.

creases with each variable. Summary statistics (See Table 2) of the model also indicate a significance at a 95 percent level of confidence, and an adjusted coefficient of multiple determination (i.e., R-Squared) of 54.4 percent. The model has some explanatory power.

Safety Analysis

Overall, 54 winter storm events, encompassing 491 hours, were defined for the crash analysis. Information for crashes that occurred during winter storm event time periods was acquired from ALAS for a 48-kilometer (km) (30-mile) interstate highway section adjacent to and centered on each RWIS locations shown in Figure 1. Hourly traffic volumes for the same time periods were approximated from nearby ATRs. It was assumed that in most cases a segment of this length would experience the same type of weather conditions.

Tables 3 and 4 summarize the winter storm and non-storm event data used in this crash analysis. On average, two crashes were reported during each winter storm event and 0.65 crashes during comparable non-storm event time periods. This non-storm event average, however, is based on a longer duration of time because the crash data represent a combination of the non-storm event hours for all the similar days during the same month as the comparable storm event time period. Overall, there were 108 winter storm event crashes during the three winter seasons under investigation.

TABLE 4 Summary of Non-Storm Data

Sample Statistic	Crash Frequency (crashes/storm)	Equivalent Duration (hrs)	Traffic Volume (veh)
Mean	0.65	30.80	32106.80
Std. Error	0.23	1.85	7409.55
Std. Deviation	1.67	13.59	54448.84
Variance	2.80	184.58	2964676702.01
Minimum	0.00	12.00	552.00
Maximum	10.00	60.00	301299.00
Sum	35.00	1663.00	1733767.00
Count	54.00	54.00	54.00

The overall winter storm event crash rate (n = 54) was calculated to be 5.86 crashes per million-vehicle-kilometers (mvkm). Note, however, that the traffic volumes recorded at the nearby ATR station do not represent actual traffic volumes along the entire 48 km-long (30 mile) highway section under investigation. Therefore, the crash rates reported in this paper do not represent the actual crash rate for the interstate sections of interest and should only be used for comparison purposes. The overall non-storm crash rate was calculated to be 0.41 crashes per mvkm (based on the same assumption as stated above). The difference in crash rates between storm and non-storm event time periods was approximately 1,300 percent, indicating a very significant change.

A Poisson regression modeling approach was used to analyze the reported number of crashes (*9*). The winter storm event crash frequency was the dependent variable, and the independent variables included exposure (the product of section length (km) and traffic volume during the winter storm events) in million-vehicle-kilometers, snowfall intensity, maximum wind gust speed, maximum average wind speed during the snowstorm, and minimum average wind speed during the snowstorm. Table 5 shows the Poisson modeling results. The model indicates significantly positive coefficients for exposure and snowfall intensity. In other words, an increased exposure and snowfall intensity during winter storm events increases crash frequency, but the model also indicates that snowstorm duration has an additional effect besides that captured by the exposure term.

TABLE 5 Poisson Model Results[1]

(Dependant variable: crash frequency during snowstorms)

Explanatory Variable	Coefficient	T-statistic	Marginal Values	Mean of Explanatory Variable
Exposure (mvkm)	0.682	6.148	0.832	0.341
Snowstorm duration (hrs)	0.156	5.826	0.190	9.093
Snowfall intensity (cms/hr)	0.494	2.226	0.603	1.068
Max wind gust speed (kmph)	0.009	1.311	0.010	37.540
Constant	-2.315	-5.142	-2.826	-

[1]Conversions: 1 centimeter=0.39 inches and 1 kilometer=0.62 miles.
Model Summary Statistics: Number of observations = 54, Log likelihood function [L(β)] = -84.314, Restricted Log likelihood [L(0)] = -151.546, $\rho^2 = 1 - L(\beta)/L(0) = 0.443$

SUMMARY OF FINDINGS

- The 64 winter storm events used in the traffic volume analysis reduced volumes by an average of approximately 29 percent, but the reduction was relatively variable. The 54 winter storm events used in the crash analysis had an overall crash rate of 5.86 mvkm compared to a non-storm crash rate of 0.41 mvkm. A difference of approximately 1,300 percent.
- The traffic volume regression analysis indicates a significant relationship between percent winter storm event volume reduction, total snowfall, and the square of maximum gust wind speed. The crash regression analysis found a significant relationship between winter storm event crash frequency, exposure (the product of section length and volume), and snowfall intensity.
- Several factors could be responsible for the difference between the non-storm and snowstorm crash rates. First, the winter storm event definition used in this study represents relatively severe weather conditions under which the likelihood of crashes could be very high. Second, under such severe weather conditions and extended snowstorm durations traffic volumes tend to reduce appreciably. With substantially reduced traffic volumes, the occurrence of only a few crashes can result in substantial crash rates. Third, there could be a bias in crash reporting during snowstorms compared to non-storm conditions. Crashes are more likely to be reported during snowstorms compared to non-storm conditions because adverse weather conditions may necessitate a call for help by crash victims.
- A combination of the results found in this research and comparable winter weather vehicle speeds could eventually be used to determine a winter weather level of service. Relationships between volume, speed, and weather/roadway conditions would need to be defined and/or established. The speeds for specific roadway and/or weather conditions might be acquired from past research, ATRs, and/or possibly the application of video-based data collection equipment. Speed and volume data would need to be collected, archived, and weather/roadway conditions defined and correlated with these traffic flow characteristics.

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