Investigation of Volume, Safety, and Vehicle Speeds During Winter Storm Events

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Winter storm events can have significant impacts on mobility and safety. During the past year, these impacts were investigated by the Center for Transportation Research and Education of the Iowa Department of Transportation. The documented project proceeded in two phases. First, data related to traffic flow, crashes, weather, and roadway conditions were collected from existing information management systems in Iowa; these data were evaluated and analyzed. Second, a mobile video data collection system was used to collect data during seven winter storm events. The results from both phases of this project are summarized.

Traffic volume, safety, and vehicle speed along a roadway segment are functions of several factors (e.g., percentage of heavy vehicles, lane widths). One of these factors is weather. Engineering designs and maintenance attempt to minimize the effects of weather on traffic, but each year winter storm events affect mobility and safety.

This research used data from several existing Iowa information management systems as well as traffic flow and roadway condition data collected from a mobile video data collection system. These data were analyzed to evaluate winter weather impacts on traffic volume, safety, and vehicle speeds.

LITERATURE REVIEW

Weather and Volume

Hanbali and Kuemmel investigated traffic volume reductions during winter storms (*1*). They collected traffic volume and weather data from at least the first 3 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. Overall, the reductions ranged from 7 to 56 percent. The researchers concluded that volume reductions increased with total snowfall but that the reductions were smaller during peak travel hours and on weekdays. A 1977 FHWA study had similar findings (*2*).

Weather and Safety

Several researchers have explored the relationship between adverse weather and safety (*2–7*). For example, Hanbali found a significant decrease in crash rates before and after deicing maintenance activity (*3*), and the results of three Swedish studies support these findings (*4–6*). The Swedish studies also indicate that severe injury rates on roads with snow and ice can be several times greater than on roadways during any other time of year (*4–6*). Perry and Symons 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 higher minor and material damage accident rates but lower

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severe and fatal crash rates in the winter months (December to March, inclusive) than in the summer months (*4*). A 1977 FHWA study had similar findings but found that the rates of severe injury crashes were increased in snowbelt states over the nonsnowbelt states during winter months (*2*).

Weather and Speed

One measure of traffic flow mobility is vehicle speed. In an economic analysis of winter weather maintenance, Hanbali used a FHWA study that found an average range of speed reduction due to snow and ice conditions of 18–42 percent on two-lane roadways and 13–22 percent on freeways (*2, 3*). A Swedish study [referenced by Brown and Baass (*4*)] also found a reduction in speed of 10–30 percent with ice and snow conditions (*8*). However, another study concluded that speed reductions might be determined more by roadway appearance than the actual friction levels provided and that the speed reductions observed were typically higher when slippery roadway conditions were combined with precipitation (*9*).

Other studies have categorized weather events and evaluated their effect on operating free-flow vehicle speeds. For example, Lamm et al. considered 24 rural two-lane highways under dry and wet conditions but found no statistical difference in operating speed (*10*). However, visibility was not limited during any of the rain events considered. On the other hand, Ibrahim and Hall found site-specific reductions in free-flow speed of 1.9 km/h (1.2 mph) for light rain, 3.1 km/h (1.9 mph) for light snow, 5.0–10.0 km/h (3.1–6.2 mph) for heavy rain, and 38.0–49.9 km/h (23.6–31.0 mph) for heavy snow (*11*). These data should be used with caution, because they may represent the effects of other data collection site characteristics. In a German study, Brilon and Ponzlet found a vehicle speed reduction of 9.5–11.9 km/h (5.9–7.4 mph) when roadways were wet (*12*). Finally, there are also several proposals for the inclusion of currently unpublished speed/weather relationship data within the *2000 Highway Capacity Manual*. Ongoing studies show that light precipitation and heavy rain may have larger impacts on free-flow speed than previously documented and that high winds also may have an influence.

The effects of visibility on vehicle speed also have been considered. Liang et al. studied a 24-km (15-mi) segment of Interstate Route 84 in Idaho from December 1995 to April 1996 (*13*). During this time, extreme weather conditions were observed on 21 days. The speed data from foggy days revealed an average speed reduction of 8 km/h (5 mph) compared with average speeds on clear days. The data from days with snow, on the other hand, showed that speeds were affected by more than visibility. A generalized linear model described speed as a function of visibility, snow cover, light, temperature, and wind. Overall, an average speed reduction of 19.2 km/h (11.9 mph) was observed during snow events, but the data were highly variable. Liang et al. concluded that the measured speed reductions resulted from a perceived reduction in safety by drivers (*13*).

DATA COLLECTION

For the first phase of this project, data were collected from a roadway weather information system (RWIS), automatic traffic recorders (ATRs), an accident location and analysis system (ALAS), and the Iowa Department of Agriculture and Land Stewardship (IDALS)/National Weather Service (NWS). The 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. These data were acquired for both winter storm events and comparable non–storm events.

Overall, seven RWIS sites along the Iowa interstate were analyzed during the first phase of this project. All of the RWIS stations had a nearby ATR, and the hourly volumes collected at these ATRs were used to approximate storm event and non–storm event traffic volumes adjacent to the RWIS station. The locations of the seven RWIS/ATR pairs are shown in Figure 1. Bidirectional ATR hourly traffic volumes were acquired for 1995, 1996, 1997, and 1998, but the data were not used if estimated (due to an ATR malfunction) or measured on a day near a holiday (i.e., an atypical travel day).

Weather and roadway data from the RWIS stations (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 as those hours when the RWIS stations recorded four kinds of data:

- Precipitation occurring,
- Air temperature below freezing,
- Wet pavement surface (indicated at any of the pavement sensors at the site), and
- A pavement temperature below freezing (indicated at all of the pavement sensors at the site).

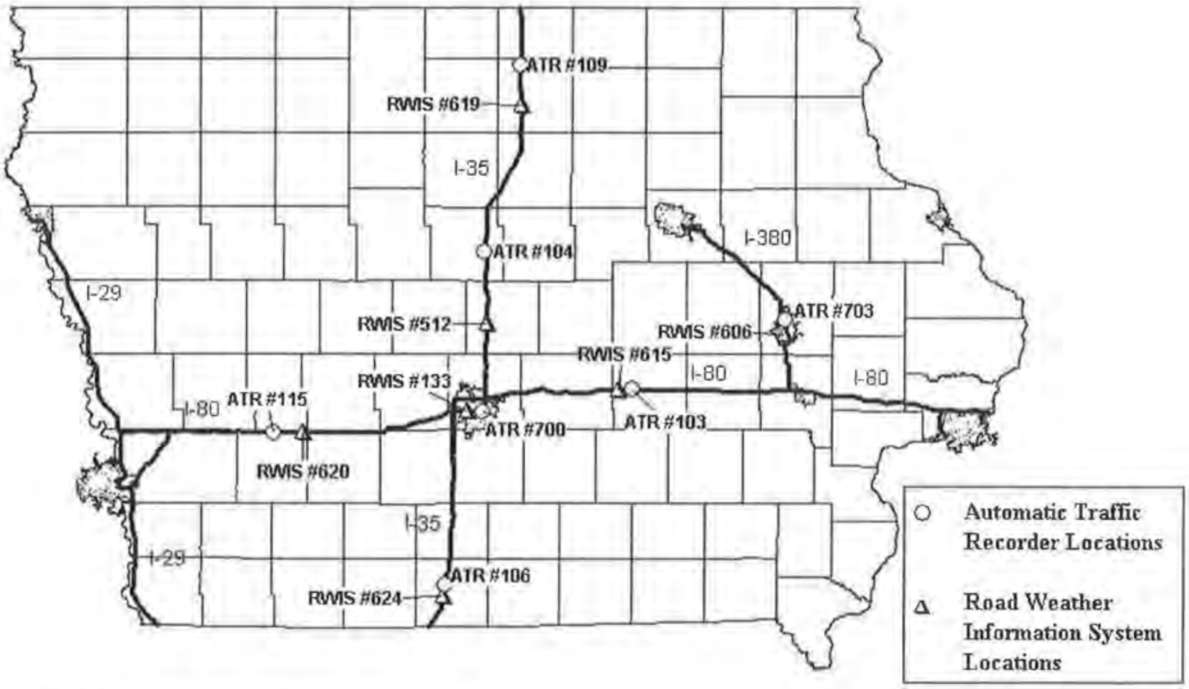

FIGURE 1 Data collection sites selected.

Any two winter storm events (as defined above) separated by only one "nonstorm" hour were combined. In addition, this research considered only those winter storm event time periods that had a duration of at least 4 h and an estimated snowfall intensity (from nearby IDALS/NWS information) of 0.50 cm/h (0.20 in./h). The goal was to limit the research analysis to relatively significant winter storm events.

For the second phase of this project, traffic flow, weather, and roadway condition data were collected. Data were collected with a mobile video traffic data collection system (commonly known as an AutoScope) during seven 1998–1999 winter storm events. The safety of the data collection team and an ability to respond quickly to approaching winter storm events were the determining factors in selecting the data collection site.

First, it was decided that the data collection equipment and personnel should not be adjacent to the interstate roadway during winter storm events and that the data should be collected from a low-volume bridge that overpasses Interstate Route 35. Second, the data collection location needed a bridge width of at least 8 m (26 ft) to allow two-way traffic flow during the data collection activities. Finally, the site had to be close to the data collection team based in Ames, Iowa. The amount of time needed to assemble the team and to prepare and set up the equipment was relatively significant (i.e., hours). The site chosen was Northeast 142nd Avenue in Polk County, Iowa. This roadway crosses over Interstate Route 35 about 16 km (10 mi) south of Ames.

WINTER STORM EVENT IMPACT ANALYSIS

Volume Analysis

Overall, 64 winter storm events, totaling 618 h, were defined for the traffic volume analysis. Some descriptive statistics of the percent volume reductions during winter storm events are shown in Table 1. The traffic volume effects of winter storm events vary widely. 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 95 percent confidence interval for the overall average percent volume reduction is 22.3–35.8 percent. The variability in the data is also shown by the fact that the standard deviation of the percent volume reduction at each RWIS location is about the same as the average percent volume reduction at that location.

Regression analysis (assuming a normal distribution of the data) was used to investigate the relationships between percent volume reduction (the dependent variable) and storm event duration, snowfall intensity and total snowfall, minimum and maximum average (during a 1-min period) wind speed, and maximum gust wind speed (maximum 4-s wind speed during a 1-min time period). The regression analysis indicated that percent volume reduction has a positive and statistically significant relationship with total snowfall and the square of maximum gust wind speed. The other variables considered

TABLE 1 Traffic Volume Summary for Winter Storm Events

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

NOTE: Negative volume reductions indicate an increase in volumes. Overall, three of the storm events defined had negative volume reductions.

were either correlated with these two variables or were not found to have a statistically significant relationship with percent volume reduction. The results of the regression analysis are shown in Table 2. Summary statistics of the model indicate a significance at a 95 percent level of confidence, and an adjusted coefficient of multiple determination (i.e., R^2) of 54.4 percent.

Safety Analysis

Overall, 54 winter storm events, totaling 491 h, were defined for the crash analysis. Information for crashes that occurred during the winter storm event time periods was acquired from ALAS for a 48-km (30-mi) Interstate highway section adjacent to and centered on each of the 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.

As expected, both the number of crashes and the crash rate increased during winter storm events. On average, 2 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, represents a combination of the non–storm event hours for all the similar days during the same month as the comparable storm event time period (i.e., it is based on a longer duration of time). In fact, the hourly crash frequency increased by about 942 percent during the winter storm events considered. In addition, this increase in crashes—and the typical decrease in traffic volumes—produced about a 1,300-percent increase in crash rate during the winter storm events considered.

A Poisson regression modeling approach was used to analyze crash frequency. The crash frequency during winter storm events was the dependent variable, and the independent variables included exposure (i.e., million vehicle miles), snow event duration, snowfall intensity, maximum gust wind speed, maximum average wind speed, and minimum average wind speed. Table 3 shows the Poisson modeling results. The model indicates significantly positive coefficients for exposure, snow event duration, and snowfall intensity. In other words, increased exposure, snow event duration, and snowfall intensity increase the predicted crash frequency during a winter storm event. The model was constructed to indicate the impact of winter storm event duration beyond the effect already captured by the exposure term.

Speed Analysis

The second phase of this research project involved collecting traffic flow, roadway, and weather-related data during seven 1998–1999 winter storm events. During these events, there was some kind of snowfall (e.g., light, moderate, or heavy), and in most cases, winter maintenance activities were taking place. The data collected and

TABLE 2 Regression Analysis Results, Traffic Volume During Winter Storm Events (Dependent Variable: Percent Winter Storm Event Volume Reduction)

Explanatory Variable	Coefficient	T-Statistic	P-Value	Mean of Variable	Std. Dev. of Variable	Range of Variable
Total Snowfall (inches)	2.289	2.16	0.035	3.764	2.377	1.05 to 10.83
Max. Gust Wind Speed (mph)	0.0296	6.87	0.000	742.7	584.1	36.0 to 2,916.0
Constant	-1.583	-0.35	0.730	-	-	-

NOTE: mph = miles per hour. 1 in. = 2.54 cm; 1 mph = 1.61 km/h. Model Summary Statistics: Number of Observations = 64; F-Value = 38.65; P-Value = 0.000; Mean Square Error = 332; Coefficient of Multiple Determination = R-Squared = 0.559; and R-Square (Adjusted) = 0.544.

TABLE 3 Poisson Model Regression Results, Crash Frequency During Winter Storm Events (Dependent Variable: Crash Frequency During Snowstorms)

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

NOTES: mvm = million-vehicle-miles; mph = miles per hour; 1 mi = 1.61 km. Model Summary Statistics: Number of Observations = 54; Log likelihood function $[L(\beta)] = -84.314$; Restricted Log likelihood $[L(0)] = -151.546$; and $\rho^2 = 1 - L(\beta)/L(0) = 0.443$.

summarized into 15-min increments included traffic volumes, vehicle speeds, vehicle gaps and headways, visibility [more than or less than 0.40 km (0.25 mi)] and roadway snow-cover conditions (snow on the roadway lanes or only the shoulders). Some of the data were collected manually, but all of the traffic flow data (e.g., volume, speed, headway, and gaps) were collected with mobile video data collection equipment (i.e., the AutoScope). Overall, 109 15-min time periods (approximately 27 h) of data were collected during the seven winter storm events. In addition, for comparison purposes, the same kinds of data were collected on a typical weekday in May, in the absence of adverse weather and roadway conditions.

The summary statistics for all the data collected during phase two of this project are shown in Table 4. Data are summarized for each winter storm event, the overall database, and the normal weekday. General relationships among average vehicle speeds, traffic volumes, vehicle gaps, roadway condition, and visibility during winter storm events appear to exist. For example, as weather and roadway conditions worsen, traffic volume decreases and vehicle gaps (i.e., the average vehicle density) increase. Not surprisingly, average vehicle speeds during winter storm events also generally decrease as weather and roadway conditions worsen. For this reason, Table 4 generally shows a decrease in average vehicle speeds during winter storm events as the volumes decrease. In addition, the average vehicle speeds during winter storm events also appear to decrease with visibility, roadway conditions, or some combination of the two.

The vehicle speeds measured during the winter storm events were lower than typical non–snow speeds at the data collection site. Overall, the average 15-min vehicle speeds during the seven winter storm events (Table 4)

TABLE 4 Variable Mean of Data for Winter Storm Events

Winter Storm Event Date	Sample Size[1]	Mean Vol. (vph)[2]	Mean Factored Vol. (vph)[2]	Mean Gap (sec.)[3]	Std. Dev. of Gap (sec.)	Range of Gap (sec.)	Mean Percent Snow Covered Rdwy.[4]	Std. Dev. of Percent Snow Covered Rdwy.	Range of Percent Snow Covered Rdwy.	Visibility over ¼-mile?[5]	Mean Speed (mph)	Std. Dev. of Speed (mph)	Range of Speed (mph)
Wed., Dec. 30, 1998	22	747	810	4.6	1.9	2 to 9	40%	0.0%	40% to 40%	16	63.6	4.8	53.0 to 69.5
Sun., Jan. 17, 1999	8	727	1,296	4.8	0.46	4 to 5	0.0%	0.0%	0.0% to 0.0%	7	69.7	0.60	68.9 to 70.5
Fri., Jan. 22, 1999	7	990	1,100	3.9	1.2	3 to 6	0.0%	0.0%	0.0% to 0.0%	4	63.8	6.33	54.7 to 70.7
Thurs., Feb. 11, 1999	19	541	590	6.8	1.7	6 to 13	21%	25%	0.0% to 50%	12	55.4	8.23	43.6 to 66.9
Thurs., Feb. 18, 1999	15	419	473	8.8	1.2	7 to 11	7%	8%	0.0% to 15%	15	61.5	1.34	59.4 to 63.5
Mon., Feb. 22, 1999	16	798	900	4.9	2.1	3 to 12	11%	29%	0.0% to 85%	16	63.7	4.38	52.6 to 67.0
Mon., Mar. 8, 1999	22	161	174	28.5	15.8	11 to 68	53%	27%	15% to 90%	12	51.3	4.88	45.3 to 62.6
Overall Winter Storm Event	109	569	662	10.4	11.7	2 to 68	25%	27%	0.0% to 90%	82	59.9	7.57	43.6 to 70.7
Normal Dry Weekday (Wed. May 19, 1999)	46	1,037	1,037	3.7	0.91	2 to 5	--	--	--	--	71.5	1.86	68.3 to 75.1

NOTES: vph = vehicles per hour, sec. = seconds; mph = miles per hour; 1 mi = 1.61 km.

[1] Sample size is the number of 15-minute time periods in winter storm event.

[2] Mean volumes are for two lanes, and not factored. Factored volumes are for proper comparison to volumes on a non-storm event Wednesday in May.

[3] Gap equals time period between vehicles traveling in both lanes.

[4] Mean percent snow covered roadway is an estimation of the roadway cross section (including shoulders) covered by snow (in percent) during a particular 15-minute time period. Forty percent and below typically represents snow covering the shoulders only.

[5] Visibility number represents those periods with visibility over ¼ mile.

ranged from 70.2 to 113.8 km/h (43.6 to 70.7 mph), and the mean vehicle speed for each winter storm event ranged from 82.6 to 112.2 km/h (51.3 to 69.7 mph). In addition, the standard deviation of the average vehicle speed during winter storm events ranged from 0.97 to 13.25 km/h (0.60 to 8.23 mph). Overall, the average vehicle speed during winter storm events was approximately 96.4 km/h (59.9 mph) and had a standard deviation of 12.18 km/h (7.57 mph) ($n = 109$). During a normal weekday, on the other hand, the average vehicle speed was approximately 115.1 km/h (71.5 mph) with a standard deviation of only 2.99 km/h (1.86 mph) ($n = 45$). This difference is about 16 percent among the normal and average vehicle speeds during winter storm events, and this reduction is significantly different from 0 at a 95-percent level of confidence. The standard deviations of the normal and average vehicle speeds during winter storm events also were substantially different.

Past research has shown that peak-period travel decisions are based on a different set of criteria than vehicle trips taken during off-peak travel periods. During phase two of this research, 90 of the 109 15-min time periods for data collection were during off-peak travel periods (i.e., not between 4 and 6 p.m.). Therefore, the statistical modeling in phase two was limited to the data collected during the off-peak time periods. The amount, variability, intercorrelation of the data collected (e.g., the range of characteristics exhibited by the seven winter storm events observed), and the number of factors that can affect average vehicle speeds during winter storm events generally limit the explanatory power of the off-peak model developed.

Regression analysis (assuming a normal distribution) was used to evaluate and quantify the apparent relationships between off-peak average vehicle speed during winter storm events and the other data collected. A statistically significant relationship was found between the off-peak average vehicle speeds during winter storm events and the square of traffic volume (an apparent surrogate for weather variables not collected in phase two), a visibility index [more than or less than 0.40 km (0.25 mi)], and a roadway condition index (snow on the roadway lanes or only the shoulders). The results of the regression analysis are shown in Table 5 and Figure 2. However, the analysis included only those 15-min time periods with at least 30 vehicles (i.e., 30 speed measurements available). This requirement reduced the number of data points by seven (i.e., $n = 83$), and the seven time periods removed from consideration may have represented the most severe weather conditions. The requirement also increased the reliability of the model results by limiting the minimum number of individual vehicle speeds on which each average data point (Figure 2) was based. Although the results of the statistical analysis are useful overall, they still should be used with caution.

Several conclusions can be reached from the model developed (Table 5, Figure 2). The relationship between the off-peak average vehicle speed during winter storm events and the square of traffic volume appears to be a surrogate for weather factors that could not be collected during this phase of the research. In fact, phase one indicated that traffic volume reductions during winter storm events were related to total snowfall and the square of maximum gust wind speed. These two weather variables were not collected during phase two, but they would appear to have at least an indirect effect on the off-peak average vehicle speed during winter storm events (through the traffic volume variable).

The model also indicates that visibility below 0.40 km (0.25 mi) reduces the predicted average vehicle speed during winter storm events by approximately 6.3 km/h (3.9 mph). The encroachment of snow on the roadway lanes (i.e., the roadway condition index), on the other hand, reduces the predicted average vehicle speed during winter storm events by about 11.6 km/h (7.2 mph). Therefore, a combination of poor visibility and roadway conditions can decrease average vehicle speeds during winter storm events by about 18 km/h (11 mph). However, the relationships quantified among average vehicle speed, visibility, and roadway cover during winter storm events are based on a small amount of data ($n = 19$ and $n = 10$). Overall, the model does have some explanatory

TABLE 5 Regression Analysis Results: Average Vehicle Speed During Winter Storm Events, Off-Peak and No Low-Volume Time Periods (Dependent Variable: Average Vehicle Speed, in mph)

Explanatory Variable	Coefficient	T-Statistic	P-Value	Mean of Variable	Std. Dev. of Variable	Range of Variable
Traffic Volume*Traffic Volume (vph)	0.00002	7.91	0.000	327,980	214,125	15,376 to 788,544
Visibility Index[1]	−3.88	−3.08	0.003	–	–	–
Roadway Cover Index[2]	−7.23	−4.28	0.000	–	–	–
Constant	55.7	52.90	0.000	–	–	–

NOTE: mph = miles per hour; vph = vehicles per hour; 1 mi = 1.61 km.

[1] The visibility index is equal to one when visibility is less than ¼ mile and zero when greater.

[2] The roadway cover index is equal to one when snow has begun to impact the roadway lanes and zero if snow is only on the shoulders or nonexistent on the roadway surface.

Model Summary Statistics: Number of Observations = 83; F-Value = 42.55; Mean Square Error = 21.85; P-Value = 0.000; Coefficient of Multiple Determination = R-Squared = 0.618; and R-Square (Adjusted) = 0.603.

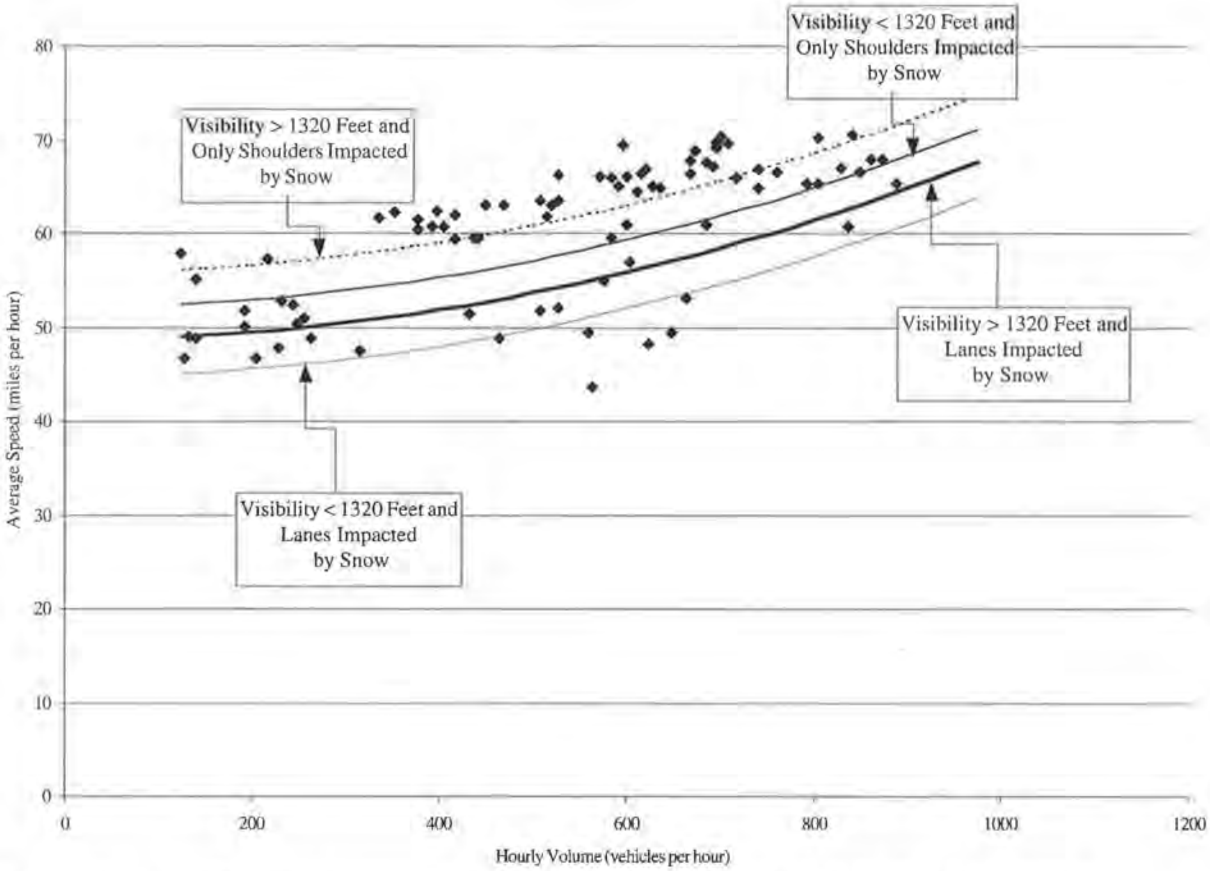

FIGURE 2 Off-peak average speed model for winter storm events (1 mph = 1.61 km/h; 1 ft = 0.3048 m).

power with an adjusted coefficient of determination (R^2) of approximately 60 percent.

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. In addition, the 54 winter storm events used in the crash analysis had an overall hourly crash frequency increase of about 942 percent and a crash rate increase of approximately 1,300 percent.

The traffic volume regression analysis indicated a significant relationship among percent volume reduction, total snowfall, and the square of maximum gust wind speed during winter storm events. The crash regression analysis found a significant relationship between crash frequency, exposure (million vehicle miles), event duration, and snowfall intensity during winter storm events.

Two factors could be responsible for the difference between the crash rates for winter storm events and non–storm events. First, the definition of *winter storm event* used in this study is "relatively severe weather conditions under which the likelihood of crashes could be very high." Second, under severe weather conditions and the extended duration of a winter storm event, traffic volumes tend to reduce appreciably. With substantially reduced traffic volumes, the occurrence of only a few crashes can result in substantial crash rates.

The seven 1998–1999 winter storm events during which data were collected had a wide range of characteristics. Conditions ranged from extremely poor conditions [e.g., snow falling, but visibility less than 0.40 km (0.25 mi) and 90 percent of the roadway cross section covered by snow] to near-normal conditions [e.g., snow falling, but no snow on the roadway and visibility more than 0.40 km (0.25 mi)]. In fact, the mean vehicle speed for the seven individual winter storm events ranged from 82.6 to 112.2 km/h (51.3 to 69.7 mph). Overall, the average vehicle speed during winter storm events was 96.4 km/h (59.9 mph), but the normal (or non–snow event) average vehicle speed was 115.1 km/h (71.5 mph). This difference represents a 16 percent reduction in average vehicle speed between normal and winter storm event conditions. The standard deviation for the average vehicle speeds during the winter storm events also was 12.18 km/h

(7.57 mph), but for the normal (or non–snow event) conditions, it was 2.99 km/h (1.86 mph). Therefore, average vehicle speeds are not only reduced during winter storm events but also more variable than during non–snow events.

A multiple regression analysis (assuming a normal distribution of the data) of the data collected during the 1998–1999 winter season was also completed. The focus of the analysis was the off-peak data for winter storm events. Relationships among average vehicle speed, traffic volume, vehicle headway and gap, visibility, and roadway snow cover during winter storm events were evaluated. A relationship (within 95 percent level of confidence) was found among average vehicle speed, the square of traffic volume, visibility [more than or less than 0.40 km (0.25 mi)], and roadway snow cover (snow on the roadway lanes or only the shoulders) during winter storm events.

Overall, average vehicle speed during winter storm events increased with the square of traffic volume and decreased when visibility dropped below 0.40 km (0.25 mi) and when snow began to cover the roadway lanes. It is believed that the traffic volume variable in this model is a surrogate for other weather characteristics that affect vehicle speed but could not be collected during the 1998–1999 winter season (e.g., total snowfall and wind speeds). The model indicates that visibility less than 0.40 km (0.25 mi) decreases average vehicle speed during winter storm events by about 6 km/h (4 mph), and that snow on the roadway lanes decreases it by about 11 km/h (7 mph). Both of these reductions in average vehicle speed were found to be statistically significant at a 95 percent level of confidence. However, because of the small data sets used to make these conclusions ($n = 19$ and $n = 10$), caution is advised with their application.

A combination of the results found in this research and comparable winter weather vehicle speeds could eventually be used to determine a customer-impact-based winter weather level of service. Relationships among volume, speed, and weather and roadway conditions would need to be defined and/or established. The speeds for specific roadway or weather conditions might be acquired from past research, ATRs, and possibly the application of video-based data collection equipment. However, speed and volume data would need to be collected and archived, and weather and roadway conditions defined and correlated with these traffic flow characteristics.

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