Impact of Inclement Weather on Hourly Traffic Volumes in Buffalo, New York

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ABSTRACT

Inclement weather conditions (such as rain, snow, fog and ice) can create hazardous driving circumstances, which affect the performance of transportation networks. This study analyzes how inclement weather affects hourly traffic volumes on freeways in Buffalo, New York by examining the impact of weather factors such as visibility, temperature, weather type, precipitation and wind speed. To do so, weather and traffic data were collected and modified to form a base case and an inclement weather case. By comparing the base case and inclement weather case several discoveries were made, including when the greatest volume reduction will occur and which weather factors affect the traffic volume. The modified volume and traffic data were also used to find a regression model that can predict traffic volume based on weather factors. The study shows that volumes for times during which inclement weather occurred were significantly lower than dry weather volumes, and that the difference was greatest during peak hours (7:00 AM to 9:00 AM, and 3:00 PM to 5:00 PM), with the volume reductions ranging from 13.3 to 33.9 percent. The study also demonstrated that among the different weather indicators considered, weather type and cumulative precipitation appear to be the most significant predictors of percent volume reductions.
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INTRODUCTION
Inclement weather (such as rain, snow, fog, and ice) can have a significant impact on traffic networks, in terms of both safety and operations. According to the Federal Highway Administration (FHWA), 24% of all vehicle crashes (over 1.5 million) are a result of adverse weather conditions. The weather-related incidents result in an average of 7,130 deaths and 629,000 injuries annually (I). In order to increase traveler safety, as well as improve the operational capabilities of traffic networks under adverse weather conditions, it is crucial to obtain a better understanding of how inclement weather affects the transportation system. The first objective of this study was to examine how inclement weather conditions affect traffic volumes. The second objective was to develop a mathematical model which could be used to predict traffic volumes in the Buffalo, New York region based on inclement weather forecasts.

The Buffalo region was chosen as the area of study for several reasons. One reason was that the Buffalo traffic dataset has not yet been analyzed for the impact of weather on traffic volume in previous research. The second, more significant reason was that Buffalo is known for its microclimates, which are small areas which experience drastic changes in weather and temperature over a relatively short period of time. The presence of these microclimates provides a unique opportunity to study a wide variety of weather patterns in a small geographic area. However, these microclimates also restrict the links which can be studied to those close to the weather data recording station (in this case, the Buffalo-Niagara International Airport). The seven links studied (Figure 1) were chosen both for their proximity to the airport and their sufficiently high traffic volumes.

The remainder of this report is organized into five sections. Literature Review will discuss the results of previous research in this field. Data Calibration and Modification will describe how the raw weather and traffic data were organized and adjusted to meet the needs of this study. Data Analysis will examine the data in order to determine the relationship between inclement weather and volume, as well as show the development of the regression model. Results will show the regression model developed in this study as well as how that model can be used to predict traffic volumes. Finally, Conclusions and Future Research will summarize the findings of this study and describe how these conclusions can be used for further future studies.
LITERATURE REVIEW
During a winter storm, it is predicted that 5.86 crashes per million-vehicle-kilometers (mvkm) will occur. Compared to the 0.41 crashes mvkm during a non-inclement weather day, this is a 1300% increase (2). When an accident occurs, it affects the road network by creating a blockage. This requires other vehicles to take alternate routes, creating more traffic congestion and increasing delay. For safety and transportation reasons, the understanding of the effects of weather on transportation is important. Based on reviews of literature pertaining to weather impacts on traffic, it can be seen that weather plays a significant role in the reduction of vehicle speed, capacity and volume as well as the increase of travel time. Weather factors considered in most of the literature review are precipitation (light rain and heavy snow storm), wind, temperature and visibility. Some of the highlights from the literature on that topic are summarized below.
Impact on Speed:
Inclement weather conditions can lead to reductions in vehicle speeds which, depending on the severity of the weather, can be very substantial. In studies of weather impact on traffic flow in three cities (Minneapolis-St. Paul, Baltimore and Seattle), the research findings show that for light rain (<0.01 cm/hr), speed is reduced by between 2 and 3.6 percent. As the intensity of the rain increases, the reduction of the speed ranges from 6 to 9 percent. When compared to the impact of rain on vehicle speed, the impact of snow is much more significant. For snowy weather, speed reduces by between 5 and 19 percent, depending on location (3).

Visibility also plays a part in the reduction of vehicle speed during inclement weather. In the same study of weather impact on freeway free-flow speed in Minneapolis-St. Paul, Baltimore and Seattle mentioned above, it was found that visibility had a much smaller effect on speed than precipitation. In the studies, the visibility is measured from 0.4 to 3.2 km and the speed reduction is found for each measurement of visibility. For the Twin Cities, the speed reduction ranges from 1.62 to 3.67 percent, while for Seattle, the speed reduction ranges from 0.14 to 0.29 percent. For Baltimore, the speed reduction ranges from 0.89 to 1.61 percent (4).

Impact on Travel Time:
Travel time is closely related to speed; the greater a vehicle’s speed, the shorter its travel time will be. Therefore, during inclement weather, if speed is reduced, then the travel time would increase. This is shown in a study performed in Washington D.C., where travel time data were taken from SmarTraveler public archive of thirty-three road segments. The analysis considered weather attributes such as wind, visibility and precipitation and also pavement condition (if road is dry, wet, snowed or iced). The study concluded that during off peak hours, the travel time increased by 13 percent when all of the previously mentioned weather factors were considered. When the impact of precipitation on travel time was isolated it was found that during the off-peak period the travel time increased by 3.5 percent, while during the peak period, the travel time increased by 11 percent (5).

Impact on Capacity:
Capacity reduction also occurs based on the changing weather attributes. For one study in Minnesota, the analysis considered wind speed, temperature, visibility and precipitation as weather factors that affect capacity. The study concluded that wind speed did not relate to the capacity at all, while the cold temperature (< -20°C) and low visibilities resulted in a 10 percent and 10 to 12 percent reduction in capacity, respectively, on the freeway. Precipitation has a greater effect on the capacity reduction. For light rain, the capacity reduces very little (5 to 10 percent) and for heavy snow, the capacity reduces greatly (19 to 28 percent) (6).
Impact on Volume:
The effect of inclement weather on volume is the main focus of this study. In previous studies, researchers have found that during inclement weather, the volume decreases. For example, in the study conducted by Knapp et al. in Iowa, hourly traffic counts and weather data were used to draw conclusions about the relationship between inclement weather and volume. The results were found by comparing volume data during winter storm and non-inclement weather time periods. It was found that for an average storm event, the volume reduction ranges from 16 to 47 percent. The overall volume reduction was found to be 29 percent. Another conclusion reached by this study was that the volume reduction is greatly impacted by the increase of snowfall intensity and wind speed (2).

Hanbali and Kuemmel looked at traffic volume in eleven locations under different types of weather conditions. The study concluded that the volume reduction ranged from 7 to 56 percent with the increase of snow intensity. They also compared the overall volume at different times of the day and found that volume reductions were smaller during peak time periods compared to off-peak time periods (7).

In another study, researchers looked into a probabilistic approach to understanding the connection between traffic volume and inclement weather in seven cities in Minnesota and Virginia. The study looked at only precipitation as a weather factor, which included rain and snow intensity. Only volume data during the weekday was considered in the study, to form a baseline data set to compare with volume during inclement weather. The volume data during inclement weather was grouped by time of day and compared with the baseline volume data. One of the results from this comparison showed that there was an increase of volume during morning peak hours and other hours showed a low volume reduction (8).

After examining the previous studies about volume reduction, several hypotheses were made about the connection between inclement weather conditions and volume reduction in the Buffalo traffic network. It was predicted that temperature and wind speed would not have a very significant impact on traffic volume, while visibility and precipitation would have the greatest connection to volume reduction. It was also predicted that for a 24 hour day, the volume reductions will be largest during off peak hours and smallest during peak hours. These hypotheses are based on the results of previous studies. As will be seen later, while many of the findings of the study agreed with our prior expectations, a few did not.

DATA COLLECTION AND PRE-PROCESSING
Traffic data for this study was provided by Niagara International Transportation Technology Coalition (NITTEC), an organization made up of fourteen transportation-related agencies in Western New York and Southern Ontario. The data consists of hourly traffic counts for
individual freeway links from January 2010 to June 2011. The weather data were the Quality Controlled Local Climatological Data (QCLCD) for the same time range. It was obtained from the National Oceanic and Atmospheric Administration (NOAA). The QCLCD is a combination of data from the Automated Surface Observing System (ASOS) and the Automated Weather Observing System (AWOS) and consists of hourly and daily weather observations from hundreds of stations nationwide. Among other weather data, the QCLCD provides visibility (in miles), Dry Bulb Temperature (in degrees Fahrenheit), wind speed (in miles per hour), hourly precipitation (in inches), and weather type (a classification system using two letter abbreviations for different forms of weather) (9).

Before this data could be used, several steps of pre-processing and modification were required. These steps are summarized below.

First, the weather data were not recorded at regular hourly intervals (i.e. 1:54 instead of 2:00), while the traffic count data were. Therefore, the weather data times were rounded to the nearest hour in order to link them to the corresponding volume data. Once the weather and volume data had been combined and aligned, the next step was to average the volumes for all seven links in order to obtain a single average hourly volume for each time. Then, Friday, Saturdays, Sundays, and Mondays, as well as holidays, were removed from the dataset, since traffic patterns tend to be different on these days.

In order to analyze the effect inclement weather has on volume, the data were used to create two smaller datasets: non-inclement weather (the base case) and inclement weather (the inclement case). The distinction between inclement and non-inclement weather was made by defining the two in terms of several weather factors, as shown in Table 1.

<table>
<thead>
<tr>
<th>Weather Factor</th>
<th>Inclement Case</th>
<th>Base Case</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air Temperature (°F)</td>
<td>N/A</td>
<td>≥ 32</td>
</tr>
<tr>
<td>Visibility (mi)</td>
<td>&lt; 3</td>
<td>≥ 3</td>
</tr>
<tr>
<td>Wind Speed (mph)</td>
<td>&gt; 16</td>
<td>≤ 16</td>
</tr>
<tr>
<td>Precipitation</td>
<td>&gt; 0</td>
<td>0</td>
</tr>
</tbody>
</table>

A threshold of 32 °F for air temperature was considered because this is the freezing point of water. When the temperature is below this value, there is the potential for icy road conditions. However, inclement weather can still occur above 32 °F, which is the reason this factor was not used to determine what times were included in the inclement case. In other words, inclement weather was considered to occur when the visibility was less than 3 miles, AND the wind speed was greater than 16 mph, AND precipitation was greater than zero. On the other hand, an hour needed to have a temperature greater than 32 °F, AND visibility greater than 3 miles, AND a wind speed of less than 16 mph, AND no precipitation for it to be considered as normal weather.
In order to determine a threshold for visibility, a plot of volume versus visibility was made and examined. The result showed that volume remains generally constant until the visibility dropped below 3 miles, which was why this value was chosen as the threshold. Similarly, the threshold for wind speed was chosen by plotting volume versus wind speed and determining visually at what point the wind speed began to impact volume. This value was determined to be approximately 16 miles per hour.

Further modifications to the data were needed in order to make it usable in the regression model. First, although temperature is predicted to affect volume, the only significant impact results from whether the temperature is above or below freezing. Simply put, an increase in temperature would not necessarily result in an increase of volume (i.e. the difference between 25 °F and 35°F would be far more significant than the difference between 35 °F and 60 °F, even though the temperature difference is far greater in the later). Therefore, a temperature index (similar to the one created in (10)) was created for use in the regression model, as shown below.

\[
\text{If Temperature} > 32 \, ^\circ\text{F, Temperature_Index} = 0; \\
\text{If Temperature} \leq 32 \, ^\circ\text{F, Temperature_Index} = -1.
\]

In addition, a weather type index, which converts the abbreviations given to weather types by the QCLCD into numerical data, was needed. The system created by Zhao, et al. (10), shown in Table 2, was used in this study. This system includes 14 different weather types and three modifiers which describe the intensity. For example, moderate rain has an index of -3. A light rain would have an index of -1 \([-3 + (+2 \text{ for the modifier “LIGHT”)})\] and a heavy rain would have an index of -5 \([-3 + (-2 \text{ for the modifier “HEAVY”)})\].
Table 2: Conversion of Weather Type Abbreviations

<table>
<thead>
<tr>
<th>Weather Type</th>
<th>Description</th>
<th>WeatherType_Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>RA</td>
<td>RAIN</td>
<td>-3</td>
</tr>
<tr>
<td>DZ</td>
<td>DRIZZLE</td>
<td>-1</td>
</tr>
<tr>
<td>SN</td>
<td>SNOW</td>
<td>-3</td>
</tr>
<tr>
<td>SG</td>
<td>SNOW GRAINS</td>
<td>-1</td>
</tr>
<tr>
<td>GS</td>
<td>SMALL HAIL &amp;/OR SNOW PELLETS</td>
<td>-3</td>
</tr>
<tr>
<td>PL</td>
<td>ICE PELLETS</td>
<td>-5</td>
</tr>
<tr>
<td>FG+</td>
<td>HEAVY FOG (FG &amp; LE.25 MILES VISIBILITY)</td>
<td>-5</td>
</tr>
<tr>
<td>FG</td>
<td>FOG</td>
<td>-3</td>
</tr>
<tr>
<td>BR</td>
<td>MIST</td>
<td>-3</td>
</tr>
<tr>
<td>FZ</td>
<td>FREEZING</td>
<td>-2</td>
</tr>
<tr>
<td>HZ</td>
<td>HAZE</td>
<td>-2</td>
</tr>
<tr>
<td>BL (SN)</td>
<td>BLOWING (SNOW)</td>
<td>-3</td>
</tr>
<tr>
<td>BCFG</td>
<td>PATCHES FOG</td>
<td>-3</td>
</tr>
<tr>
<td>TS</td>
<td>THUNDERSTORM</td>
<td>-2</td>
</tr>
<tr>
<td><strong>Modifiers</strong></td>
<td><strong>Description</strong></td>
<td></td>
</tr>
<tr>
<td>-</td>
<td>LIGHT</td>
<td>+2</td>
</tr>
<tr>
<td>+</td>
<td>HEAVY</td>
<td>-2</td>
</tr>
<tr>
<td>&quot;NO SIGN&quot;</td>
<td>MODERATE</td>
<td>0</td>
</tr>
</tbody>
</table>

Finally, it was necessary to consider the cumulative effect of precipitation (i.e. wet roads from rain, snow accumulation, etc.). Therefore, a new parameter called Cumulative_Precipitation was created, which was the sum of all precipitation that had occurred during a given day up to a given time.

**DATA ANALYSIS**

Before a regression model can be developed, two statements must be proven to be true. First, it must be shown that the base case volume data is relatively consistent for each hour of the day. This would show that no factors apart from weather or time of day were having a significant impact on traffic volume. In addition, it must be shown that the difference in traffic volume between the base case and the inclement case is great enough to show that inclement weather has a significant impact on volume.

In order to determine if the base case data were sufficiently consistent, the data were sorted by time of day and each hour was examined separately. This was done because volume changes greatly based on time of day. Then, a statistical analysis was performed on the average volumes from each hour of day for the base case data. The central part of this statistical analysis involved
determining the standard deviation for each hour’s volumes and determining if it was sufficiently small relative to the hour’s average volume. For almost every hour of the day the standard deviation was found to be less than 10% of the mean, and no hour had a standard deviation greater than 15% of the mean. This was determined to be sufficiently small and the base data consistent enough to proceed with the study.

To show whether a significant difference in traffic volumes existed between the base case and the inclement case, the average of the volumes for each hour was plotted for both cases, as seen in Figure 2.

Figure 2: Comparing Volume during Non-Inclement Weather and Inclement Weather

As can be seen, with the exception of the low volume hours, there appears to be a significant difference between the inclement weather and the non-inclement weather hourly volumes. However, contrary to what was expected from previous studies, our results showed that the difference in traffic volumes between the base case and inclement case was actually greatest during peak hours. One possible explanation for this is that the observed volume could be constrained by the reduced capacity caused by inclement weather. Another possible explanation is that, while it is true that the majority of commuters must travel to work regardless of the weather, inclement weather could cause reductions in speed, and therefore a similar number of people could be traveling, but the inclement weather causes their trips to be spread out over a greater interval of time.

After eliminating outlying data the percent volume reduction caused by inclement weather was found to range from 13.3 to 33.9 percent. With the results confirming that there is a significant
difference in traffic volume under inclement weather conditions when compared to non-inclement conditions, the study proceeded to develop a regression model which will be able to predict traffic volumes based on weather forecasts.

RESULTS

Using Minitab, a statistics package software, the information from the dataset was used to create a regression model for average hourly volume in terms of weather type index (Weather_Type_Index), wind speed (Wind_Speed), 24-hour cumulative precipitation (Cumul_Precipitation), visibility (Visibility), base case average volume (Baseline), and temperature index (Temperature_Index). The resulting model to predict volume under inclement weather condition was:

\[
Volume = 65.07 \text{Weather}_\text{Type}_\text{Index} + 24.52 \text{Wind}_\text{Speed} + 28.06 \text{Visibility} - 419.73 \text{Cumul}_\text{Precipitation} + 61.06 \text{Temperature}_\text{Index} + 0.76 \text{Baseline}
\]

(Equation 1)

The base case average volume is a function of time of day. The values of Baseline for each corresponding time which are required for the model are shown in Table 3.

<table>
<thead>
<tr>
<th>Time</th>
<th>Baseline</th>
<th>Time</th>
<th>Baseline</th>
</tr>
</thead>
<tbody>
<tr>
<td>12:00 AM</td>
<td>588.6264</td>
<td>12:00 PM</td>
<td>3635.603</td>
</tr>
<tr>
<td>1:00 AM</td>
<td>331.9783</td>
<td>1:00 PM</td>
<td>3727.665</td>
</tr>
<tr>
<td>2:00 AM</td>
<td>239.2268</td>
<td>2:00 PM</td>
<td>4232.384</td>
</tr>
<tr>
<td>3:00 AM</td>
<td>278.5391</td>
<td>3:00 PM</td>
<td>5042.075</td>
</tr>
<tr>
<td>4:00 AM</td>
<td>454.4856</td>
<td>4:00 PM</td>
<td>5352.192</td>
</tr>
<tr>
<td>5:00 AM</td>
<td>1155.67</td>
<td>5:00 PM</td>
<td>5135.184</td>
</tr>
<tr>
<td>6:00 AM</td>
<td>3019.478</td>
<td>6:00 PM</td>
<td>3921.348</td>
</tr>
<tr>
<td>7:00 AM</td>
<td>4978.068</td>
<td>7:00 PM</td>
<td>2864.226</td>
</tr>
<tr>
<td>8:00 AM</td>
<td>4569.668</td>
<td>8:00 PM</td>
<td>2468.197</td>
</tr>
<tr>
<td>9:00 AM</td>
<td>3587.800</td>
<td>9:00 PM</td>
<td>2226.611</td>
</tr>
<tr>
<td>10:00 AM</td>
<td>3333.133</td>
<td>10:00 PM</td>
<td>1558.301</td>
</tr>
<tr>
<td>11:00 AM</td>
<td>3512.792</td>
<td>11:00 PM</td>
<td>1078.142</td>
</tr>
</tbody>
</table>

The R-squared value for this regression model was found to be 97.4%, indicating that the model is a very accurate representation of the real world data. A plot of regression model data versus recorded volume data for inclement weather is shown in Figure 3.
Minitab was also used to examine the significance of the role each variable plays in the regression model. In addition to using this information to determine if there are any superfluous factors in the model, this information can also be used to verify the significance of the individual weather factors. Minitab assigns each variable a p-value, with values of p less than 0.05 indicating a highly significant factor.

For this regression model, the p-value for every factor was found to be significantly less than 0.05, except for visibility and temperature, which were found to have a p-value of 0.565 and 0.648 respectively. This result shows that visibility and temperature are not highly significant factors of the regression model.

Alternatively, a second regression model was made for volume in which visibility and temperature were not included as independent variable. The only weather factors considered in this regression model are thus the weather type index, cumulative precipitation and wind speed, as shown in Equation 2:

\[
Volume = 68.09[W_{\text{Weather\_Type\_Index}}] + 24.45[W_{\text{Wind\_Speed}}]
- 410.52[C_{\text{Cumul\_Precipitation}}] + 0.76[B_{\text{Baseline}}]
\]  
(Equation 2)
This regression model, similar to the first regression model, has an R-squared value of 97.4%. As stated before, the high R-square value is an indication that the model is an accurate representation of the real world data. A plot of regression model data versus recorded volume data for inclement weather is shown in Figure 4.

![Regression Model vs Recorded Data for Second Regression Model](image)

**Figure 4: Comparing Volume from Second Regression Model and Recorded Volume Data**

By comparing Figures 3 and 4, it can be seen that the plots are visibly similar. The R-squared values of the two regression models are similar as well. The similarity between the two regression models further shows that temperature and visibility are not significant weather factors in terms of their impact on volume reduction. One possible reason for this could be the correlation among the individual weather factors in the regression model. To further examine the issue, Minitab was used to examine the correlation among the variables. Table 4 lists the correlation coefficient for the different pairs of variables. As can be seen, the correlation between the weather type index and visibility is the highest among all pairs of variables examined. This could have contributed to the insignificance of visibility in the model.
Table 4: Correlation between Weather Factors

<table>
<thead>
<tr>
<th></th>
<th>Weather Type Index</th>
<th>Temperature Index</th>
<th>Wind Speed</th>
<th>Cumulative Precipitation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature Index</td>
<td>0.045</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wind Speed</td>
<td>0.036</td>
<td>0.023</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cumulative Precipitation</td>
<td>-0.173</td>
<td>-0.117</td>
<td>-0.027</td>
<td></td>
</tr>
<tr>
<td>Visibility</td>
<td>0.263</td>
<td>0.193</td>
<td>0.056</td>
<td>0.092</td>
</tr>
</tbody>
</table>

However, the conclusion for visibility does not stand true for temperature. Temperature does not appear to have any strong correlation with the other weather factors, with the exception of perhaps visibility. It can thus be concluded that temperature does not appear to significantly affect volume during inclement weather based on this set of data.

In a further attempt to analyze the data, another regression model was made. In this case, instead of using volume as the dependent variable, a model was made to solve for percent reduction in volume, as shown below:

\[
Percent\,Reduction = 0.0254[Weather\_Type\_Index] - 0.1030[Temp\_Index] - 0.0012[Wind\_Speed] + 0.0467[Cumul\_Precipitation] + 0.0090[Visibility]
\]

(Equation 3)

This model had a lower R-squared than the previous model (75.6%). This model also reported additional information concerning the impact of individual weather factors compared to what this study had previously found. Similar to the previous observation from the volume regression model, visibility was ranked as one of the least significant factor (p-value = 0.509). Furthermore, wind speed was also observed to have low significance to the regression model (p-value = 0.565), while all other factors were determined to be highly significant.

As explained previously, weather type considers visibility in the regression model because of the moderate correlations between the two factors. On the other hand, wind speed does not have a correlation with any of the other weather factors, as shown in Table 4. Given that wind speed is an independent weather factor with a low significance factor, it can be concluded that wind speed has a smaller impact on traffic volume reduction in relation to the other weather factors.

**CONCLUSIONS AND FUTURE RESEARCH**

The weather and traffic volume data obtained from NOAA and NITTEC, respectively, was used in this study in an effort to model and predict the impact of inclement weather on the Buffalo traffic network. After analyzing the data, the following conclusions were reached:
1. The volumes for times during which inclement weather did not occur (the base case) remained relatively consistent on an hourly basis.

2. The volumes for times during which inclement weather did occur were significantly lower than the volumes for times that it did not. This difference was greatest during peak hours (7:00 AM to 9:00 AM, and 3:00 PM to 5:00 PM) and the percent volume reduction ranged from 13.3 to 33.9 percent.

3. The regression model developed based on the weather and volume data, which had an R-squared value of 97.4%, can be used to predict traffic volume based on predicted inclement weather conditions and time of day at a high level of accuracy.

4. Wind speed and temperature have a lower impact on traffic reduction when compared to the other weather factors. Visibility is highly associated with weather type, which means that it is still a significant factor even though it had a high p-value.

One limitation which could be amended in future studies was the relatively small number of data points corresponding to inclement weather conditions. From January 2010 to June 2011, there were relatively few inclement weather data points. Approximately 18,000 data points were used in this study but less than 300 of them fell under the category of inclement weather. The regression model could better predict the relationship between volume and inclement weather if there were more data about volume during inclement weather to analyze.

A second limitation of the study stemmed from the fact that there were no Road Weather Information Systems (RWIS) in place in the region, and therefore the study had to depend upon data from atmospheric weather stations. As a result, the actual pavement condition, along with the impact of road surface treatments and plowing operations by maintenance crews, could not be quantified. Pavement conditions, while related to weather, are not directly analogous. For example, air temperature could be above freezing but there could still be ice on the roads. Actions taken against inclement weather, such as salting roads to prevent ice from forming for example, could have a positive impact on improving traffic flow conditions. Future studies should consider pavement conditions and response to inclement weather by local or state agencies.

Possible applications of the models developed in this study could also be the topic for future research. In recent years, widespread use of smartphones and an increase in a person’s ability to connect to the internet regardless of location have led to a much higher level of information accessibility. A model such as the one created in this study could thus be used to help enhance traveler information systems. The model could also be helpful in understanding and evaluating the performance of transportation systems under inclement weather and in devising weather-responsive transportation management strategies.
REFERENCES


