IMPACTS OF WEATHER ON RURAL HIGHWAY OPERATIONS

Showcase Evaluation # 2

Final Report

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Prepared for the

Research and Innovative Technology Administration
U.S. Department of Transportation

in cooperation with the

California Department of Transportation
Division of Research and Innovation

and the

Traffic Management Section
Oregon Department of Transportation

June 2006

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ACKNOWLEDGMENTS

The authors are thankful for the support of the Rural California/Oregon Advanced Transportation Systems (COATS) Steering Committee through this project, and are hopeful that the results will be useful as they work to improve the safety and efficiency of the rural transportation system in northern California and southern Oregon. The authors would also like to thank the Oregon and Montana Departments of Transportation who provided valuable weather and traffic data for this research. The authors thank Deepu Philip, Jay Srinivas and Yurii Shvetsov of the Western Transportation Institute (WTI) for their work on the data quality control and data integration, Dan Bisom and Chandra Roth of Montana Department of Transportation, Don Crownover and Robert Sechler of Oregon Department of Transportation for their help with collecting the traffic volume and weather station data from their respective agencies. The authors also thank Emilie Berglund and Jaime Eidswick of WTI for their earlier work on the literature research and data collection efforts for this project.

The authors would like to thank the U.S. Department of Transportation Research and Innovative Technology Administration (RITA) for their funding of this study, and the California and Oregon Departments of Transportation, who are partners in the COATS Showcase project.

GLOSSARY OF ABBREVIATIONS

ARIMA	Autoregressive Integrated Moving Average
ATR	Automatic Traffic Recorder
Caltrans	California Department of Transportation
COATS	California/Oregon Advanced Transportation Systems
FARS	Fatality Analysis Reporting System
ITS	Intelligent Transportation Systems
JPO	Joint Program Office
kmph	Kilometer per hour
MDT	Montana Department of Transportation
MP	Mile Post
mph	Miles per hour
MVMT	Million Vehicle Miles Traveled
NB	North Bound
ODOT	Oregon Department of Transportation
PCU	Passenger Car Units
PM	Preventive Maintenance or Post Mile
RWIS	Road Weather Information Systems
SAS®	Statistical Analysis System
SB	South Bound
TOC	Traffic Operations Center
VMS	Variable Message Sign
XML	eXtensible Markup Language

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1. INTRODUCTION

There have been numerous intelligent transportation systems (ITS) applications deployed all over the nation to help improve the safety and operations of roadways in both urban and rural areas. One major goal of these applications is to help reduce both recurrent and non recurrent congestion. While recurrent congestion is primarily an urban transportation problem, non-recurrent congestion occurs in both urban and rural areas.

Adverse weather conditions affect the safety and operations of all components of the nations' roadway system. It has been estimated that there are nearly 6,500 fatal crashes and over 450,000 injury crashes during adverse weather conditions. After delays caused by incidents, the largest source of non-recurrent congestion on highways is adverse weather conditions (1). While weather cannot be controlled, the effects of weather on the surface transportation system can be mitigated through surveillance, monitoring and prediction, information dissemination, decision support, control and treatment. In order to evaluate the effectiveness of any of these measures, it is important to have an accurate estimate of the baseline condition. This is especially true in rural areas where the resources available for ITS deployments are relatively low.

Stakeholders in California and Oregon, working in partnership with the respective state departments of transportation and in concert with the Western Transportation Institute (WTI) at Montana State University, have been researching and demonstrating the application of ITS in a rural context through the Rural California/Oregon Advanced Transportation Systems (COATS) Showcase project. The COATS Showcase effort includes evaluations of ITS improvements. In that context, it is necessary to document baseline highway capacity and speeds in rural environments under adverse weather conditions that cause non-recurrent congestion, in order to determine to what extent ITS may improve capacity and reduce traveler delay.

This project does not directly address any COATS goals and objectives, but should provide data to justify technology investments that support many goals and objectives, including the following (2):

- **Goal 1:** Improve the safety and security of the Northern California/ Southern Oregon Region rural transportation system users;
- **Objective 1.1:** Provide sustainable traveler information systems that collect and disseminate credible, accurate "real-time" information;
- **Objective 1.4:** Coordinate public fleet responses to unsafe conditions (weather, incidents, detour routes) and provide for improved regional movement;
- **Goal 3:** Increase operational efficiency and productivity of the transportation system focusing on system providers;
- **Objective 3.1:** Collect, process and share data between local, state, and federal agencies to increase efficiency and resources utilization;
- **Objective 3.2:** Provide automated notification of conditions that may impact operations and maintenance of regional roadways to improve resource management and allocation;
- **Benefit 1:** Increase safety; and
- **Benefit 6:** Reduce congestion.

1.1. Project Objectives

The primary objective of this study is to establish the correlation if any, empirically between rural highway operations, specifically volume, capacity or travel speed, and weather events. The following are the overall objectives of this study:

- research the documented studies on the impacts of severe weather events on highway operations;
- examine the correlation between severe weather events and highway operations;
- quantify the impacts of severe weather events on traffic volume and capacity on rural highways; and
- quantify the impacts of severe weather events on traffic speed on rural highways.

As mentioned earlier, there needs to be a base case to evaluate the benefits of ITS applications on improving highway operations during severe weather events. The motivation of this study was to make progress toward estimating this baseline data. As this baseline data is gathered, there are two primary benefits. First, empirical validation of the correlation between rural highway operations (i.e. capacity and speed) and severe weather events will help evaluate the benefits of ITS improvements in rural areas. Second, quantification of the impacts of severe weather events on rural highway operations may help in maintenance decision-making.

The expected benefits of this study will be realized with further comprehensive study of highway operations in rural areas using comprehensive sets of highway operations data.

1.2. Organization of This Document

This report summarizes the findings of this COATS Showcase research project. Chapter 2 reviews a variety of previous studies on the impact of severe weather events on highway operations. Chapter 3 explains the methodology chosen for this study while Chapter 4 explains the data collected for this study and the data process procedures. Chapter 5 provides details on the analysis and presents the results of this study. The report concludes with a summary of the findings along with recommendations for future research.

2. BACKGROUND

In 2001, more than 22 percent of vehicle crashes were weather-related. Over 16 percent of crash fatalities and more than 20 percent of crash injuries in passenger vehicles occurred in adverse weather and/or slick pavement. Most weather-related crashes occur when the pavement is wet and during rainfall (3). The Fatality Analysis Reporting System (FARS) database for the year 2004 indicates that the percentage of weather-related crashes was about 12 percent.

It has been well-documented in the literature that severe weather events increase the crash potential for traveling vehicles. The literature also suggests that severe weather events generally cause changes in the traffic demand (volume) and the traveling speeds. Thus, the roadway capacities are generally reduced due to severe weather events.

This chapter provides a summary of the existing literature on the impacts of weather events on highway traffic volumes, traveling speeds and highway capacity. Documented impacts of severe weather events on highway safety found in the above literature are also presented in this chapter.

2.1. Impacts of Weather Events on Traffic Volume

The Highway Capacity Manual (HCM) states that capacity and operating speed reductions can be seen as a result of inclement weather (4). HCM also states that rain does not reduce travel speeds unless visibility is reduced and refers to a German study that determined that 12 percent and 18 percent reduction in capacities occurred on a 6-lane and 4-lane freeways respectively during daylight times and 13 and 19 percent reduction in capacities for the same during darkness.

Hanbali and Kuemmel studied the traffic volume reductions caused by snow and icy conditions on eleven highways outside of urban areas in Minnesota (Olmstead County), Illinois (Ogle and Lee counties), New York (Wayne, Monroe, Steuben, and Onondaga counties), and Wisconsin (Walworth, Kenosha, and Waukesha counties) (5). They also examined the impact of the interaction between the trip makers' willingness to travel, the importance of the destination, and winter storms on traffic volume.

Eleven ATRs were used for data collection. The annual average daily traffic and 24-hour counts were measured continuously and collected at all sites in Minnesota, Illinois, New York, and Wisconsin from January to March of 1991. Additional data was acquired in Wisconsin (December 1990) and New York (December 1989 to March 1990 and December 1990).

The weather data was acquired from the participating highway agencies and the National Climatic Data Center in Asheville, North Carolina. The type of data collected included temperature range (high and low), storm period (start and end time, day, date), and depth and type of snow (dry, wet, sleet, etc.).

Traffic counts were categorized by day of the week (weekday or weekend), snow precipitation, temperature range, and normal average daily traffic volume (ADT). Each ATR was categorized based on its normal ADT:

- rural and suburban freeways: 11,000 to 20,000, and 21,000 to 30,000; and

- rural and suburban highways: 3,000 to 6,000, and 7,000 to 10,000.

The hourly traffic volumes during the winter storm events were compared to the normal hourly traffic volumes for the same location during a similar hour at the same day, month, and year. Hourly reduction factors were then derived for each snowstorm:

Model: $SRF = SV / NV$

SRF	=	Snowstorm reduction factor: (snow volume) / (normal volume) in relative time (hour);
SV	=	Snow volume**:** hourly traffic volume during snowstorm; and
NV	=	Normal volume: normal traffic volume.

A conclusion of this study was the average reduction in traffic volume due to winter storm event conditions increases with the severity of the weather.

Table 2-1 provides the range of percent average traffic volume reductions for rural and suburban freeways and highways for weekdays and weekends. Volume counts occurring on holidays were not included. No justifications were provided for the breakdown of the precipitation endpoints provided in Table 2-1.

Based on Table 2-1, the average traffic volume during precipitation decreases when the amount of precipitation increases. Also, the average reduction in traffic volume due to precipitation was less during weekday hours than weekend hours. This supports another conclusion Hanbali and Kuemmel made that the average traffic volume will be less affected by snow precipitation when there is greater importance in the destination (work and necessary trips on the weekday).

The authors divided similar snowstorm events into hourly periods: peak-hour periods and off-peak-hour periods. Dividing the sum of the hourly reductions by the sum of the respective hourly normal volumes resulted in an average reduction for each group. It was concluded from these comparisons that weekday and weekend peak-hour periods (necessary trips) experienced a lower average reduction in traffic volume than weekday and weekend off-peak-hour periods (discretionary trips).

Table 2-1: Variables Included in Minnesota Traffic Volume Model

Amount of snow precipitation	Weekday average traffic volume reduction	Weekend average traffic volume reduction
< 25 mm (< 0.98 in)	7 – 17%	19 – 31%
25 – 75 mm (0.98 – 2.95 in)	11 – 25%	30 – 41%
75 – 150 mm (2.95 – 5.91 in)	18 – 43%	39 – 47%
150 – 225 mm (5.91 – 8.86 in)	35 – 49%	41 – 51%
225 – 375 mm (8.86 – 14.76 in)	41 – 53%	44 – 56%

Knapp investigated the impact of winter storm events on the volume, safety, and speed characteristics of interstate traffic flow in Iowa (6). Archived data of roadway and weather conditions and hourly traffic volumes from seven locations where road weather information system (RWIS) stations and automated traffic recorders (ATR) were collocated, and daily snowfall data from the National Weather Service (NWS) and Iowa Department of Agriculture and Land Stewardship (IDALS) for the winters of 1995-1998 were used to develop a model for volume reduction.

Only severe winter storm events (determined from IDALS/NWS data) were considered. Knapp made the following requirements to define a severe winter storm event, which led to more reliable data (less variability):

- air temperature below freezing;
- wet pavement surface;
- pavement temperature below freezing;
- more than 0.2 inches of snowfall per hour;
- minimum of four hours of duration;
- event not occurring near a holiday; and
- event not occurring on a day when hourly volumes were estimated (exact traffic counts unavailable).

Twenty-six percent of the 336 winter storm events, encompassing 618 hours of data qualified to create the database, the following variables were created:

- traffic volume during winter storm event;
- comparable average monthly non-storm volumes for that time period and day of the week; and
- winter storm event percent volume reduction (calculated from volume difference and percent change between winter storm event volume and average non-storm volume).

Stepwise regression analysis was then used to quantify the relationships between the following variables:

- winter storm event percent volume reduction (dependent variable);
- storm event duration;
- snowfall intensity;
- total snowfall;
- minimum and maximum average wind speed; and
- maximum wind gust speed.

The variables excluded from the model (e.g. storm event duration, snowfall intensity, minimum wind speed, maximum wind speed) were either not statistically significantly related to winter storm event percent volume reduction or were correlated with other variables and therefore could not be included.

Based on the analysis of 54 storm events encompassing 491 hours a strong correlation between the reduction in traffic volume during severe weather events and total precipitation along with square of wind speeds was shown and the following model was developed.

Model: $SV = -1.583 + 0.0296WGS^2 + 2.289TS$

SV = Winter storm event percent volume reduction (SV): A variable calculated from the volume difference and percent change between winter storm event volume and average non-storm volume (dependent variable);

WGS = Maximum wind gust speed: variable for the maximum wind gust speed in (km/h) squared; and

TS = Total snowfall: variable for the amount of snow fallen during the winter storm event in inches.

Although snowfall intensity (0.2 inches per hour) was used as criteria for the winter storms, no relationship was found between percent traffic volume reductions and snowfall intensity (inches of snow per hour). The model indicates that as the square of maximum wind gust speed and total snowfall increase, the average volume reductions increase. The coefficient of determination, R^2, of 0.544 (a measure of the percent variability in the response that is explained by the model) indicates that the model does have some explanatory power.

Table 2-2 provides the variables, variable ranges, and coefficient estimates. The response is winter storm event percent volume reduction. All variables are significant at the 0.05 level.

Table 2-2: Variables Included in Iowa Traffic Volume Model

Variable	Variable Range	Coefficient
Intercept		-1.583
(Maximum wind gust speed)^2	36.0 to 2,916.0	0.0296
Total snowfall (inches)	1.05 to 10.83	2.289
R^2		0.544

2.2. Impacts of Weather Events on Traffic Speed

A Federal Highway Administration study published in 1977 assessed impacts of weather on highways during various types of inclement weather. As a basis for supporting their research, the authors collected speed data from interstate highway facilities in the Washington D.C. area during six types of inclement weather conditions including rain, snow, etc. The results of their analysis showed significant percentage reductions in travel speeds compared to dry pavement conditions, as shown in Table 2-3 (7).

Table 2-3: Speed Reductions from D.C. Area Study

Pavement Condition	Percent Reduction in Travel Speeds
Wet and Snowing	13 %
Wet and Slushy	22 %
Slushy in Wheel Paths	30 %
Snowy and Sticking	35 %
Snowing and Packed	42 %

Knapp's investigation of speed characteristics during winter storms used different data than the volume study (6). Over twenty-seven hours of data for seven winter storms from December 1998 to March 1999 were collected using the Autoscope®, a mobile video traffic data collection system. This data and manually collected data recorded approximate roadway snow cover (snow on the roadway lanes or not) and visibility (estimation of how far one can see through snow fall and blowing snow) near seven bridges over Interstate 35 between Des Moines, Iowa and the Iowa/Minnesota border. Eventually, only one site proved to allow sufficient traffic data collection--Northeast 142nd Avenue, which is two miles north of the I-35 Elkhart Interchange in Polk County, Iowa.

The data were summarized in 109, 15-minute increments and identified as occurring during peak-period or off-peak period times. Knapp used 90, 15-minute off-peak-period increments for the modeling, because only 19 peak-period increments were available and off-peak-period and peak-period increments have different traffic patterns.

The databases included the following variables:

- average vehicle speed;
- traffic volume;
- estimated visibility,
- average gap;
- headway between vehicles; and
- roadway condition.

For comparison purposes, the data were then compared to data during similar time periods in the month of May. These comparisons and multiple regression analysis led to the following model. Table 2-4 provides the variables, variable ranges, and coefficient estimates. The response is average vehicle speed in miles per hour (mph). All variables are statistically significant at the 0.05 level.

Model: $SP = 55.7 - 7.23RCI - 3.88VI + 0.00002TV^2$

The variables in the model are as follows:

SP = Speed: average vehicle speed in mph (dependent variable);

RCI = Roadway cover index: variable indicating the absence (0) or presence (1) of snow on the roadway;

VI = Visibility index: variable indicating visibility less than (0) or greater than (1) 0.25 miles; and

TV = Traffic volume: variable for the square of traffic volume measured in units vehicles per hour squared.

The traffic speed data collected with mobile video data collection equipment as part of this Iowa study found that snow cover could reduce the average off-peak vehicle speeds by 7.3 mph (8).

Table 2-4: Variables Included in Iowa Travel Speed Model

Variable	Variable Range	Coefficient
Intercept		55.7
Roadway Cover Index	0 = snow on shoulders or non-existent on roadway surface 1 = snow impacting roadway lanes	-7.23
Visibility Index	0 = > 0.25 miles (0.40 km) 1 = < 0.25 miles (0.40 km)	-3.88
Traffic Volume ^{2} (vph)^2		0.00002
R^2		0.618

The model indicates that as the traffic volume increases during winter storm events, the average vehicle speed increases, suggesting that drivers are more comfortable driving in poor conditions when more drivers are on the road.

The model also shows that average vehicle speed decreases as the visibility decreases and more roadway snow cover is present. When snow is impacting the roadway lanes, the average vehicle speed will decrease by 7 mph (11.3 km/h). If visibility is less than 0.25 miles (0.40 km), the average vehicle speed will decrease by 4 mph (6.4 km/h). When both events occur simultaneously, average vehicle speed is reduced by 11 mph (17.7 km/h).

The R^2 value (0.618) indicates the model's power in describing the data. However, Knapp stated that as weather conditions decreased, the variability in the driving speeds increased.

Kyte et al. (9) analyzed capacity and level-of-service during less than ideal weather conditions (i.e. during weather events). The baseline of normal/ideal weather conditions are no precipitation, dry roadway, visibility greater than 0.37 km (0.23 miles), wind speed less than 16 km/h (9.9 mph) for the Idaho storm warning Project.

The data was collected between 1996 and 2000 on a four-lane section of Interstate 84 in southeastern Idaho. Data was collected from sensors measuring volume, visibility, roadway, and weather. ATRs recorded lane number, time, speed, and length of each vehicle passing the sensor site. Two types of environmental sensor systems were combined to provide the following data: wind speed and direction, air temperature, relative humidity, road surface condition, and the type and amount of precipitation. The weather and visibility sensors were located adjacent to the ATRs. Of the data collected, the authors focused on the effects of reduced visibility, high winds, and pavement condition on free-flow speed.

The authors calculated a critical wind speed by plotting passenger car speed against wind speed in order to find the points at which wind speed affects passenger-car speeds. In the graph, there was a significant drop in passenger-car speed when the wind speed reached 24 km/h (14.9 mph), and therefore this was considered the critical wind speed. The plot indicated that wind speed below 16 km/h had little effect on passenger-car speed. Neither wind direction, nor its impact on speed was specified.

A similar process, plotting passenger car speed against visibility, was used to calculate a critical visibility, the level of visibility at which driver speeds are affected. The authors noted that when visibility dropped below 0.3 km (0.19 miles), there was a significant drop in speed. Therefore, the decided critical visibility was 0.28 km (0.17 miles), indicating that vehicle speeds drop significantly when visibility falls below this level.

The following model was developed using multiple regression analysis.

Model: $SP = 100.2 - 16.4S - 9.5W + 77.3V - 11.7WS$

The variables in the model are as follows:

SP = Speed (SP): average passenger car speed in km/h (dependent variable);

S = Snow-covered surface (S): variable indicating the absence (0) or presence (1) of snow on roadway;

W = Wet surface (W): variable indicating that the pavement is dry (0) or wet (1);

V = Visibility (V): variable in km that takes on value of 0.28 when visibility exceeds 0.28 km (0.17 miles) and value of actual visibility when visibility is below 0.28 km (0.17 miles); and

WS = Wind Speed: variable indicating that the wind speed is less than or greater than 24 km/h (15mph).

Table 2-5 provides the variables, variable ranges, and coefficient estimates. The response is average vehicle speed in km/h. All variables are significant at the 0.05 level.

Table 2-5: Variables Included in Idaho Travel Speed Model

Variable	Variable Range	Coefficient
Intercept		100.2
Snow-covered surface	0 = snow is absent on roadway 1 = snow is present on roadway	-16.4
Wet surface	0 = roadway is dry 1 = roadway is wet	-9.5
Visibility (km)	=0.28 if visibility => 0.28 km (0.17 miles) =Actual visibility if visibility < 0.28 km (0.17 miles)	77.3
Wind speed	0 = < 24 km/h (15 mph) 1 = > 24 km/h (15 mph)	-11.7
R^2		0.34

This model indicates a greater average speed reduction when there is snow (16.4 km/h (10.2 mph)) than for a wet surface (9.5 km/h (5.9 mph)). When wind speed exceeds 24 km/h (14.0 mph), speed drops by 11.7 km/h (7.3 mph). When visibility is less than 0.28 km (0.17 miles), passenger car speeds decline 0.773 km/h (0.48 mph) for every 0.01 km (0.06 miles) below the critical visibility. The R^2 value (0.34) indicates the ability of the model to explain the variability in the data. It was stated and shown graphically that more variability in the average car speed occurred on days of bad weather.

In another study, Kyle, Khatib, Shannon, and Kitchener also studied the effect of weather-related environmental factors on speed flow rates and speed during poor driving conditions in Shoshone, Idaho(10). The data was collected during the winters of 1997-1998 and 1998-1999 in the same manner as the study conducted by Kyle, Khatib, Shannon, and Kitchener (9). Eighty-six 5-minute observations were used to determine normal driver speeds based on the baseline of normal/ideal weather conditions of no precipitation, dry roadway, visibility greater than 0.37 km (0.23 miles), and wind speed less than 16 km/h (9.9 mph). Four key weather-related factors considered in this model are visibility, roadway surface condition, precipitation intensity, and wind speed.

The wind speeds were categorized in four groups:

- 0 – 16 km/h (0 – 9.9 mph);
- 16 – 32 km/h (9.9 – 19.9 mph);
- 32 – 48 km/h (19.9 mph – 29.8 mph); and
- greater than 48 km/h (greater than 29.8 mph).

The precipitation is broken down into four levels:

- none;
- light;

- moderate; and
- heavy.

The sensors record this data based on National Weather Service criteria. The snowfall rate is converted into its liquid equivalent and its rate represents the rate of its liquid equivalent.

Visibility was categorized in three groups:

- 0 – 0.16 km (0 – 0.10 miles);
- 0.16 – 0.37 km (0.10 – 0.23 miles); and
- greater than 0.37 km (greater than 0.23 miles).

Multiple regression analysis led to the development of several models.

Model: $SP = 115.82 - 0.34WS - 4.77PI + 0.62V - 4.54RC$

The variables in the model are as follows:

SP	=	Speed (SP): average vehicle speed in km/h (dependent variable);
WS	=	Wind speed (WS): variable indicating speeds less than 16 km/h (9.9 mph) (1), between 16 and 32 km/h (9.9 and 19.9 mph) (2), between 32 and 48 km/h (19.9 and 29.8 mph) (3), and greater than 48 km/h (29.8 mph) (4);
PI	=	Precipitation intensity (PI): variable indicating increasing levels of precipitation: none (1), light (2), medium (3), heavy (4);
V	=	Visibility (V): variable indicating speeds less than 0.16 km (0.10 miles) (1), between 0.16 and 0.37 km (0.10 and 0.23 miles) (2), greater than 0.37 km (0.23 miles) (3); and
RC	=	Roadway condition: variable indicating dry (1), wet (2), or snowy/icy (3) roadways.

Table 2-6 provides the variables, variable ranges, and coefficient estimates. The first model developed is the following. The response is average vehicle speed in km/h. The R^2 value was 0.40. The coefficients for wind speed and visibility are small relative to the other variables, 0.34, and 0.62 respectively, which indicates that they are not as influential in the estimation of average vehicle speeds during weather events. Consequently, a second model was estimated with wind speed having only two levels: less than 48 km/h (29.8 mph) and greater than 48 km/h (29.8 mph). In this model, however, visibility was not statistically significant. Visibility was excluded from the third and final model because of its lack of significance.

Table 2-6: Variables Included in Idaho Travel Draft Second Speed Model

Variable	Variable Range	Coefficient
Intercept		115.82
Wind speed (kmph)	1 = 0 – 16 km/h (0 – 9.9 mph) 2 = 16 – 32 km/h (9.9 – 19.9 mph) 3 = 32 – 48 km/h (19.9 – 29.8 mph) 4 = > 48 km/h (> 29.8 mph)	-0.34
Precipitation intensity	1 = none 2 = light 3 = medium 4 = heavy	-4.77
Visibility (km)	1 = < 0.16 km (< 0.10 miles) 2 = 0.16 – 0.37 km (0.10 – 0.23 miles) 3 = > 0.37 km (> 0.23 miles)	0.62
Pavement condition	1 = dry 2 = wet 3 = snow/ice	-4.54

The final model best represents the factors affecting average speed during weather events.

Model: $$SP = 126.53 - 9.03WS - 8.74PI - 5.43RC$$

The variables in the model are as follows:

SP = Speed: average vehicle speed in km/h (dependent variable);

WS = Wind speed: variable indicating speeds less than (1) or greater than (2) 48 km/h (29.8 mph);

PI = Precipitation intensity: variable indicating increasing levels of precipitation: none (1), light (2), medium (3), heavy (4); and

RC = Roadway condition: variable indicating dry (1), wet (2), or snowy/icy (3) roadways.

Table 2-7 provides the variables, variable ranges, and coefficient estimates. The response is average vehicle speed in km/h. All variables are significant at the 0.05 level. The variables included in this model are additive. If normal conditions exist (wind speed is less than 48 km/h (29.8 mph), no precipitation exists, and the roadway is dry), the average vehicle speed is 103.3 km/h (64.2 mph). If the wind speed is greater than 48 km/h (29.8 mph), heavy snow is falling, and there is snow or ice on the roadway, average vehicle speed is reduced by 69.3 km/h (43.1 mph) to 34 km/h (21.1 mph).

Table 2-7: Variables Included in Idaho Travel Final Second Speed Model

Variable	Variable Range	Coefficient
Intercept		126.53
Wind speed (km/h)	1 = < 48 km/h (29.8 mph) 2 = > 48 km/h (29.8 mph)	-9.03
Precipitation intensity	1 = none 2 = light 3 = medium 4 = heavy	-8.74
Roadway condition	1 = dry 2 = wet 3 = snow/ice	-5.43

Heavy snow has the largest effect on free-flow speed. As a result of the high wind speed of 48 km/h (29.8 mph) as a critical value, high wind speed becomes a critical factor in determining average vehicle speed. No R^2 value was provided once visibility was removed and wind speed was combined into two levels.

Ibrahim and Hall conducted a study of the effect of rainy and snowy weather on flow-occupancy and speed-flow relationships on the Queen Elizabeth Way (QEW) in Mississauga, Ontario (11).

Traffic data were recorded at two locations (Stations 14 and 21) 24 hours a day at 30-second intervals and obtained from the freeway traffic management system (FTMS) for the QEW. The data were collected on the median lane and the average across three lanes. The variables measured were volume, occupancy, and speed. Weather data was obtained from the Atmospheric Environment Service and compared with FTMS weather data.

In order to ensure the collection of adverse weather data, the months of October 1990 through February 1991 were considered. Data for clear days during these same months were also collected. Traffic comparisons were limited to the same time of day (10:00 a.m. to 4:00 p.m.) on weekdays because of the reliable traffic patterns. Three comparisons were analyzed: clear and rainy weather, clear and snowy weather, and rainy and snowy weather. Definitions of light precipitation and heavy precipitation were not provided. However, it was stated that visibility was used to determine the snowfall intensity and rate of fall was used to determine the rainfall intensity.

Two steps were used in the analysis of the data. First, in order to examine each weather condition for consistency, regression analysis was conducted within each weather condition, and a function for each was developed. Then the six underlying functions for each weather condition were plotted on the same graph, which resulted in separate graphs for clear, rainy, and snowy weather. The lowest functions (heavy precipitation) and highest functions (light precipitation) were selected for each condition. Second, multiple regression analyses were then conducted to test for statistically significant differences between the highest functions and lowest functions within each weather condition.

It was concluded that a statistically significant difference between the low and high functions for clear weather did not exist. However, statistically significant differences did exist between the lowest and highest functions for both rainy weather and snowy weather. Therefore, the three weather conditions were divided into five categories: clear, light rain, heavy rain, light snow, and heavy snow.

Comparisons were then made within and between the following weather conditions: clear and rainy weather, clear and snowy weather, and rainy and snowy weather. It was concluded that light rain and light snow had nearly the same effect on free-flow speed. A statistically significant difference existed between the effects of heavy snow and heavy rain on free-flow speed with heavy snow having a greater effect than heavy rain. These tests between functions also indicated that there was a greater difference within rainy weather (light rain versus heavy rain) and within snowy weather (light snow versus heavy snow) than between rainy weather and snowy weather or between clear weather and light precipitation (light rain or light snow).

It is evident that more severe weather conditions lead to a greater decrease in traffic speed from Table 2-8. Also, it is evident that light snow and light rain have nearly the same effect on free-flow speed.

Table 2-8: Types of Precipitation Included in Ontario Speed Model

Type of precipitation	Amount of decrease
Light rain	Maximum of 2 km/h (1.2 mph)
Light snow	Maximum of 3 km/h (1.9 mph)
Heavy rain	5 to 10 km/h (3.1 to 6.2 mph)
Heavy snow	38 to 50 km/h (23.6 to 31.0 mph)

2.3. Impacts of Weather Events on Rural Highway Traffic

All of the above studies were conducted in urban or suburban areas that carry more traffic than the rural highways. To assess the operational improvements to travel during severe weather events on rural highway due to the ITS deployments, it is needed to establish how much the severe weather events affect the traffic operations on rural highways. In most urban areas, the highway capacity during peak periods becomes a bottleneck and the temporary losses of highway capacity caused by severe weather events often worsen the conditions on congested highway networks. Those relationships have been well documented. Prior to this study, no empirical estimation had been made to document the correlation between the rural highway volumes or travel speeds and weather events.

Earlier attempts at estimating the impacts of weather events on highway capacity have either not been based on empirical data or have not been conclusive. For example, a 1991 investigation concluded that reductions in highway capacity due to adverse weather ranged from 7 to 56 percent (12). This represents a very wide range of variations, and does little to lend credibility to any estimated benefits resulting from ITS deployment.

The goal of this project was to find a better way to estimate changes in road capacities, if any, on rural highways due to weather events with greater accuracy. The effects of severe weather events on rural highway operations are expected to be different from the same on urban roadways because of lower traffic volumes and higher operating speeds on rural highways. This effort represents a promising start in this area. This study attempted to investigate the effects of roadway grade on rural highway operations during severe weather events. but, there were not enough number of sites that had both weather and ATR data and the variations in the roadway grade in a statistically significant way.

2.4. Impacts of Weather Events on Safety

A recent study in Iowa found that the crash rates during 54 storm events encompassing 491 hours showed that the crash rate during these storm events was 9.46 per million vehicle miles traveled (MVMT) while the crash rate during non-storm time periods was found to be 0.66 per MVMT (13). This study included only the weather events that lasted for four or more hours and a precipitation rate threshold of 0.2 inches per hour was used to select the winter storms to be included in the analysis. The data for this study was obtained from seven RWIS and ATR stations along the Interstates I-80, I-380, and I-35 in Iowa. The focus of our research was not the impacts of severe weather events on the safety of rural highway traffic. So, this topic was not comprehensively researched in the literature.

2.5. Summary of Literature Review

Table 2-9 provides a summary of number of sites used for the studies on the impacts of severe weather events on average highway speeds and traffic volumes reviewed.

Table 2-9: Summary of Studies on Weather Impacts on Average Speeds

Study Type	Author	Number of sites	Additional information
Volume	Hanbali and Kuemmel	11	
Volume	Knapp	7	64 storm events with 618 hours of data
Speed	Ibrahim and Hall	2	68 data files
Speed	Knapp	1	90 15-minute off-peak-period increments
Speed	Kyte, Khatib, Shannon, and Kitchener (2000)	Not given	86 5-minute increments
Speed	Kyte, Khatib, Shannon, and Kitchener (2001)	Not given	5-minute increments

Table 2-10 provides a summary of the variables used in the four speed models.

Table 2-10: Variables Used in Speed Studies

Study	Mobility and Safety Impacts of Winter Storm Events in a Freeway Environment Final Report	Effect of Weather on Free-Flow Speed	Effect of Environmental Factors on Free-Flow Speed
Roadway Cover Index	X		X
Wet Surface Index		X	
Snow-Covered Surface Index		X	
Visibility Index	X	X	
Precipitation Index			X
Wind Speed Index		X	X
(Traffic Volume)^2	X		

3. METHODOLOGY

The primary objective of this study was to determine whether there is a significant correlation between severe weather events and traffic volumes or speeds on rural highways. To meet this objective, this study used data from automatic traffic recorders (ATR) and data from road weather information systems (RWIS). Initially, the scope of the study was limited to the COATS region. But, the study was subsequently expanded to include data from Montana as archived RWIS data from Caltrans Districts 2 and 1 were not readily available.

3.1. Traffic Volume, Speed and Capacity

Traffic volume represents the number of vehicles that pass through a roadway in an hour and it is related to the average space mean speed of the vehicles through the roadway. This study focuses on the impacts of severe weather events on specifically rural highways. The traffic flow on rural highways is considered to be the type of uninterrupted flow.

The general speed-flow-density relationship is as follows:

$q = k*v$

Where q = flow (vehicles / hour);
k = density (vehicles / mile or vehicles / kilometer); and
v = speed (miles / hour or kilometers/ hour).

Highway Capacity Manual (HCM) 2000 defines uninterrupted flow as *a category of facilities that have no fixed causes of delay or interruption external to the traffic stream; examples include freeways and unsignalized sections of multilane and two-lane rural highways*. Greenshield's model explains the relationship among volume speed and density of uninterrupted flow.

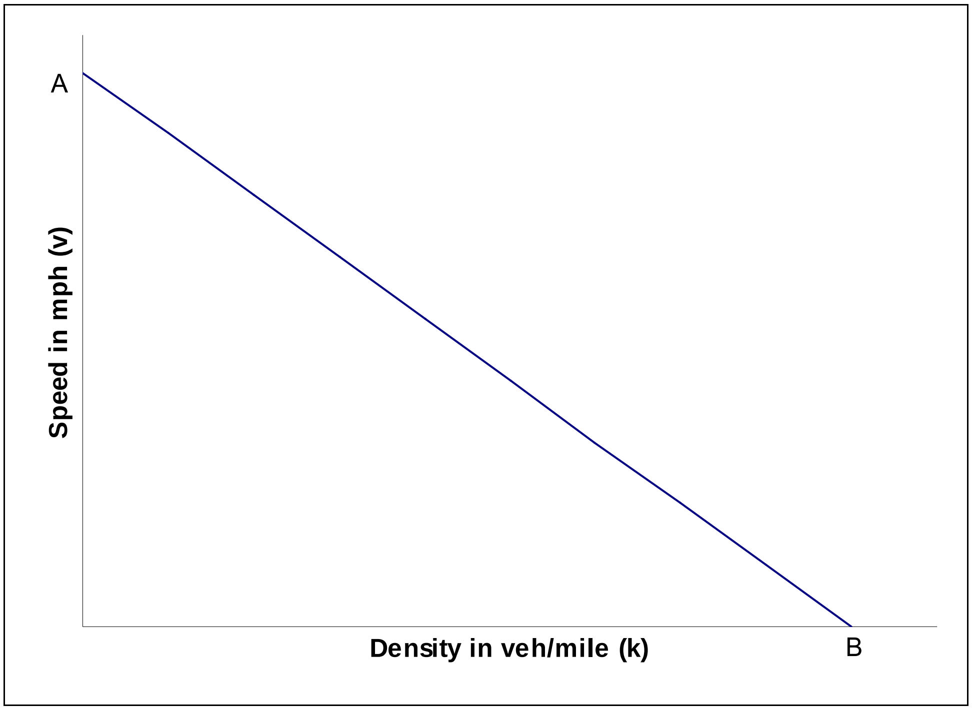
The relationship between speed and density is as follows:

$v = A-B*k$

where v = speed (mph or km/h);
A, B = constants determined by field observations; and
k = density (vehicles/mile, vehicles/kilometer).

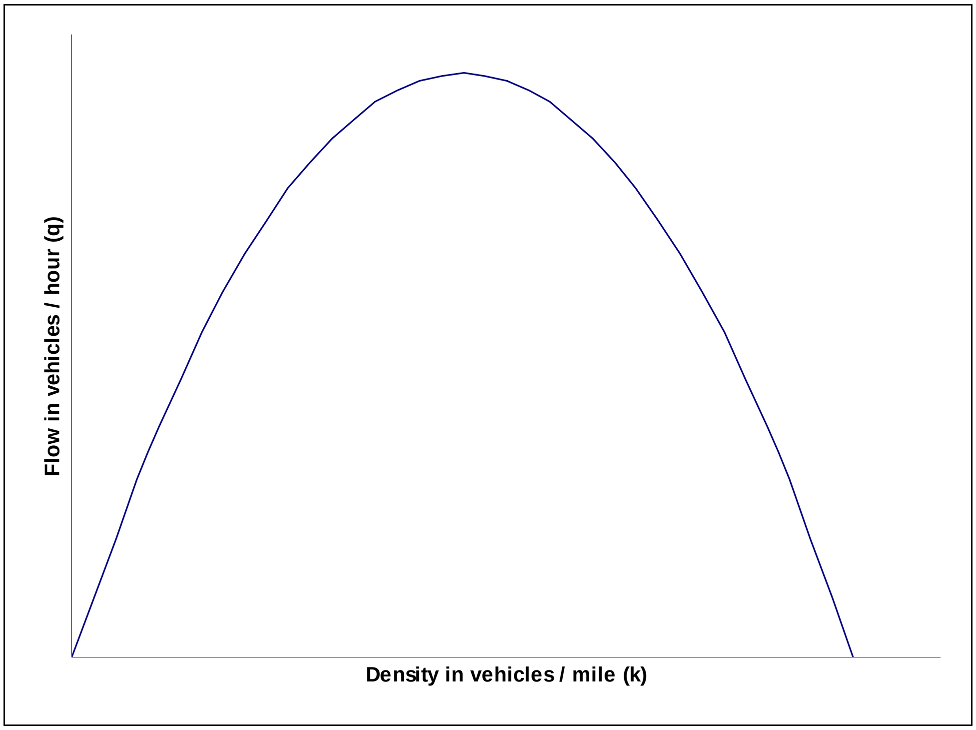
Using this Greenshield's model, general schematic diagrams of the speed-flow-density relationship can be drawn. Figure 3-1 shows the speed-density relationship.

Figure 3-1: Speed (*v*) vs. Density (*k*) Schematic for Uninterrupted Flow



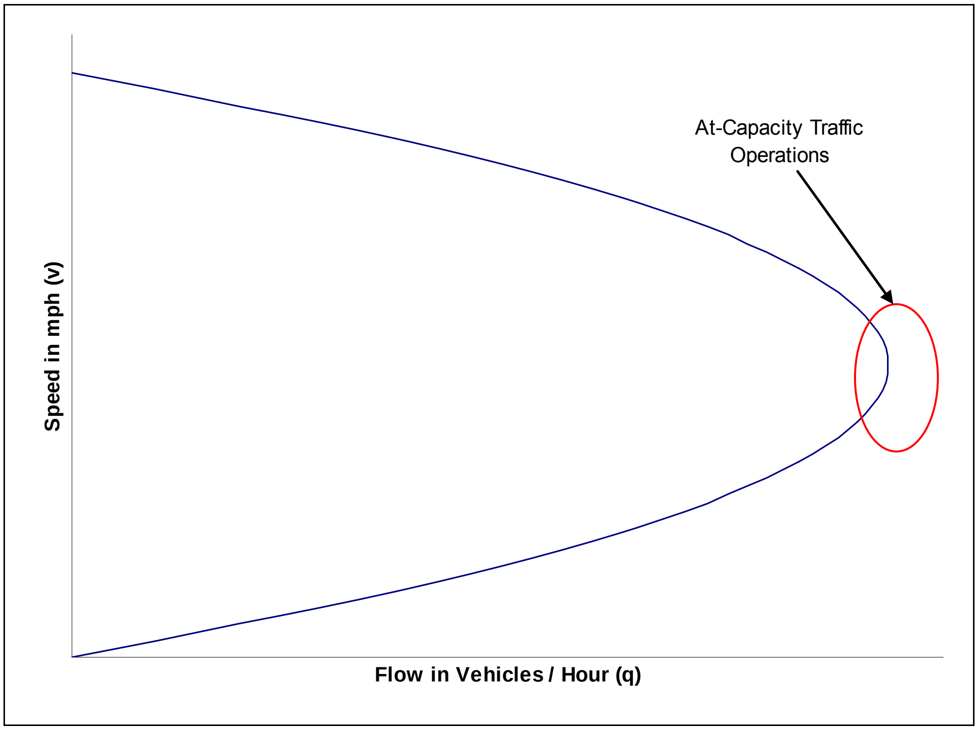
As seen in Figure 3-1, the constant A represents the free flow speed of the roadway in consideration and the value of B is influenced by the jam density of the roadway. Figure 3-2 shows a conceptual diagram of the relationship between flow and density. It can be seen that the flow increases as the density increases from zero up to a certain level of density and then starts decreasing with the density due to congested conditions.

Figure 3-2: Flow (*q*) vs. Density (*k*) Schematic for Uninterrupted Flow



The relationship between flow and speed is non-linear like the flow-density relationship as shown in Figure 3-3. The actual curves (i.e. not the general shape of the curves) defining the speed-flow-density relationships will vary with geometric, roadway, environmental and traffic control conditions.

Figure 3-3: Flow (*q*) vs. Speed (*v*) Schematic for Uninterrupted Flow



In HCM 2000, flow or volume is defined as the number of vehicles passing a point on a lane, roadway, or other traffic-way during some time interval, often one hour, expressed in vehicles per hour. Capacity is defined as the maximum sustainable flow rate at which vehicles reasonably can be expected to traverse a point or uniform segment of a lane or roadway during a specified time period under given roadway, geometric, traffic, environmental and control conditions; usually expressed as vehicles per hour.

The observed volumes at traffic recording stations such as ATR (Automatic Traffic Recorders) represent the flow rate or traffic volume. As mentioned above, capacity is affected by numerous factors including road weather conditions. To determine the changes in capacity due to weather conditions using empirical data, the data should contain information on traffic operating at the roadway capacity during normal and severe weather conditions. Severe weather events may or may not affect traffic volumes (flow) on a roadway operating at much lower levels compared to the capacity.

3.2. Methodology for Traffic Volume Impact Assessment

This study estimated the traffic volume change due to two kinds of weather events that affect rural highway travel: rain and snow. The weather data identifies both snow and rain as precipitation. These two weather conditions are expected to reduce visibility and/or vehicle traction, causing drivers either to change their travel (e.g. postpone the trip) or to change their traveling speeds. This part of the study focused on capturing the first effect (i.e. drivers changing their travel plans) that would result in lesser traffic volumes than the same during normal weather conditions. Due to data resource limitations, the traffic volume changes due to ice were not included in the study.

Two methodologies were used to calculate the change in traffic volume due to weather events each using different methods to determine the normal volume (i.e. the expected traffic volume in the absence of weather events). The first method assumed that traffic volume from the previous year for the same hour, month, and the day of the week of the weather event represented the corresponding normal volume. The second method determined the normal volume using a predicted value by a time series fitted with the hourly traffic volume for one whole year. The details of these two methods are provided in the later sections of this chapter. The selection of sites, data collection, quality control of the weather traffic data are explained in Chapter 4. The sites were selected by searching for pairs of ATR and RWIS stations that were located within five miles of each other.

3.3. Volume Methodology One

A brief overview of the first methodology is presented in terms of the consecutive steps used to calculate the change in volume due to severe weather events and is also explained with the help of Figure 3-4.

Step 1: Identify all rain, snow weather events based on the rules defined in the next chapter. The durations of the weather events were calculated. If the weather event lasted more than an hour, the weather event was treated as two separate hourly weather events for modeling purposes.

Step 2: The calculated durations for each hour along with other weather information was combined with the traffic information from the nearby ATR station identified earlier.

Step 3: For the hours that have one or more weather events, the normal volume was identified by using the traffic volume from the previous year for the same day of the week and hour of the day.

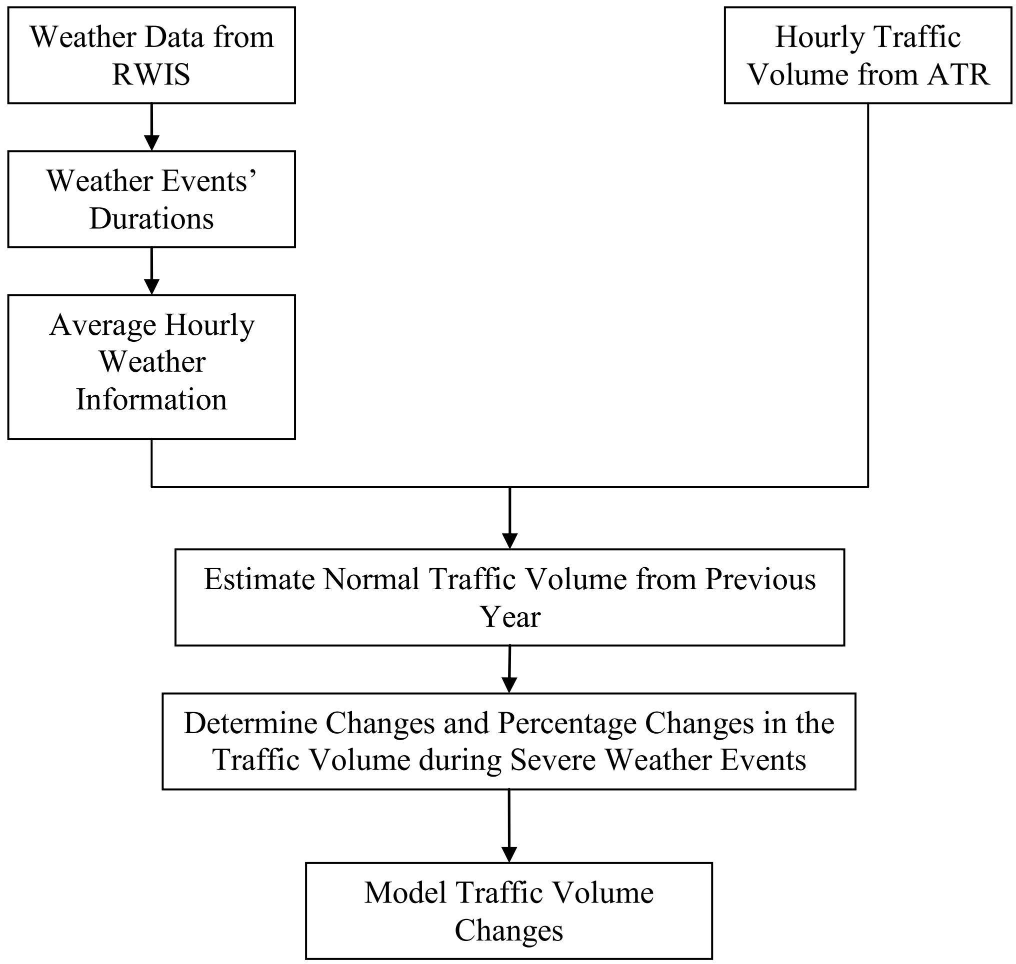
Step 4: Estimate the change in traffic volume during weather events using the normal volume estimated in step 3 during the time of the event. Based on this estimated change in traffic volume, a percentage change in volume was calculated as follows:

$$\Delta V = (V_n - V_w) * 100 / V_n$$

Where ΔV = percentage change in volume
V_n = normal traffic volume
V_w = traffic volume during weather events

Step 5: Model the percentage change in volume using the variables; duration of the weather event, precipitation rate, precipitation intensity, air temperature, etc.

Figure 3-4: Schematic of Volume Methodology One



The modeling used a multiple regression approach and the results of this approach are presented in Chapter 6.

3.4. Volume Methodology Two

The second methodology for the traffic volume analysis was to use the 24 hour-cycle of hourly traffic volumes to fit a time series Autoregressive Integrated Moving Average (ARIMA) model. This time series model was then used to estimate the normal traffic volume (i.e. the expected traffic volume on the roadway if there were no weather events). The volume methodology two largely varied in the estimation of normal volume during weather events (i.e. step 3 in volume methodology one). The volume methodology two can be summarized using the following steps:

Step 1: Identify all rain and snow weather events based on the rules defined in the next chapter. The durations of the weather events were calculated. If the weather event lasted more than an hour, the weather event was treated as two separate hourly weather events for modeling purposes.

Step 2: The hourly volume data from the nearby ATR station identified earlier was cleaned and a time series ARIMA model was developed. This model had a predicted value for normal volumes for every hour of the year.

Step 3: The calculated durations of weather events for each hour along with other weather information was combined with the ARIMA model to determine the normal volume (i.e. the expected volume on the roadway if the weather event did not occur).

Step 4: Estimate the change in traffic volume during weather events using the normal volume estimated by the ARIMA model for the time of the event. Based on this estimated change in traffic volume, a percentage change in volume was calculated as follows:

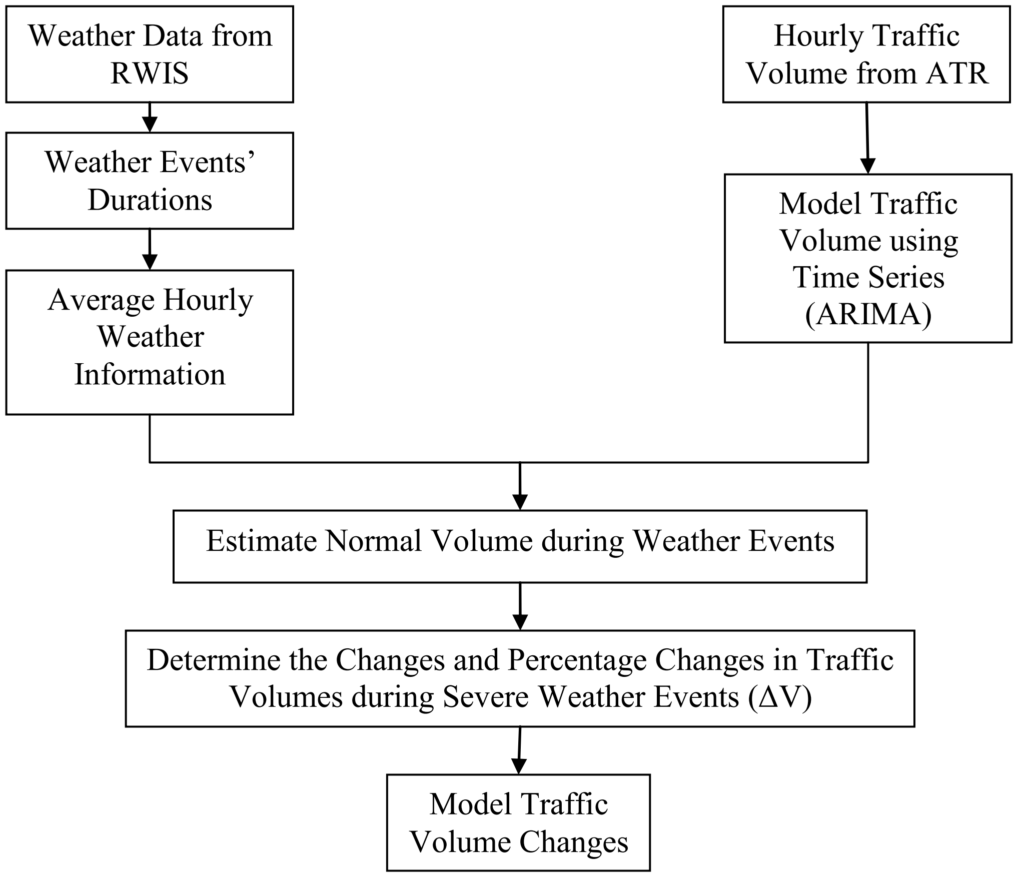
$$\Delta V = (V_n - V_w) * 100 / V_n$$

Where ΔV = percentage change in volume
V_n = normal traffic volume
V_w = traffic volume during weather events

Step 5: Model the percentage change in volume using the variables: duration of the weather event, precipitation rate, precipitation intensity, air temperature, etc.

Figure 3-5 shows the schematic of this methodology using a time series approach. The modeling of the changes in volume during weather events used the same approach as the volume methodology one. It should be noted that the data for the day for which hours of data was missing, was not included in the time series model. The results of this modeling effort are provided in Chapter 5.

Figure 3-5: Schematic of Volume Methodology Two



3.5. Methodology for Traffic Speed Impact Assessment

This study also estimated the traffic speed change due to two kinds of weather that affect rural highway travel: rain and snow. These two weather events were categorized into one and is referred to as precipitation in this report. The process for estimating traffic speed impact for adverse weather consisted of the following steps.

Step 1: Identify all rain, snow weather events based on the rules defined in the next chapter. The durations of the weather events were calculated. If the weather event lasted more than an hour, the weather event was treated as two separate hourly weather events for modeling purposes.

Step 2: The calculated durations for each hour along with other weather information was combined with the hourly average traffic speeds from the nearby ATR station that records traffic speed. The traffic speeds were recorded in terms of number of vehicles in an hour in eight different ranges of speeds (see Appendix D for the data structure of the speed data). Hourly average traffic speeds are estimated by a weighted average of speed ranges where the weights are the number of vehicles in each speed range.

<u>Step 3</u>: Estimate the average normal speed during the time of the weather event. The normal speed was estimated by two methods as follows:

Method 1: An annual average travel speed for every hour of the day was developed based on the traffic speed data for the hours with out any weather events. These annual average speeds were used as the normal speeds (S_n) for the corresponding time of the day for weather events (i.e. the expected average travel speed for the hour of weather event).

Method 2: The average travel speed is calculated by averaging the travel speeds for the hours of the same day that had no weather events.

$$S_n = \sum (N_i \times S_i) / \sum N_i$$

Where S_n = Normal average travel speed

N_i = Number of vehicles for the i^{th} hour the same day that had no weather events

S_i = Mean speed for the i^{th} hour {Calculated by a weighted average of mean speed of speed ranges (e.g. 62.5 mph for the speed range (60, 65)) and the weights being the number of vehicles in each speed range}

i = [1, 24] except the hours that had a weather event

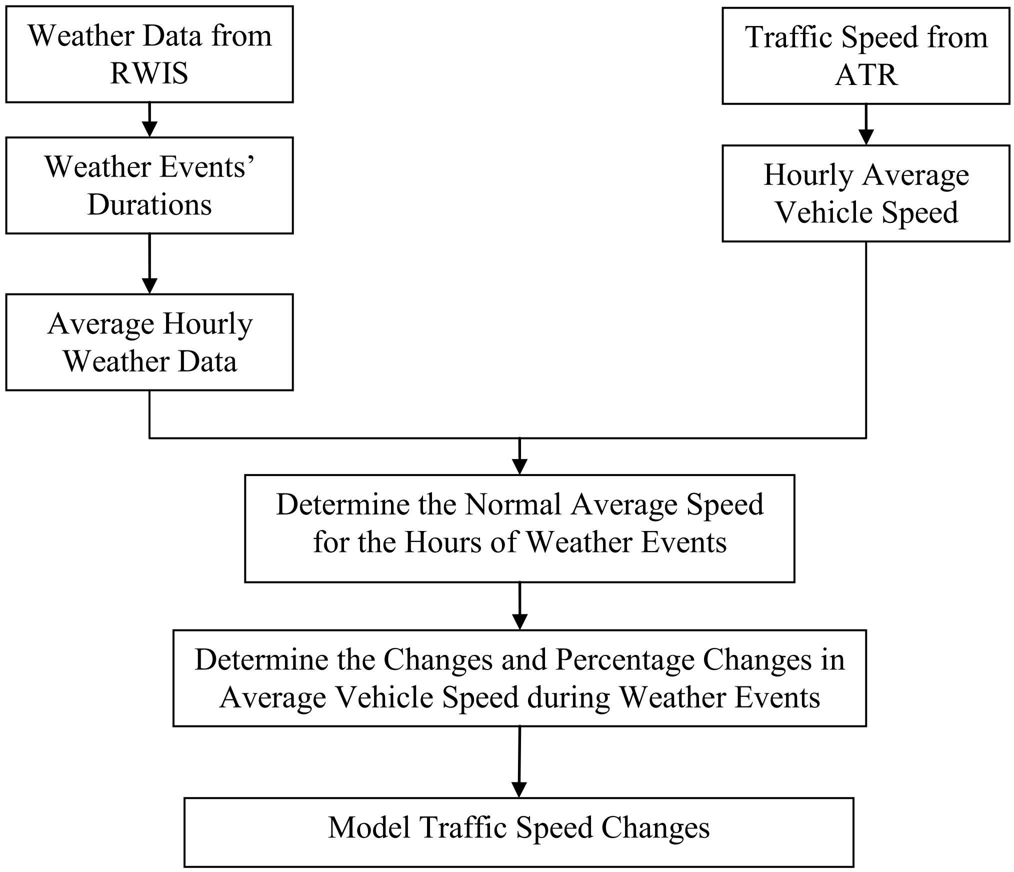
<u>Step 4</u>: Determine the changes and percentage changes in average travel speed during the time of the weather event by calculating the difference between the normal speed and the actual observed average travel speed for the hour. "i" corresponds to the hour of the weather event.

$$\Delta S = (S_n - S_i) * 100 / S_n$$

<u>Step 5</u>: Model the percentage change in traffic speeds using the variables: precipitation rate, etc.

This methodology is also explained in Figure 3-6.

Figure 3-6: Schematic of Traffic Speed Impact Analysis



4. DATA COLLECTION AND PREPARATION

Weather and traffic volume and speed data is scarce for rural highways and this study focused on the effects of weather events on rural highways. The first step in collecting data for this study was to compile the location details of the weather data sources (i.e. RWIS stations) and traffic data sources (i.e. traffic count stations or ATR stations). This chapter focuses on the process of selecting the sites, subsequent data collection, and data processing.

4.1. Site Selection

To quantify the correlation between severe weather events and traffic volumes and speeds on rural highways, weather and traffic data need to be correlated. The weather conditions, especially precipitation, can vary significantly over short distances (e.g. 1 mile); therefore, the research team collected information on the locations of weather and traffic data sources. State departments of transportation commonly collect traffic data (i.e. traffic lane volumes and vehicle classification information or number of vehicles in each travel speed range) through the use of automated traffic recorders (ATRs). The frequency of the traffic data collection is typically set to be one observation per hour. Many states also collect weather data using road weather information systems (RWIS). The locations of these devices are often different because the use of the data is generally driven by different sets of customers (ATRs for planning purposes, RWIS for maintenance and traveler information). Therefore, it is important to match a list of ATR and RWIS sites for data collection in the study area. The study area for this project is the same as the COATS study area encompassing southern Oregon and northern California. Based on the relative locations of ATRs and RWIS sites in Oregon, California and Montana, a list of potential ATR and RWIS station pairs was created. Based on this list, the availability of archived weather and traffic data was explored. The archived weather information from the RWIS stations in California was not readily available; thus, the sites from California were not included in this study. ATR locations that collected and archived travel speed information could not be identified in the COATS study area; therefore, Montana was included in the study to perform a travel speed impact assessment.

Table 4-1 and Table 4-2 present all the potential ATR and RWIS pairs in this study for Oregon and Montana, respectively. For each paired ATR and RWIS station, an ATR station on rural highway was used to provide hourly traffic counts on the rural highway segment and the RWIS station was used to identify when severe weather events (snow and rain) occurred. Archived roadway surface and weather condition data were collected from RWIS, analyzed as explained in Chapter 3, and were combined with archived ATR traffic data.

Table 4-1: List of Potential RWIS and ATR Pairs in Oregon

Highway #	ATR & RWIS Locations		Mile Post	Distance between RWIS and ATR
I-5	WEATHER	SISKIYOU	5.0	6.0
I-5	ATR	SISKIYOU	11.0	
I-5	WEATHER	MEDFORD VIADUCT	28.9	0.6
I-5	ATR	MEDFORD VIADUCT	28.3	
I-5	WEATHER	SEXTON PASS	69.1	4.9
I-5	ATR	GRAVE CRK.	64.2	
I-5	WEATHER	WARD'S BUTTE	165.0	5.0
I-5	ATR	MARTIN CRK	170.0	
140	WEATHER	LAKE OF THE WOODS	36.0	21.2
140	ATR	LAKE OF THE WOODS	14.8	
199	WEATHER	O'BRIEN	41.3	0.0
199	ATR	O'BRIEN	41.3	
199	WEATHER	HAYES HILL	16.0	10.6
199	ATR	TIMBER RIGDE	5.4	
HWY.42	WEATHER	Remote- Coosbay	42.0	28.5
HWY.42	ATR	BROCKWAY	70.5	
101	WEATHER	PORT ORFORD	301.0	0.0
101	ATR	PORT ORFORD	301.0	

It was assumed that an ATR station would experience similar weather conditions as those recorded at the nearby RWIS station located less than ten miles away (i.e. the criteria used for selecting RWIS and ATR pairs). In other words, snow and rain event characteristics recorded at an RWIS station were assumed to exist within a 10 mile radius of that station. Only paired stations within 10 mile distance were used in the study and the other pairs were dropped.

Table 4-2: List of Potential RWIS and ATR Pairs in Montana

Highway #	ATR & RWIS Locations		Mile Post	Distance between RWIS and ATR
I-90	RWIS	Yellowstone	452.3	8.3
	ATR	A-203, A-119	444.0	
I-94	RWIS	Beaver Hill	234.8	8.0
	ATR	A-25	242.8	
I-90	RWIS	Reedpoint	390.8	25.5
	ATR	A-120	416.3	
I-90	RWIS	Ninemile	81.8	35.0
	ATR	A-30	46.8	
I-90	RWIS	Arrow Creek	468.6	10.0
	ATR	A-123	458.7	
I-90	RWIS	Bozeman Hill	321.8	1.4
	ATR	A-71	323.2	
I-94	RWIS	Sweeny Creek	112.6	18.3
	ATR	A-31	130.9	
P-8	RWIS	MacDonald Pass	27.9	14.9
	ATR	A-21	42.8	
P-5	RWIS	Pablo	52.4	25.6
	ATR	A-62	78.0	
P-10	RWIS	Loma	53.1	21.8
	ATR	A-115	31.3	
P-3	RWIS	Pendroy	62.6	26.3
	ATR	A-53	36.3	
P-50	RWIS	Karst	55.3	5.5
	ATR	A-43	49.8	
P-24	RWIS	Greenough Hill	22.1	16.9
	ATR	A-15	5.2	
P-24	RWIS	Helmville	53.3	19.7
	ATR	A-70	73.0	
P-3	RWIS	Pendroy	62.6	18.9
	ATR	A-39	81.5	
P-60	RWIS	Monarch Hill	53.5	18.5
	ATR	A-127	72.0	
P-37	RWIS	Lame Deer	50.1	26.6
	ATR	A-63	76.7	
I-15	RWIS	Monida	0.3	14.9
	ATR	A-202	15.2	
I-15	RWIS	Boulder Hill	170.9	20.9
	ATR	A-3	191.8	
I-15	RWIS	Gary Cooper	242.0	10.1
	ATR	A-125	231.9	

The following section explains the structure of the weather and traffic data that were collected from Oregon and Montana.

4.2. Description of Data

Severe weather events are determined using definitions detailed in the following sections. In this study, two broad weather categories were considered: rain and snow. These events were identified using the RWIS data (i.e. weather data). The structures of the weather data from Montana and Oregon RWIS are detailed below.

4.2.1. Weather Data

The archived data from RWIS stations in Montana and Oregon had different structures and formats.

Oregon RWIS Data:

Archived RWIS data from 1997 to 2004 were collected from the Oregon Department of Transportation (ODOT) for the RWIS sites in the selected RWIS-ATR pairs. The following information in a RWIS records were used in this study:

- date and time;
- air temperature;
- dewpoint temperature;
- precipitation intensity(light, moderate, heavy, no data);
- precipitation type(none, rain, yes, no com);
- precipitation rate(inches per hour); and
- relative humidity.

Montana RWIS Data:

Archived RWIS data from 2000 to 2004 were obtained from Montana DOT for the RWIS sites in the selected pairs. The RWIS record includes the following information of interest to this study:

- date and time;
- wind speed (average and gust);
- wind direction;
- precipitation type (0-none,1-yes,2-rain,3-snow);
- precipitation rate(inches per hour);
- surface temperature;
- air temperature; and
- surface conditions.

The frequency of observation for the weather data from both Oregon and Montana was between 8 and 15 observations per hour. This information was used to calculate the weather event durations within every hour of the year. After this assessment, the weather data for each hour was condensed to one data point for the whole hour along with the duration of the weather event for that hour. This was achieved by averaging the weather variables that could be averaged and by picking a representative value for other variables as explained in section 4.3.2 below.

4.2.2. Traffic Data

Two kinds of traffic data were collected. The first kind was traffic volume data from ATR stations located in Oregon and Montana as identified in the pairs in earlier sections. The volume data were recorded year round at these ATR stations in Oregon and Montana.

The second kind of data was the travel speed data collected from ATR stations located in Montana. There were three Montana ATR stations that recorded travel speeds for about four weeks in one year (i.e. one week of data in each quarter). The data was provided to WTI by Oregon Department of Transportation and Montana Department of Transportation. The format of these data can be found in Appendices B, C, and D.

4.3. Data Processing

The weather data collected from Oregon was in the XML format. This data was opened in Wordpad® and then split into multiple files so that it can be opened in MS Excel®. The ATR data from Oregon was in ".txt" file formats and were then converted to MS Excel® files.

4.3.1. Traffic Data Processing

The ATR data obtained from Oregon included traffic volume data only. Traffic volume data and traffic speed data were collected from the ATR stations selected from Montana. All ATR data as shown in Appendices B, C, and D were processed using the codes shown in Appendix A such that hourly traffic volumes per lane were expressed in equivalent Passenger Car Units (PCU). The ATR traffic volume data had a set of vehicle classes which were combined using the PCU equivalents provided in HCM 2000. The details of this conversion are provided in Appendix E.

The ATR speed data was also in ".txt" file formats and the numbers of vehicles in each of the eight speed ranges were used as the weights for averaging the mid-speeds of the speed ranges (e.g. 27.5 for the range between 25mph and 30mph) to arrive at an average travel speed for each hour.

4.3.2. Weather Data Processing

The RWIS data from both Oregon and Montana ranged between 8 and 15 observations per hour with varying time intervals between consecutive observations. Therefore, RWIS data was aggregated to one data point per hour using the following logic and combined with ATR data for that hour for further analysis. As indicated earlier, the variables in the weather data that can be averaged were averaged and a representative value from the observations of the hour was chosen for other variables. Since the durations of the weather events within an hour were calculated using the 8 to 15 observations per hour, this aggregation of weather data does not affect the impact assessment.

1. If there was precipitation in the hour, the duration of precipitation in that hour was calculated assuming that the precipitation continued between two observations that showed precipitation and the precipitation ended at the observation that showed no precipitation.

2. For Oregon RWIS data: If the precipitation type was **Rain**, it was classified as a rain event. If the precipitation type was **Yes** and the air temperature was below 32, it was snow, otherwise it was rain. If precipitation type was **None**, there was no rain or snow event.

3. For Montana RWIS data: If the precipitation type was 2 and 3, it was rain and snow event respectively. If precipitation type was 1 and the air temperature was below 32, it was snow event, otherwise it was rain event.

To identify severe weather events, the authors chose to use weather events that lasted more than 20 minutes in processing the hourly traffic and weather data so the impact of the weather event can be measured using the hourly traffic volume and hourly travel speed data. ATR data was not available for any smaller unit of time intervals.

4.4. Summary

The hourly traffic volume, traffic speed, weather event duration and other weather information were all combined using the programs (i.e. codes in C language) provided in Appendix A. This hourly data was used along with the methodology explained in Chapter 3 to estimate the volume and speed changes. The volume and speed changes were then modeled using multiple-regression. The results of this effort are summarized in the next chapter.

5. ANALYSIS AND RESULTS

The analysis and modeling of the data colleted from the selected RWIS - ATR pairs is described in this chapter. First, the impacts of severe weather events on the traffic volumes at the selected sites in Oregon were analyzed. A thorough analysis of two selected sites in Oregon did not show any statistically significant relationship between the percentage change in volume during weather events and the occurrence and the duration of the weather events; thus, further inquiry into the impact of weather events on traffic volumes was not done. The results of the analysis of the two Oregon sites are provided in the following sections of this chapter.

The assessment of impact of weather events on average travel speeds was completed for three selected sites in Montana using the multiple-regression modeling approach. All three sites showed a significant reduction in the travel speeds during weather events. The results of this analysis are presented in the following sections. The travel speed impact assessment was done only for the Montana sites as archived traffic speed data could be obtained for selected sites in Oregon.

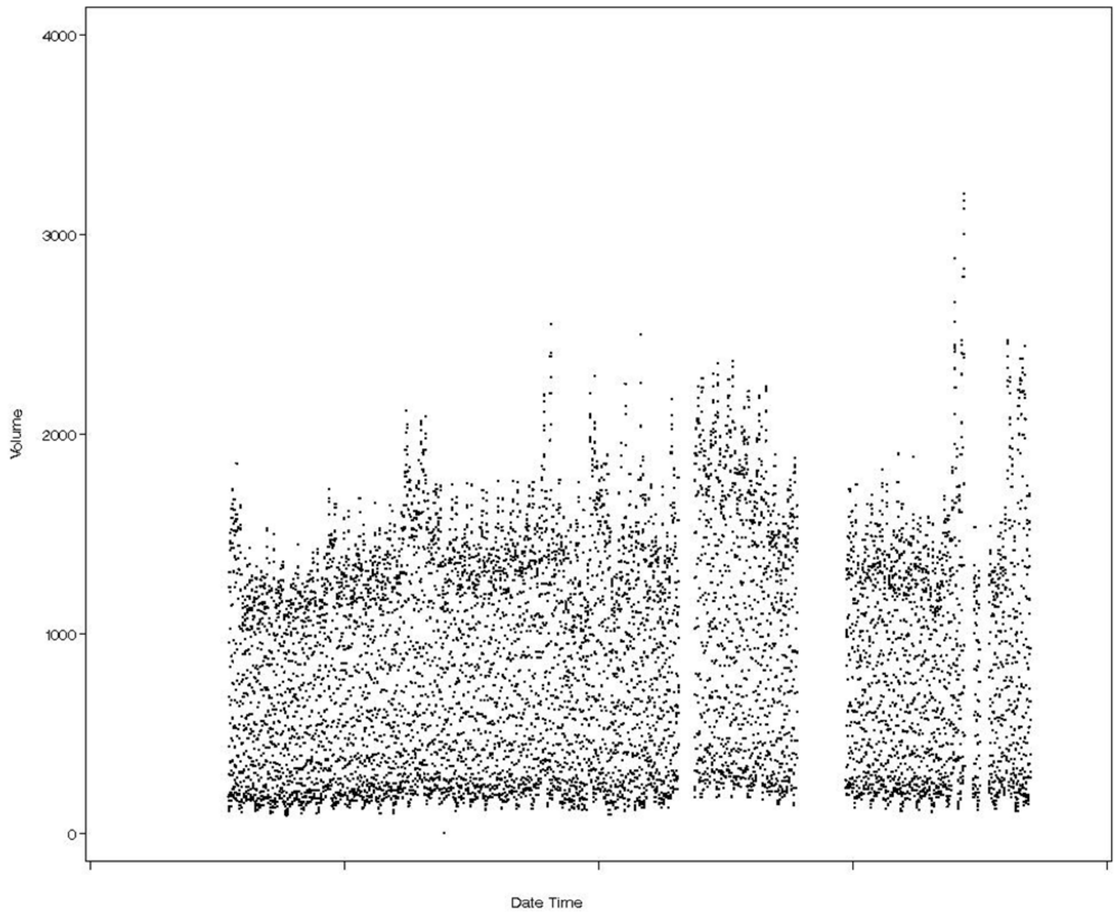
5.1. Traffic Volume Impact Analysis

As explained earlier, the traffic volume impact assessment was initially done for two selected sites in Oregon (i.e. RWIS sites at Grave Creek and O'Brien).

A major challenge faced in this study was the fact that the hourly traffic volumes varied over the time of day, day of the week, month of the year. This volatile characteristic of hourly traffic volume made it difficult to accurately determine the normal volume (i.e. the expected traffic volume if the weather event did not occur). As an example, the sum of hourly traffic volumes of the two traffic lanes from the Grave Creek ATR site for the year 2002 are shown in Figure 5-1. It can be readily seen that the variations in the hourly traffic volumes are often large. In addition, none of the data points represent at-capacity operations as explained in Chapter 3. Therefore, researchers were not able to determine the capacity changes due to weather events.

The results showed no significant correlation between the percentage change in volume and the occurrence or duration of severe weather events; thus, no further exploration of other sites from Oregon or Montana in terms of traffic volume changes was performed.

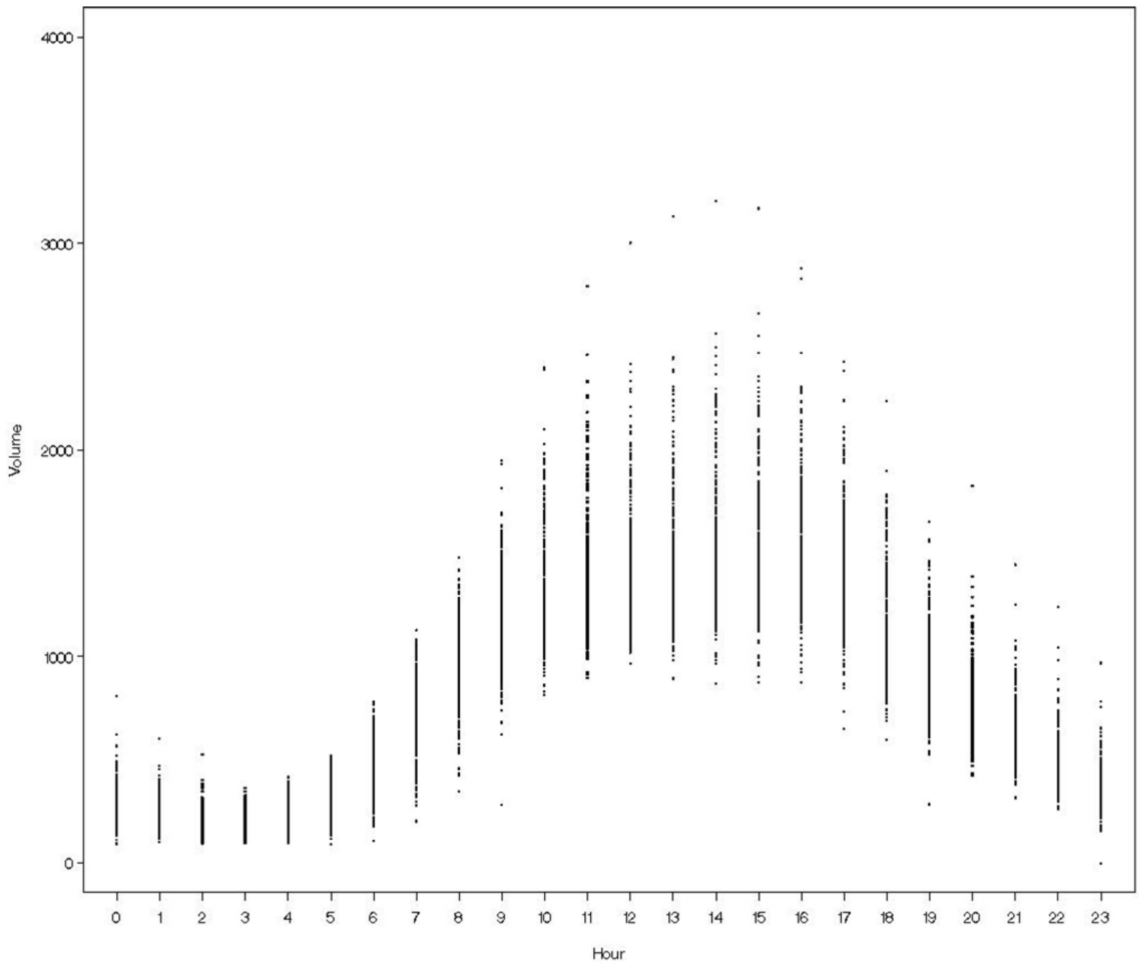
Figure 5-1: Hourly Traffic Volumes for Grave Creek (Oregon), 2002



Note: Some date of ATR records missing during ATR maintenance. The horizontal axis here is the date and hour corresponding to the traffic volume data.

To highlight the variability across hours of the day, Figure 5-2 shows the same data grouped by the hour of the day (0 to 23) the volume was observed. In a given hour, the volume ranged from 100 to 3,000 vehicles per hour. A visual inspection of the plots shows the there is a high degree of variability in the hourly traffic volume data within a day, over the week and over a year. To evaluate the weather impact to the traffic volume, it is critical to estimate the hourly normal traffic volume and the normal traffic volumes were estimated as explained in Chapter 3.

Figure 5-2: Hourly Traffic Volumes for Grave Creek (Oregon) by Hour of Day, 2002



Note: The horizontal axis represents the hour of the day corresponding the hourly traffic volume

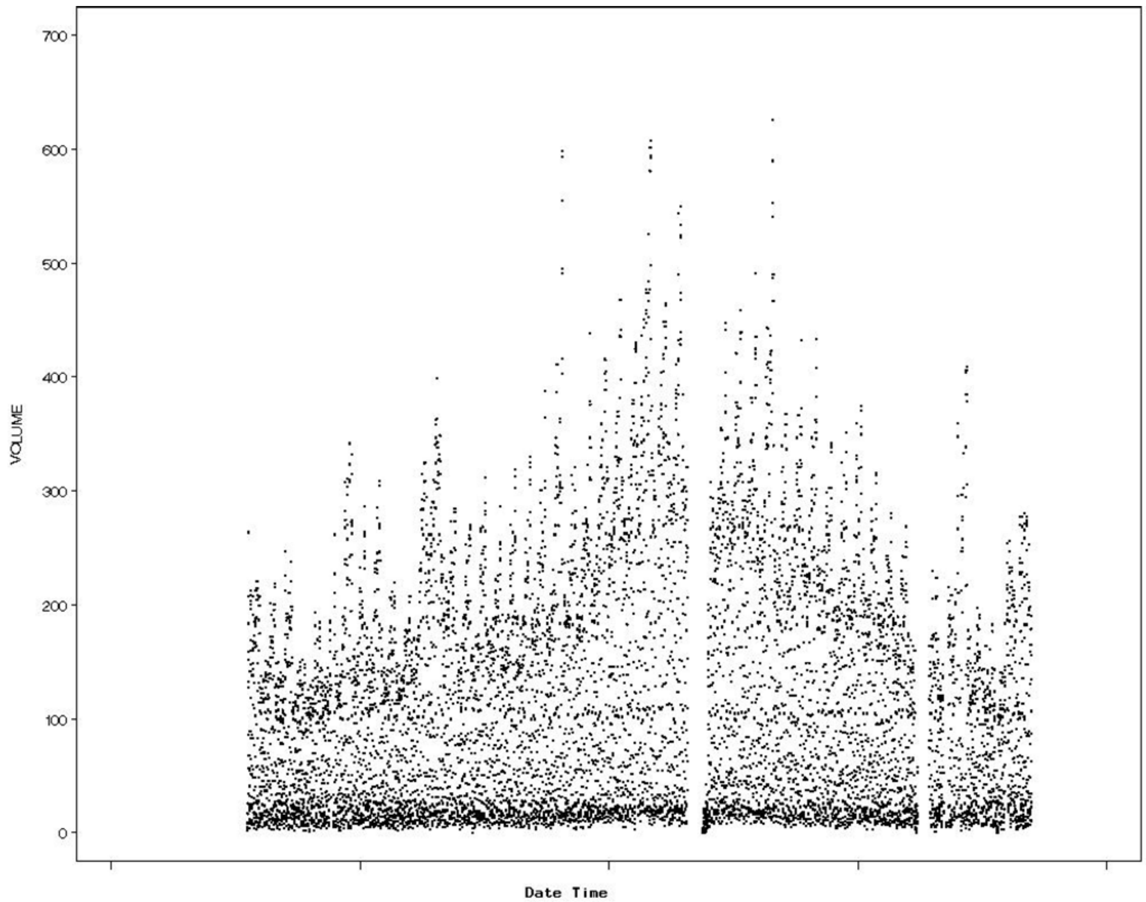
Two different methods have been used to estimate hourly normal traffic volume. The following sections detail the results of the analysis using the two methods.

5.1.1. Volume Methodology One Results for O'Brien

First method to determine the normal volumes used formal year normal weather traffic volumes for the same location during a same or similar hour at the same hour, weekday, and month under the assumption that the traffic volume profile should be similar as the previous year. Considering a holiday may impact hourly traffic volume, two statistical tests (F test and t-test pair sample test) for variance and mean were conducted and did not find any significant impact of a holiday to the traffic volume. The results of this test of significance of holidays on traffic volumes are shown in Appendix F.

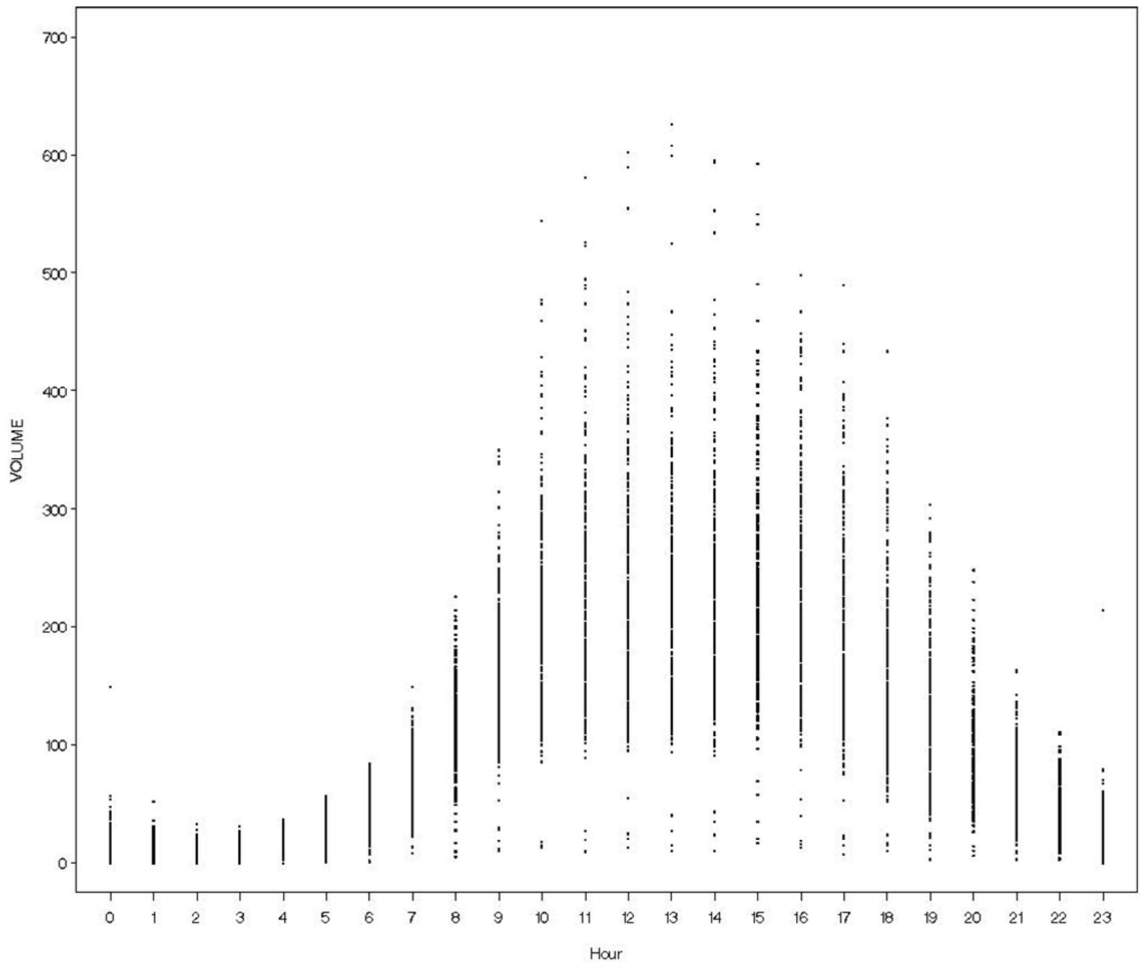
Figure 5-3 and Figure 5-4 show the same trends for the other site (i.e. O'Brien) in Oregon.

Figure 5-3: Hourly Traffic Volumes for O'Brien (Oregon), 2002



Note: Some date of ATR records missing during ATR maintenance. The horizontal axis here is the date and hour corresponding to the traffic volume data.

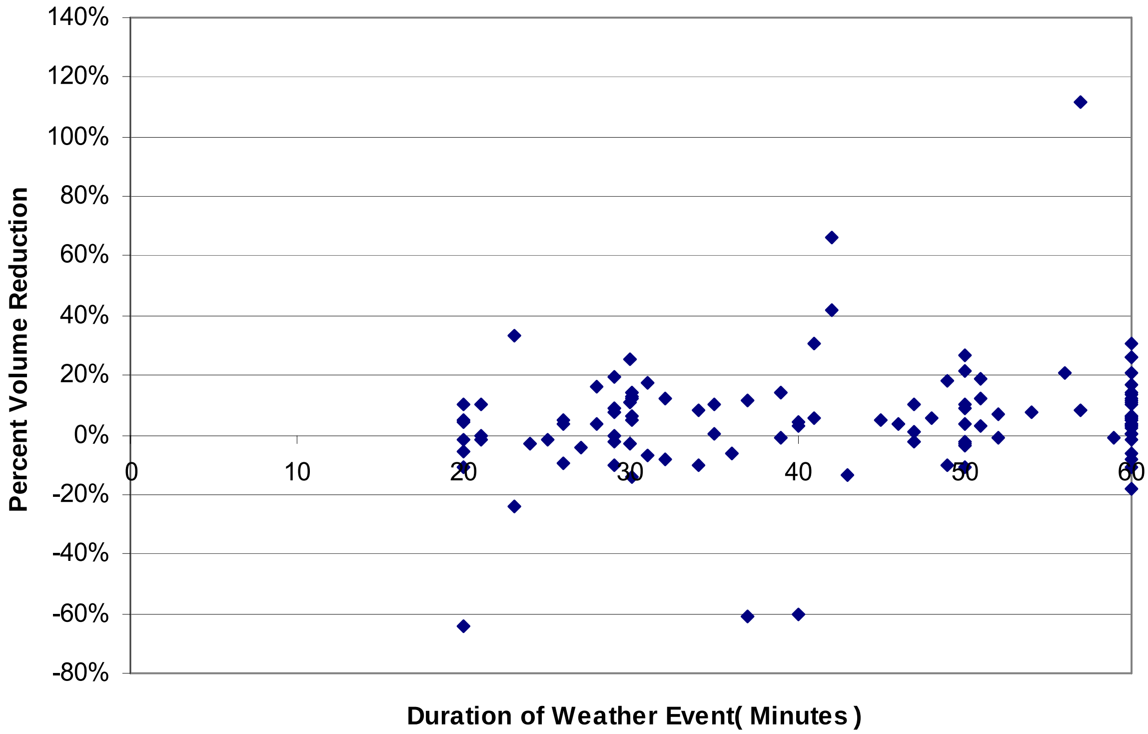
Figure 5-4: Hourly Traffic Volumes for O'Brien (Oregon) by Hour of Day, 2002



Note: The horizontal axis represents the hour of the day corresponding to hourly traffic volume

Rain and snow were the only weather events that the authors could deterministically identify from the weather data collected from both Oregon and Montana. Thus, these two weather events were the focus of this analysis. Figure 5-5 shows the volume changes that were observed for various durations of snow and rain events using data from the Grave Creek site (i.e. 2003 weather events and the normal volumes estimated from corresponding 2002 non-weather volume data). As seen in Figure 5-5, the percentage change in volume (i.e. observed volume – estimated normal volume) is distributed evenly over the horizontal axis. The descriptive statistics of the change in volume estimations shown in Figure 5-5 can be found in Appendix G. This suggested that there may not be a way to conclude statistically whether weather events reduce the traffic volume (i.e. traffic demand) at this site on a rural highway in Oregon.

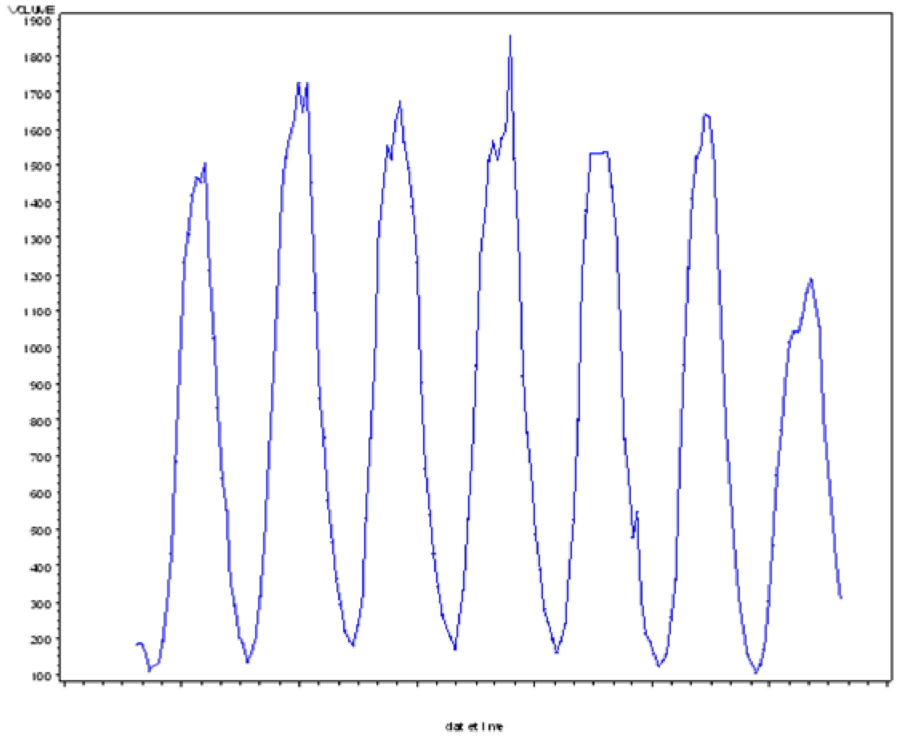
Figure 5-5: Duration of Weather Event and Percent Volume Reduction for Grave Creek (Oregon) using Volume Methodology One



5.1.2. Volume Methodology Two Results for Grave Creek

As an enhancement to the current method, another way to estimate the hourly normal traffic volume was used. This method estimated normal traffic volumes by applying the time series ARIMA model as discussed in Chapter 3. Figure 5-6 shows hourly traffic volumes during one week (January 1-7, 2002) at the Grave Creek ATR site. This trend suggested that the hourly traffic volume can be considered to be a time series. A time series is a series of observations at regular intervals.

Figure 5-6: Hourly Traffic Volumes for Two Lanes for Grave Creek (OR), Jan 1-7, 2002



Note: The horizontal axis represents the date and hour of the day corresponding to the traffic volume data

Figure 5-7 depicts the procedure for using time series model to estimate the traffic volume change during weather events for the Oregon Grave Creek ATR site using 2002 traffic volumes. Through SAS software, the best fit for both of the Oregon sites using the time series model was an auto-regression AR (2) (i.e. the model uses two immediate past observations to predict the next observation). The R^2 for these models were found to be 0.95 and 0.93 for the Grave Creek and O'Brien sites respectively. The model and equation follow:

Model for Grave Creek site: $\hat{V}_t = 867.26 + 1.65 * \hat{V}_{t-1} - 0.72 * \hat{V}_{t-2}$ (R^2=0.95)

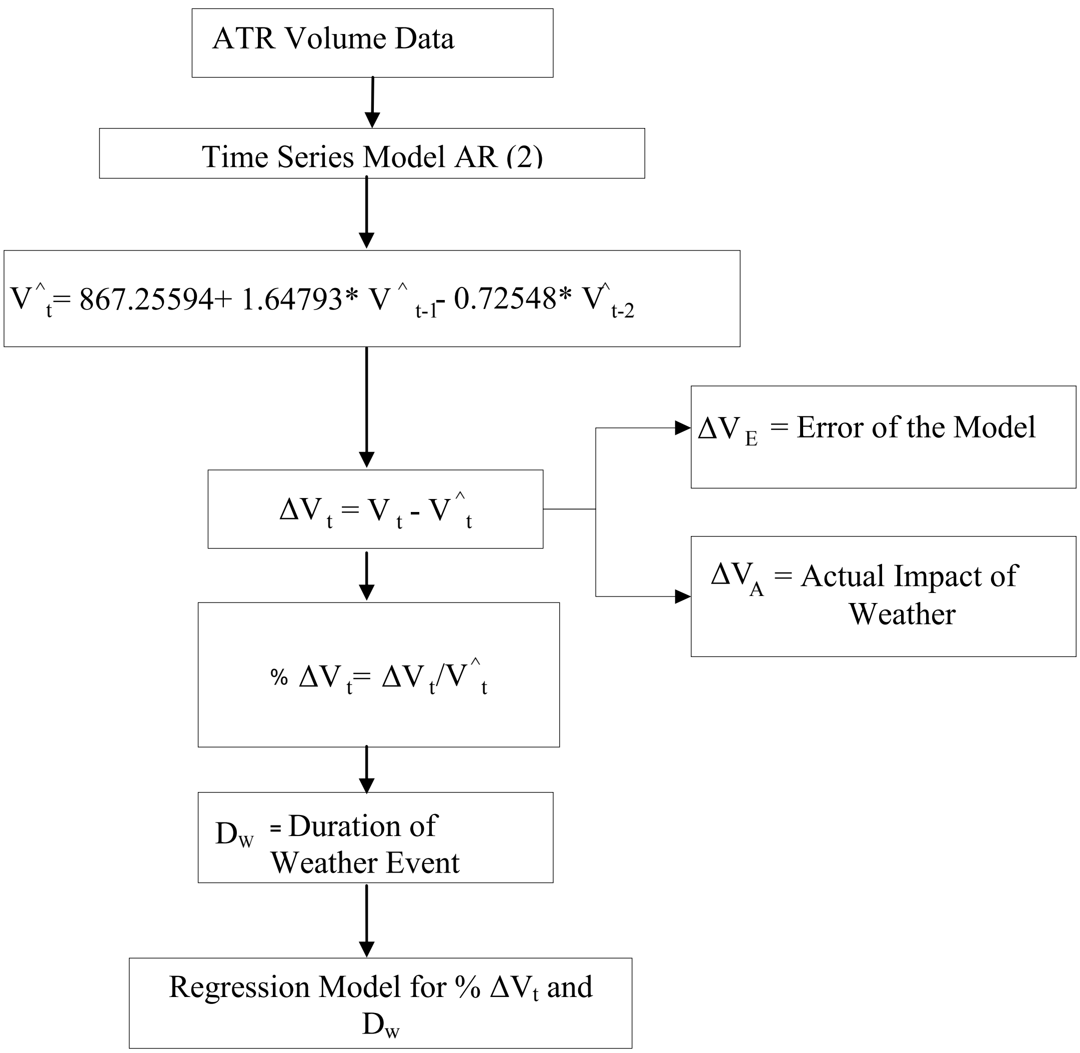
Model for O'Brien site: $\hat{V}_t = 114.90 + 1.43 * \hat{V}_{t-1} - 0.50 * \hat{V}_{t-2}$ (R^2=0.93)

Where

$\hat{V}_t$ = Estimated traffic volume for the hour t.
$\hat{V}_{t-1}$ = Estimated traffic volume for the hour t-1
$\hat{V}_{t-2}$ = Estimated traffic volume for the hour t-2

The traffic volume changes (ΔV_t) were then calculated by deducting the observed hourly traffic volumes (V_t) from the estimated traffic volume ($\hat{V}_t$). This was used to calculate the percentage traffic volume as shown in Figure 5-7. The relationships between duration of rain, snow event and traffic volume change were investigated through a multiple regression approach and found to not be statistically significant. The results of this analysis can be found in Appendix H.

Figure 5-7: Applying Time Series Model to Grave Creek Traffic Volume Data (2002)



Using the models mentioned above to estimate the normal volume during weather events, the change in volume, and percent change in volume were determined. Figure 5-8 shows the distribution of the change in volume for Grave Creek site in Oregon for the year 2002. As seen in Figure 5-8, the percent change in volume is also evenly distributed about the horizontal axis similar to the results found using Volume Methodology One. The descriptive statistics of the change in volume estimations show that there was about an average of 2 percent reduction in traffic volumes during weather events at Grave Creek site with a standard deviation of 14. The descriptive statistics are shown in Table 5-1.

Figure 5-8: Duration of Weather Event and Percent Volume Reduction for Grave Creek (Oregon) using Volume Methodology Two

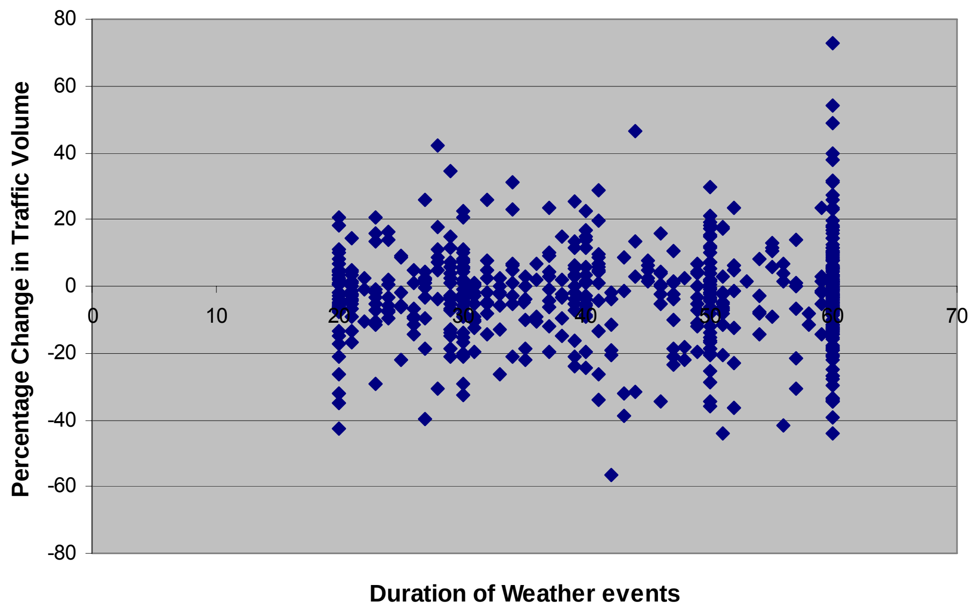


Table 5-1: Descriptive Statistics for the Percentage Change in Volume for Grave Creek Oregon using Methodology Two

%Delta V	
Mean	-2.44
Standard Error	0.58
Median	-2.21
Mode	#N/A
Standard Deviation	14.28
Sample Variance	203.82
Kurtosis	2.58
Skewness	0.20
Range	128.94
Minimum	-56.35
Maximum	72.59
Sum	-1453.19
Count	596.00

Since the mean of the percentage change in volume during weather events was found to be negative, a regression based model was developed. The results of this modeling effort are shown in Table 5-2.

Table 5-2: Regression Model for Grave Creek (Oregon) using Methodology Two Results

Regression Statistics					
Multiple R	0.0143				
R Square	0.0002				
Adjusted R Square	-0.0015				
Standard Error	0.1429				
Observations	596				
ANOVA					
	df	*SS*	*MS*	*F*	*Significa nce F*
Regression	1	0.0024638	0.0025	0.1207	0.73
Residual	594	12.124537	0.0204		
Total	595	12.127001			
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*
Intercept	-0.031	0.02	-1.64	0.10	-0.07
Duration	0.000	0.00	0.35	0.73	0.00

These results do not show a strong correlation between the duration of the weather events and the percentage change in traffic volume. It should be noted that the estimated percentage change in volumes were found to be only about 2 percent and it only represents a change in number of vehicles of about 34 vehicles per hour when the hourly volume is about 1400 vehicles per hour per lane (i.e. the maximum average hourly traffic for this site).

Using the volume methodology two, another site was also analyzed to see whether the results would be more conclusive. The results of this effort are presented in the following section.

5.1.3. Volume Methodology Two Results for O'Brien (Oregon)

The time series model of the O'Brien site as presented earlier is also shown below for quick reference.

Model for O'Brien site: $\hat{V}_t = 114.90 + 1.43 * \hat{V}_{t-1} - 0.50 * \hat{V}_{t-2}$ ($R^2=0.93$)

Where

$\hat{V}_t$ = Estimated traffic volume for the hour t.
$\hat{V}_{t-1}$ = Estimated traffic volume for the hour t-1
$\hat{V}_{t-2}$ = Estimated traffic volume for the hour t-2

The normal volumes during weather events were estimated using the above model for the O'Brien site in Oregon and the change in volume and percentage change in volumes were determined. Figure 5-9 shows the distribution of percentage change in volume with respect to the duration of weather events for O'Brien site in Oregon for the year 2002.

Figure 5-9: Duration of Weather Event and Percent Volume Reduction for O'Brien (Oregon) using Volume Methodology Two

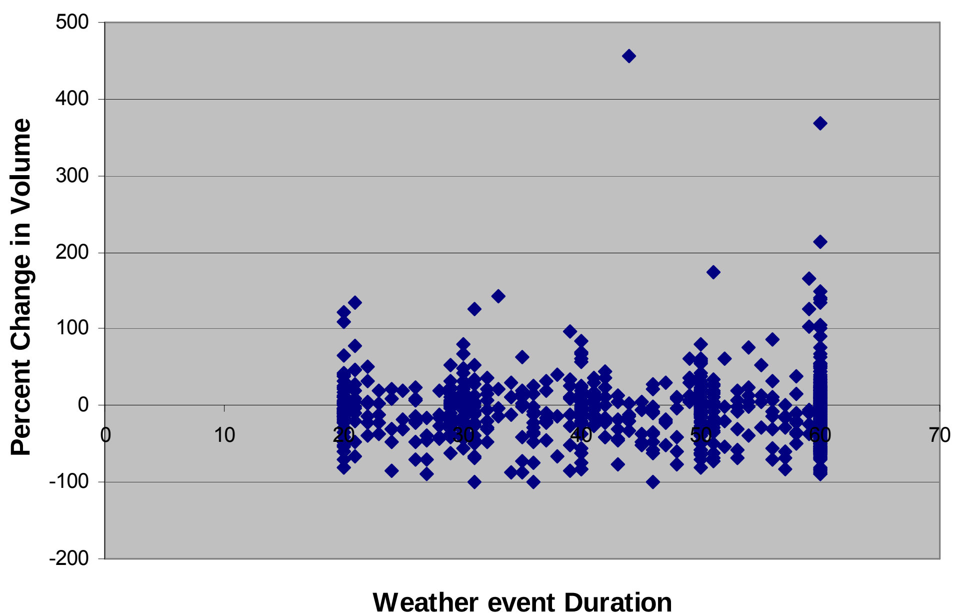


Table 5-3 shows the descriptive statistics of the percentage change in volume for the O'Brien site in Oregon. The mean of the change in volume for this site was found to be about a reduction of 7 percent during weather events. This is significantly greater than the reduction found in the Grave Creek analysis.

The two sites vary in their characteristics including the fact that Grave Creek is a on a highway with two lanes each way while the O'Brien site is on a two-lane rural highway.

Table 5-3: Descriptive Statistics for the Percentage Change in Volume for O' Brien using Methodology Two (Oregon)

% Delta V	
Mean	-7.17
Standard Error	1.53
Median	-8.86
Mode	-100.00
Standard Deviation	44.01
Sample Variance	1937.28
Kurtosis	22.12
Skewness	2.78
Range	556.30
Minimum	-100.00
Maximum	456.30
Sum	-5975.47
Count	833

The percentage change in volume data estimated in this analysis was then modeled using multiple-regression function in SAS®. The results of this effort are presented in Table 5-4.

Table 5-4: Regression Model for O' Brien (Oregon) using Methodology Two Results

Regression Statistics					
Multiple R	0.03				
R Square	0.00				
Adjusted R Square	0.00				
Standard Error	44.02				
Observations	833				
ANOVA					
	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	1619.712	1619.7	0.836	0.361
Residual	831	1610201	1937.7		
Total	832	1611821			
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*
Intercept	-2.586	5.244	-0.493	0.622	-12.879
Duration	-0.100	0.109	-0.914	0.361	-0.314

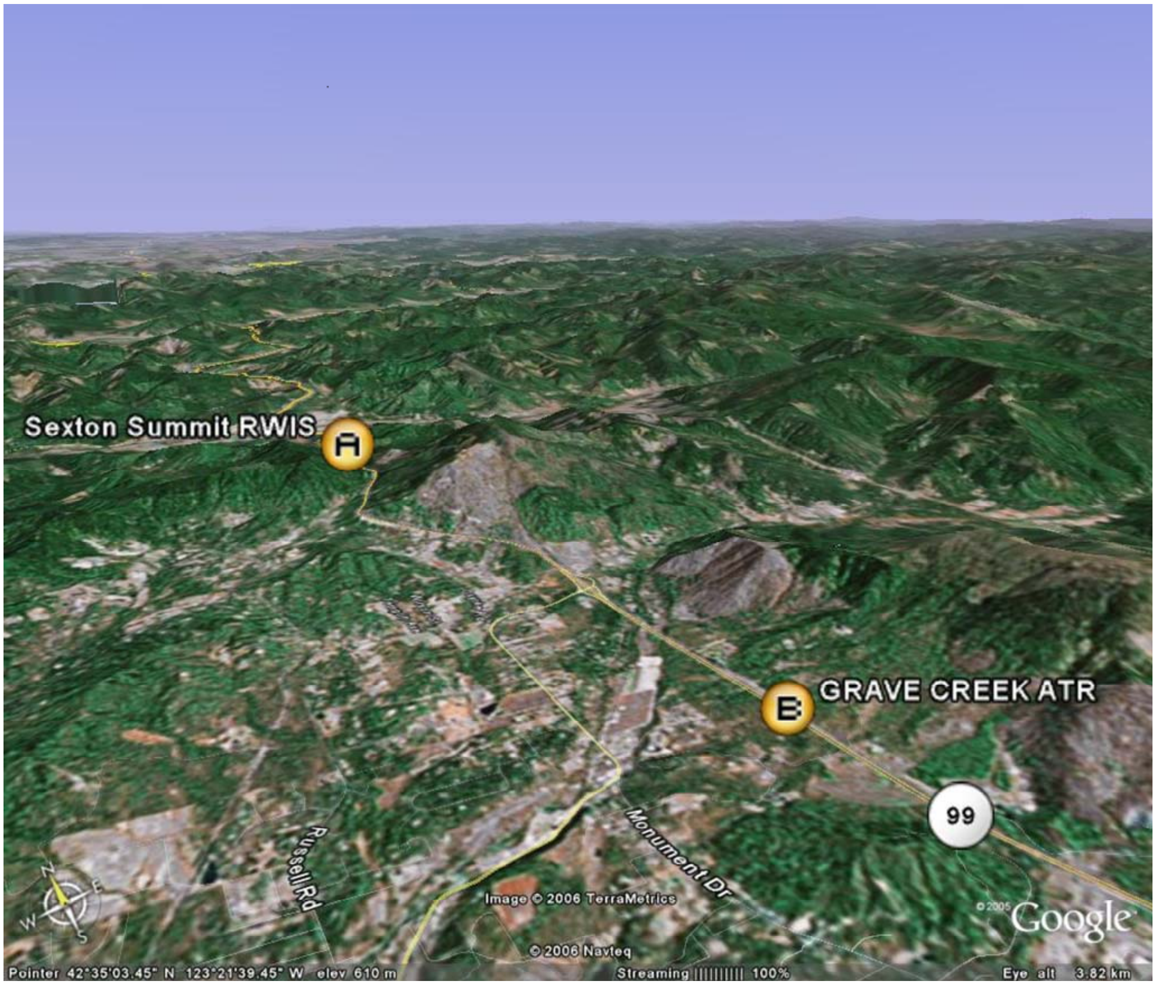
These results do not explain the large variation in the changes in volume that occur during weather events (i.e. -100 percent to + 500 percent).

5.2. Discussion of Volume Results

A number of transformations of the change in volume and interactions between the dependent variables were also investigated. As discussed earlier, a linear correlation between the percentage change in volume and the duration of weather events could not be made for reasons presented in the above sections. These estimated values by the time series model for an hour (e.g. t) in Volume Methodology Two have an error associated with the model. If the impact due to the weather event is within this error attached with the model, this modeling approach will not be able to capture those impacts.

Figure 5-10 shows the relative elevation and distance between the RWIS and ATR stations that were paired for the Grave Creek site analysis in this study. It shows that the five miles between Grave Creek ATR and the Sexton Summit RWIS station could influence the accuracy of determining the weather events and estimating the weather event durations. The closer the RWIS and ATR are located, the better the correlation is expected to be. The O'Brien site had both the RWIS and ATR at the same location, so the distance and elevation effects are minimal. It should also be noted that O'Brien highway segment is a two-lane undivided rural highway and the Grave Creek highway segment is four-lane undivided highway. This may imply that the winter maintenance activities, design factors, and travel patterns for these two highway segments may be significantly different. Further discussions of the results are provided in the next chapter.

Figure 5-10: The Relative Locations of the RWIS and ATR stations for the Grave Creek Site

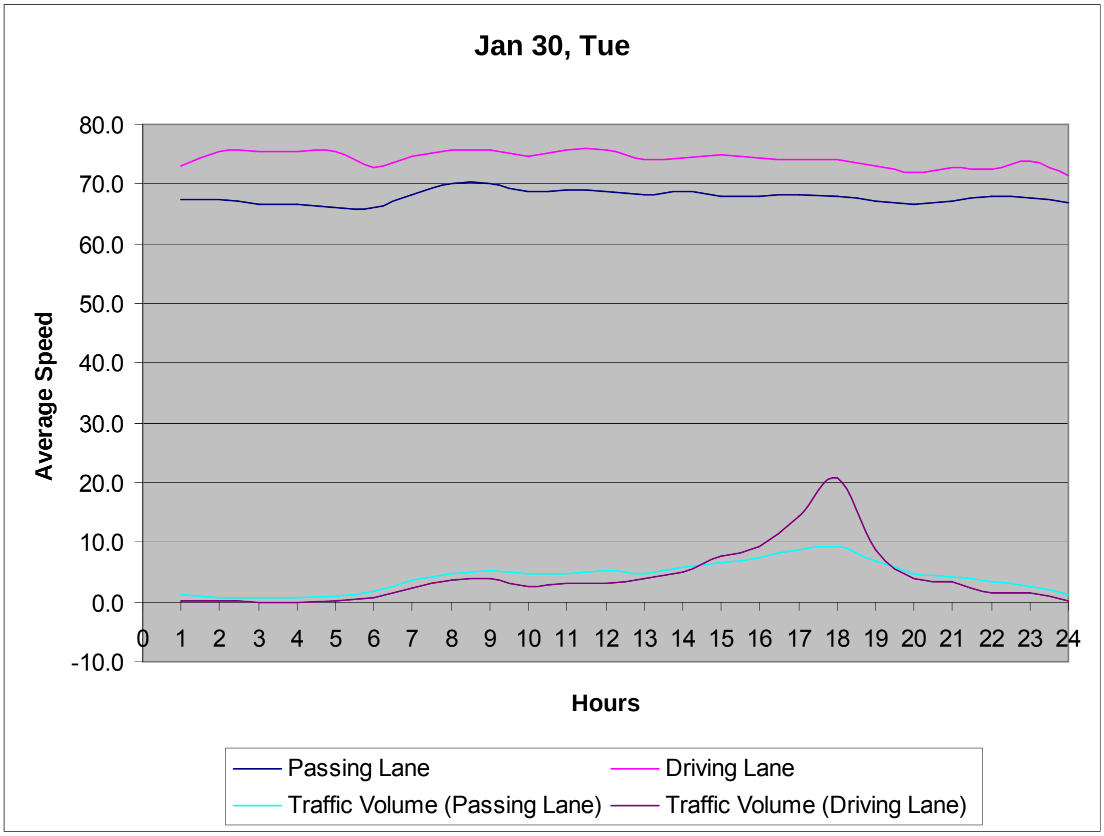


Source: Google Earth®

5.3. Traffic Speed Impact Analysis

Since Oregon ATR data did not include traffic speed data, Montana ATR data was used to evaluate the impact of weather events on traffic speed on rural highways. A review of hourly average travel speed plots shows that the average traffic speed was relatively little variation over the time of day. Figure 5-11 shows an example profile of the average hourly traveling speeds and hourly traffic volumes along the Mossmain site (Montana) for the driving and passing lanes. It is noted that speeds did not significantly reduce when the volume almost doubled in the evenings. Therefore, the average traffic speed for that year and that day without weather event were tried as the normal traffic speed. The results between the two methods of calculating the normal speed did not vary significantly (statistically); thus, the annual average travel speed for the corresponding year was used as the normal speed.

Figure 5-11: Average Hourly Travel Speed Profile over the Time of the Day



Note: The two lines at the bottom portion of the diagram shows the traffic volumes on the passing and driving lanes for reference

In this analysis, it was determined that none of the data included in the analysis represented operations that were congested. This may be clear from the fact that the hourly traffic volumes for the durations of the travel speeds ranged from 227 vehicles per hour per lane to 830 vehicles per hour per lane. This means that there was sufficient roadway capacity at each ATR location for the travel demands during the time periods of the available speed data and no congestion occurred as a result of any speed reductions due to weather events.

Table 5-5 shows the summary of travel speed changes estimated for both rain and snow events and snow events only. Including rain events in the modeling was not desirable as they were obscuring the effect of snow events on travel speeds. Research has also shown that wet pavement caused by rain will not particularly affect the traffic speeds until visibility is also affected (14). Therefore, the regression modeling explained later includes only the snow events.

Table 5-5: Average Speed Changes (*Δs*) between All Weather Events and Snow Events

	Pine Hill		Mossmain	
	ΔS for Driving Lane *for All Events*	ΔS for Driving Lane *for Snow Events Only*	ΔS for Driving Lane *for All Events*	ΔS for Driving Lane *for Snow Events Only*
Mean	-1.76	-4.44	-2.98	-6.09
Standard Error	0.65	1.25	0.43	0.68
Median	-0.08	-6.61	-0.32	-3.39
Mode	-11.84	-11.84	#N/A	#N/A
Standard Deviation	6.74	8.83	5.96	6.76
Sample Variance	45.44	78.02	35.49	45.73
Skewness	-0.86	0.02	-1.46	-0.66
Range	30.91	30.91	29.15	27.44
Minimum	-23.17	-23.17	-25.71	-25.71
Maximum	7.74	7.74	3.44	1.73
Count	108	50	194	99

The impacts of snow events on rural traffic speeds have been summarized and evaluated for each of the data collection sites and are listed in Table 5-6. Overall, a general decrease in traffic speed was observed, with average speed reductions at each location ranging from 6 to 11 mph during snow events. A simple t-test of the average speed reduction revealed that the average speed reduction was significantly different than zero at a 95 percent level of confidence. It should also be noted that the values of speed reductions varied depending on the site.

Table 5-6: Weather Event Traffic Speed Impact Summary

RWIS Location	Number of Events	Average Speed Change	Std. Error Speed Change	Std. Dev. Speed Change	Min. Speed Change	Max.Speed Change	Conf. Level (95%)
Mossmain	99	-6.09	0.68	6.76	-25.71	1.73	1.35
Pine Hill	50	-4.44	1.25	8.83	-23.17	7.74	2.51
Wolf Creek	101	-11.76	0.62	6.28	-22.79	6.87	1.24

A multiple regression analysis of the traffic speed and RWIS weather data was then conducted to evaluate and quantify their relationship. Table 5-7 shows the summary statistics of the model for the Pine Hill (2001 to 2003) data. In the regression model, the relationship between snow event, change in average hourly travel speed, and the duration of the snow event, average wind speed, precipitation rate, road surface temperature was considered. In this analysis, only average wind speed and surface temperature had a statistically significant effect on traffic speed reduction at a 95 percent level of confidence; this model has reasonable explanatory power (R^2=0.56). Other variables considered in this analysis (duration of snow event, precipitation rate) were not statistically related to the reduction of traffic speed. Table 5-7 shows the results of this multiple-regression model.

Table 5-7: Snow Event Traffic Speed Regression Analysis Results for Pine Hill (Montana)

Regression Statistics	
Multiple R	0.75
R Square	0.56
Adjusted R Square	0.52
Standard Error	6.13
Observations	50

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	4	2133.671	533.418	14.203	0.000
Residual	45	1690.089	37.558		
Total	49	3823.76			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-8.321	3.611	-2.304	0.026	-15.595	-1.048	-15.595	-1.048
WN_AVGSPD	0.201	0.094	2.141	0.038	0.012	0.389	0.012	0.389
DURATION	-0.005	0.074	-0.071	0.944	-0.153	0.143	-0.153	0.143
PR_RATE	-0.024	0.028	-0.838	0.407	-0.081	0.033	-0.081	0.033
SF_TEMP	1.200	0.192	6.259	0.000	0.814	1.587	0.814	1.587

Similar modeling was attempted for the other two sites from Montana. The results of this modeling are shown in Table 5-8 and Table 5-9.

Table 5-8: Snow Event Traffic Speed Regression Analysis Results for Mossmain (Montana)

Regression Statistics	
Multiple R	0.27
R Square	0.07
Adjusted R Square	0.03
Standard Error	6.65
Observations	99

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	4	322.321	80.580	1.821	0.131
Residual	94	4158.766	44.242		
Total	98	4481.087			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-6.498	2.376	-2.735	0.007	-11.215	-1.780	-11.215	-1.780
WN_AVGSPD	-0.049	0.036	-1.375	0.172	-0.121	0.022	-0.121	0.022
DURATION	0.154	0.118	1.307	0.194	-0.080	0.388	-0.080	0.388
PR_RATE	-0.018	0.030	-0.586	0.559	-0.077	0.042	-0.077	0.042
SF_TEMP	-0.363	0.221	-1.648	0.103	-0.801	0.074	-0.801	0.074

Table 5-9: Snow Event Traffic Speed Regression Analysis Results for Wolf Creek (Montana)

Regression Statistics	
Multiple R	0.45
R Square	0.20
Adjusted R Square	0.17
Standard Error	5.73
Observations	101

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	4	790.001	197.500	6.014	0.000
Residual	96	3152.904	32.843		
Total	100	3942.906			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-7.979	1.709	-4.668	0.000	-11.371	-4.586	-11.371	-4.586
WN_AVGSPD	-0.011	0.099	-0.109	0.913	-0.208	0.186	-0.208	0.186
DURATION	-0.086	0.036	-2.370	0.020	-0.158	-0.014	-0.158	-0.014
PR_RATE	-0.007	0.005	-1.445	0.152	-0.016	0.003	-0.016	0.003
SF_TEMP	0.413	0.121	3.420	0.001	0.173	0.653	0.173	0.653

As seen in the above modeling results, the change in average hourly travel speeds varied with the sites. However, the average hourly travel speeds during weather events always dropped from the average hourly travel speeds at normal conditions. As part of this study, researchers attempted to develop a model using the change in speed estimations for all three sites together. The results are shown in Table 5-10.

Table 5-10: Snow Event Traffic Speed Regression Analysis Results for All Three Sites

Regression Statistics	
Multiple R	0.41
R Square	0.16
Adjusted R Square	0.15
Standard Error	7.07
Observations	250

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	4	2410.58	602.64	12.05	0.00
Residual	245	12256.87	50.03		
Total	249	14667.44			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-8.387	1.371	-6.120	0.000	-11.087	-5.688	-11.087	-5.688
WN_AVGSPD	0.230	0.059	3.891	0.000	0.114	0.347	0.114	0.347
DURATION	-0.048	0.027	-1.799	0.073	-0.100	0.005	-0.100	0.005
PR_RATE	-0.016	0.005	-2.990	0.003	-0.026	-0.005	-0.026	-0.005
SF_TEMP	0.004	0.001	4.113	0.000	0.002	0.006	0.002	0.006

5.4. Summary of Traffic Impacts Assessment

As shown in the previous section, the hourly travel speed changes during snow events across the three sites analyzed showed consistent reduction in travel speeds during weather events. The speed reduction during rain events was not found to be statistically significant for the three sites included in the travel speed impact study. The quantity of speed reduction was found to be site-specific and dependent on average wind speed and surface temperature.

6. SUMMARY AND RECOMMENDATIONS

This study represents an initial attempt to identify the correlation between severe weather events (rain and snow) and the traffic operations on rural highways. The traffic operations' parameters chosen were traffic volume and speed. Depending on the availability of data on traffic operations at capacity, the impact of weather events on capacity was to be explored.

The lack of available empirical data for at-capacity operations on rural highways made it infeasible to assess the impact of weather events on capacity. Though a correlation between traffic volumes on rural highways and the occurrence of severe weather events could be established, the percentage change in traffic volume during weather events was not found to be conclusive (about 2 and 7 percent reduction in traffic volumes with standard deviations of about 14 and 44). This is largely due to the fact that this analysis involves estimating the expected traffic volumes during weather events, if the weather event did not take place (i.e. normal volumes). The authors tried two different ways of estimating the normal volumes, Volume Methodology Two involving time series showed better results than the Volume Methodology One that used a comparable volume from previous year for normal volume. It should be noted that any estimation involves an error and estimating the normal volumes is no exception. Any error in the estimation of normal volumes gets propagated through the rest of the analysis and affects the results of this effort. The fact that the traffic volumes on these rural highways were not much higher than the traffic volumes for free flow operations, may also have contributed to the inconclusive results from the modeling of change in volume due to weather events. As explained in Chapter 3, hourly traffic volumes represent traffic demands which are not representative of the roadway capacity for rural highways that operate at low volumes.

The estimates of the volume impacts due to severe weather impacts from the current literature are not specific to rural highways and are usually inconclusive. Most peer studies cited in Chapter 2 used annual traffic volume or assumed normal traffic volume and their methods are not suitable for analyzing the rural highway volume changes due to weather events. For the first time in our study, an ARIMA (Autoregressive Integrated Moving Average) time series model was proposed and used to estimate the normal traffic volumes. Limitations such as the lack of available data, pre-defined scope of the study, and constraints of time and effort required for additional analysis, did not allow for a more thorough comparison of the methods to estimate the normal volumes to be completed.

In this study, a correlation between rain events and the changes in hourly average travel speeds could not be established; however, a statistically conclusive correlation between the snow events and the hourly average travel speeds on rural highways was established and a regression model was also developed.

One of the basic assumptions of this study was that the assessed changes in traffic volumes and travel speeds during weather events were solely caused by weather events. This may not always be the case. Normal speed estimations using the first method (i.e. annual average travel speeds using the data from the hours that had no weather event) would generally be affected by travel speed reductions due to incidents other than weather events. The completeness and reliability of the traffic volume and traffic speed evaluation models could be improved by incorporating the lane control and traffic accident data.

This study has developed several models that attempt to explain the traffic volume and travel speed changes. Much has been learned about the methodologies and the data sources during the course of this study that can be explored and applied to a future study. During the factorial analysis of weather impact to the traffic volume and speed, researchers only considered factors of duration of weather event, precipitation rate, wind speed, and surface temperature; the following factors should be considered for inclusion in a future study:

- effects of weekday, weekend in the speed impact assessment;
- other variables such as the vehicle classification in the speed modeling;
- volume and speed data on at-capacity traffic operations on rural highways to assess the capacity impacts of weather events; and
- other data sources to determine the occurrence of weather events other than rain and snow than RWIS data;

The volume and speed change models can also be improved by including more variety of sites with different geographies including road section with significant up or down grades.

APPENDIX A: CODES FOR PROCESSING OREGON ATR DATA

Code Done by: Deepu Philip of WTI

Myfunctions1.h

```
//------------------------------------- myfunctions1.h --------------------------------------
// myfunctions.h contains the structure definition for an rwis and atr entry
//  file contains the utility functions used in the main program
//  the constants used in the program is defined here
//  coded by: deepu philip; 20/07/2004, revision 1
//     added the readin, readhar, readval functions

#include <string.h>
#include <string>
#include <stdlib.h>
#include <stdio.h>
#include <iostream>
#include <fstream>

#define UNKNOWN_INT (int) -9999      // any missing integer values will be identified
#define UNKNOWN_STRING (string)"ABCDEF"   // any missing values will be identified
#define SIZE 500   // define the size of the structure array
#define COLUMNS 28   // how many columns to read
#define HOURSLOTS 24  // number of hour slots available
#define DEBUG FALSE  // debug flag to toggle trace prints

using namespace std;   // for the usage of string

// ATRData structure stores the values read from the data file
struct AtrData {     // General ATR Data structure
  int month;
  int year;
  int date;
  int direction;       // direction of lane
  int volume[HOURSLOTS];  // array to store the volume information
  int lane;          // lane number information
};

// the functions reads in the information from the data file
// and stores in the appropriate entity of the Atr Data structure
// written by Deepu Philip; 21/07/2004
void readin(struct AtrData& holder, char value[50], int pos)
{
   int base = 5;
        holder.volume[pos-base] = atoi(value);
} // end of readin function
```

ATR4.cpp

```
//------------------------------------------------ atr4.cpp-------------------------------------
// The main program for the obtaining ATR file from the stripped info for sites with 4 lanes
//  The functions used here are available in the myfunctions.h file
//  coded by: Deepu philip; 09/10/2004


#include <stdio.h>
#include <iostream>
#include <stdlib.h>
#include <math.h>
#include <cstring>
#include <fstream>
#include "myfunctions1.h"  // include the header files with the functions

using namespace std;  // for the strings

FILE *infile, *ofile;  // pointer for input file and output file

int main(int argc, char *argv[])   // allows to pass the arguments by command line
{
   // varaible declaration block
         AtrData set[SIZE];   // array of structures to hold the data
   char outfile[25]="";   // stores the output name of the dat file
   char inpfile[25]="";   // store the input file of the text file
   char iname[15] = ""; // input file name only
   char tmp[50];  // temp array of characters for reading values in
   int Done = 0;  // logical test variable - set to false
   int month = 0;  // set month
   int year = 0;  // set year

  if(argc > 1) { // command line parameters
    if( !strcmp( argv[1], "-?")) {  // if the user wants to know how to run the program
      cout <<" Usage: atr [input file] [month-mm] [year-yyyy]" <<endl;
      exit(0);
    }
    else {
      strcpy(iname, argv[1]);  // copy output file name from command line
      month = atoi(argv[2]);  // obtain month info
      year = atoi(argv[3]);  // obtain year info;
    } // end of inner if
  }
  else {  // tell the user how to use it
    cout <<" Usage: atr [input file] [month-mm] [year-yyyy]" <<endl;
    exit(1);
```

```
} // end of outer if

sprintf(inpfile, "%s.dat", iname);   // generate the input file name
sprintf(outfile, "%s.csv", iname);   // generate output file name
ifstream infile(inpfile);    // input data file - contains atr unprocessed data

if(!infile) {  // check whether the input file is present in the directory
   cout <<" Cannot open the input file." <<endl;
   exit(1);
}  // end of if

cout <<"\n Reading the value from the data file " <<endl;
cout <<endl;

int index = 0;
int day = 0;
int count = 0;
while(infile) { // until all data is read from the file
         for (int i=1; i<=COLUMNS; i++)  // for all the attributes do
         {
                     infile >> tmp;   // read values to tmp

                       if(index == 0) {  // first column info
                         switch(i) { // start of switch statement
                           case 1: set[count].lane = 1;    // store first lane
                                   break;
           case 2: set[count].direction = atoi(tmp);
                   break;   // direction is stored
           case 3: set[count].month = month;
                   set[count].year = year;
                   set[count].date = atoi(tmp);
                   break;
           case 4: break;   // ignore day of week
         } // end of switch
         if(i >= 5) {  // for all values greater than 5 store the info
            readin(set[count], tmp, i);
         } // end of if
      }  // end of if
      else { // if index is not zero
         if(index == 1) {
           switch(i) { // start of switch statement
                             case 1: set[count].lane = 2;    // store second lane
                                    break;
             case 2: set[count].direction = atoi(tmp);
                    break;   // direction is stored
             case 3: set[count].month = month;
```

```
                set[count].year = year;
                set[count].date = atoi(tmp);
                 break;
          case 4: break;   // ignore day of week
        } // end of switch
      }
      else {
        if(index == 2) {
          switch(i) { // start of switch statement
                      case 1: set[count].lane = 3;    // store third lane
                         break;
            case 2: set[count].direction = atoi(tmp);
               break;   // direction is stored
            case 3: set[count].month = month;
               set[count].year = year;
               set[count].date = atoi(tmp);
                break;
            case 4: break;   // ignore day of week
          } // end of switch
        }
        else {  // it is the third lane
          switch(i) { // start of switch statement
                      case 1: set[count].lane = 4;    // store third lane
                         break;
            case 2: set[count].direction = atoi(tmp);
               break;   // direction is stored
            case 3: set[count].month = month;
               set[count].year = year;
               set[count].date = atoi(tmp);
                break;
            case 4: break;   // ignore day of week
          } // end of switch
        } // end of inner most if
      } // end of outer if - 3

      if(i >= 5) {  // for all values greater than 5 store the info
        readin(set[count], tmp, i);
      } // end of if
    } // end of else
      } // end of for loop - variable j
      index = index + 1;  // increment index
      if(index > 3) {
        index = 0;
  } // end of if
  count = count + 1;
} // end of while
```

```
// for debugging to see whether the data is read in properly
#if !DEBUG
  cout <<endl;
  cout <<" Number of lines read in: " << count <<endl;
  cout <<" The data stored in the structure is given below: " <<endl;
  for(int i=0;i<(count-1);i++)   // print the examples
  {
      cout <<set[i].lane <<" " <<set[i].month <<"-" <<set[i].date <<"-" <<set[i].year <<" "
      <<set[i].volume[0] <<" " <<set[i].volume[1] <<" " <<set[i].volume[2] <<" "
      <<set[i].volume[21] <<" " <<set[i].volume[22] <<" " <<set[i].volume[23] <<endl;
  }
#endif
 cout <<endl;
 infile.close();  // close input file

  int in = 0;
  ofstream out(outfile);
  while(Done != 1) {
    for(int j=0; j<24; j++) {
      out <<set[in].month <<"/" <<set[in].date <<"/" <<set[in].year <<"," <<j <<":" <<"00,"
          <<set[in].volume[j] <<"," <<set[in].lane <<"," <<set[in].direction <<","
          <<set[in+1].volume[j] <<"," <<set[in+1].lane <<"," <<set[in+1].direction <<","
          <<set[in+2].volume[j] <<"," <<set[in+2].lane <<"," <<set[in+2].direction <<","
          <<set[in+3].volume[j] <<"," <<set[in+3].lane <<"," <<set[in+3].direction <<endl;
    } // end of for
    in = in + 4;

    if(in >= (count-1)) {
      Done = 1;
    }
  } //end of while

  out.close();
  fflush(stdout);

return 1;   // ansi c requires the main to return a value

} // end of main program
```

Myfunctions2.h

```
//------------------------------------- myfunctions2.h --------------------------------------
// myfunctions.h contains the structure definition for an rwis and atr entry
//  file contains the utility functions used in the main program
//  the constants used in the program is defined here
//  coded by: deepu philip; 20/07/2004, revision 1
//     added the readin, readhar, readval functions


#include <string.h>
#include <string>
#include <stdlib.h>
#include <stdio.h>
#include <iostream>
#include <fstream>

#define UNKNOWN_INT (int) -9999      // any missing integer values will be identified
#define UNKNOWN_STRING (string)"ABCDEF"   // any missing values will be identified
#define SIZE 100   // define the size of the structure array
#define COLUMNS 28   // how many columns to read
#define HOURSLOTS 24  // number of hour slots available
#define DEBUG FALSE  // debug flag to toggle trace prints

using namespace std;   // for the usage of string

// ATRData structure stores the values read from the data file
struct AtrData {     // General ATR Data structure
  int month;
  int year;
  int date;
  int direction;       // direction of lane
  int volume[HOURSLOTS];  // array to store the volume information
  int lane;          // lane number information
};


// the functions reads in the information from the data file
// and stores in the appropriate entity of the Atr Data structure
// written by Deepu Philip; 21/07/2004
void readin(struct AtrData& holder, char value[50], int pos)
{
    int base = 5;
            holder.volume[pos-base] = atoi(value);
} // end of readin function
```

atr.cpp

```
//------------------------------------------------- atr.cpp-------------------------------------
// The main program for the obtaining ATR file from the stripped info for Siskiyou
//  The functions used here are available in the myfunctions2.h file
//  coded by: Deepu philip; 09/10/2004


#include <stdio.h>
#include <iostream>
#include <stdlib.h>
#include <math.h>
#include <cstring>
#include <fstream>
#include "myfunctions2.h"  // include the header files with the functions

using namespace std;  // for the strings

FILE *infile, *ofile;  // pointer for input file and output file

int main(int argc, char *argv[])   // allows to pass the arguments by command line
{
   // varaible declaration block
          AtrData set[SIZE];   // array of structures to hold the data
   char outfile[25]="";   // stores the output name of the dat file
   char inpfile[25]="";   // store the input file of the text file
   char iname[15] = ""; // input file name only
   char tmp[50];  // temp array of characters for reading values in
   int Done = 0;  // logical test variable - set to false
   int month = 0;  // set month
   int year = 0;  // set year

  if(argc > 1) { // command line parameters
     if( !strcmp( argv[1], "-?")) {  // if the user wants to know how to run the program
       cout <<" Usage: atr [input file] [month-mm] [year-yyyy]" <<endl;
       exit(0);
     }
     else {
        strcpy(iname, argv[1]);  // copy output file name from command line
        month = atoi(argv[2]);  // obtain month info
        year = atoi(argv[3]);  // obtain year info;
     } // end of inner if
  }
  else {  // tell the user how to use it
     cout <<" Usage: atr [input file] [month-mm] [year-yyyy]" <<endl;
     exit(1);
```

```
}  // end of outer if

cout <<"\n Reading the value from the data file " <<endl;
cout <<endl;

sprintf(inpfile, "%s.dat", iname);   // generate the input file name
sprintf(outfile, "%s.csv", iname);   // generate output file name
ifstream infile(inpfile);    // input data file - contains atr unprocessed data

if(!infile) {  // check whether the input file is present in the directory
   cout <<" Cannot open the input file." <<endl;
   exit(1);
}  // end of if

int index = 0;
int day = 0;
int count = 0;
while(infile) { // until all data is read from the file
         for (int i=1; i<=COLUMNS; i++)  // for all the attributes do
         {
                     infile >> tmp;   // read values to tmp

                       if(index == 0) {  // first column info
                         switch(i) { // start of switch statement
                           case 1: set[count].lane = 1;    // store first lane
                                   break;
           case 2: set[count].direction = atoi(tmp);
                   break;   // direction is stored
           case 3: set[count].month = month;
                   set[count].year = year;
                   set[count].date = atoi(tmp);
                   break;
           case 4: break;   // ignore day of week
         } // end of switch
         if(i >= 5) {  // for all values greater than 5 store the info
            readin(set[count], tmp, i);
         } // end of if
      }  // end of if
      else { // if index is not zero
           switch(i) { // start of switch statement
                           case 1: set[count].lane = 2;    // store first lane
                                   break;
           case 2: set[count].direction = atoi(tmp);
                   break;   // direction is stored
           case 3: set[count].month = month;
                   set[count].year = year;
```

```
                    set[count].date = atoi(tmp);
                    break;
                case 4: break;   // ignore day of week
              } // end of switch
              if(i >= 5) {  // for all values greater than 5 store the info
                 readin(set[count], tmp, i);
              } // end of if
           } // end of else
              } // end of for loop - variable j
              index = index + 1;  // increment index
              if(index > 1) {
                 index = 0;
      } // end of if
      count = count + 1;
    } // end of while

// for debugging to see whether the data is read in properly
#if !DEBUG
  cout <<endl;
  cout <<" Number of lines read in: " << count <<endl;
  cout <<" The data stored in the structure is given below: " <<endl;
  for(int i=0;i<(count-1);i++)   // print the examples
  {
      cout <<set[i].lane <<" " <<set[i].month <<"-" <<set[i].date <<"-" <<set[i].year <<" "
      <<set[i].volume[0] <<" " <<set[i].volume[1] <<" " <<set[i].volume[2] <<" "
      <<set[i].volume[21] <<" " <<set[i].volume[22] <<" " <<set[i].volume[23] <<endl;
  }
#endif
 cout <<endl;

  int in = 0;
  ofstream out(outfile);
  while(Done != 1) {
    for(int j=0; j<24; j++) {
      out <<set[in].month <<"/" <<set[in].date <<"/" <<set[in].year <<"," <<j <<":" <<"00,"
          <<set[in].volume[j] <<"," <<set[in].lane <<"," <<set[in].direction <<","
          <<set[in+1].volume[j] <<"," <<set[in+1].lane <<"," <<set[in+1].direction <<endl;
    } // end of for
    in = in + 2;

    if(in == (count-1)) {
       Done = 1;
    }
  } //end of while

  out.close();
```

```
return 1;   // ansi c requires the main to return a value

} // end of main program
```

Myfunctions3.h

```
//------------------------------------ myfunctions3.h --------------------------------------
// myfunctions.h contains the structure definition for an rwis and atr entry
//  file contains the utility functions used in the main program
//  the constants used in the program is defined here
//  coded by: deepu philip; 20/07/2004, revision 1
//     added the readin, readhar, readval functions

#include <string.h>
#include <string>
#include <stdlib.h>
#include <stdio.h>
#include <iostream>
#include <fstream>

#define UNKNOWN_INT (int) -9999      // any missing integer values will be identified
#define UNKNOWN_STRING (string)"ABCDEF"   // any missing values will be identified
#define ASIZE 192    // array size
#define SIZE 96    // number of total data points in the 1-3 format atr data
#define FACTORS 9  // number of factors
#define DEBUG FALSE  // debug flag to toggle trace prints

using namespace std;   // for the usage of string

// ATRData structure stores the values read from the data file
struct AtrData {     // General ATR Data structure
  string date;       // date of the file
  string time;       // time stored in the file
  int field1;        // first field information
  int field2;        // second field information
  int field3;        // third field information
  int field4;        // fourth field information
  int field5;        // fifth field information
  int field6;        // sixth field information
  int field7;        // seventh field information
  int lane;          // lane number
};

// reads the attribute name stores in the structure and returns a string
// coded by deepu philip; 21/07/2004
string readchar(AtrData holder, int pos)
{
        switch(pos)  // for the values of positions
        {
        case 1:
```

```
                return holder.date;   // return date string
                break;
        case 2:
                return holder.time;   // return time string
                break;

        } // end of switch
        return NULL;   // by default if nothing then return null
} // end of readchar()

// reads the values for the continious attribute and returns the float value
float readout(AtrData holder, int pos)
{
        int temp = 0; // local variable - initialize to zero

        switch(pos)  // for each continious attribute position
        {
        case 3:
                temp = holder.field1;
                break;
        case 4:
                temp = holder.field2;
                break;
        case 5:
                temp = holder.field3;
                break;
        case 6:
                temp = holder.field4;
                break;
        case 7:
                temp = holder.field5;
                break;
        case 8:
                temp = holder.field6;
                break;
        case 9:
                temp = holder.field7;
                break;
        case 10:
                temp = holder.lane;
                break;
        } // end of switch

return temp;   // return the integer value of the fields or the lanes
} // end of read out
```

```
// the functions reads in the information from the data file
// and stores in the appropriate entity of the Atr Data structure
// written by Deepu Philip; 21/07/2004
void readin(struct AtrData& holder, char value[50], int pos)
{
        switch(pos)  // for all positions
        {
        case 1:
            if (value=="?") {   // value missing
                holder.date = UNKNOWN_STRING;
            }
            else {
                holder.date = (string)value;  // store the date string
            }
            break;

        case 2:
            if(value=="?") {   // value missing
                holder.time = UNKNOWN_STRING;
            }
            else {
                holder.time = (string)value;  // store the time
            }
            break;

        case 3:
            if(value=="?") {
                holder.field1 = UNKNOWN_INT;
            }
            else {
                holder.field1 = atoi(value);  // store field1 value
            }
            break;

        case 4:
            if(value=="?"){
                holder.field2 = UNKNOWN_INT;
            }
            else {
                holder.field2 = atoi(value);  // store field2 value
            }
            break;

        case 5:
            if(value=="?"){
                holder.field3 = UNKNOWN_INT;
```

```
        }
        else {
                holder.field3 = atoi(value);  // store field3 value
        }
        break;

case 6:
        if(value=="?") {
                holder.field4 = UNKNOWN_INT;
        }
        else {
                holder.field4 = atoi(value);   // store field4 value
        }
        break;

case 7:
        if(value=="?"){
                holder.field5 = UNKNOWN_INT;
        }
        else {
                holder.field5 = atoi(value);  // store field5 value
        }
        break;

case 8:
        if(value=="?"){
                holder.field6 = UNKNOWN_INT;
        }
        else {
                holder.field6 = atoi(value);   // store field6 value
        }
        break;
case 9:
        if(value=="?"){
                holder.field7 = UNKNOWN_INT;
        }
        else {
                holder.field7 = atoi(value);  // store field7 value
        }
        break;
case 10:
        if(value=="?"){
                holder.lane = UNKNOWN_INT;
        }
        else {
                holder.lane = atoi(value);   // store the lane value
```

```
                    }
                    break;

            } // end of switch
} // end of readin()

// generates a random number for shuffling the input data
int randnumgen(void)
{
  float rnum=0.0;
  float srnum=0.0;
  int randnum=0;

  for(int i=0; i<SIZE; i++) {
    rnum = (float) rand() / RAND_MAX;  // obtain random number betwen 0,1
    srnum = rnum * SIZE;   // scale the random number
    randnum = (int) srnum;  // type cast to integer
  } // end of for loop

return randnum;
} // end of randnumgen()
```

SK.cpp

```
//--------------------------------------------------- sk.cpp--------------------------------------
// The main program for the atr file manipulation of Siskiou in Oregon
// The program strips the ATR file with unwanted data and missing information
//  The functions used here are available in the myfunctions3.h file
//  coded by: Deepu philip; 09/10/2004


#include <stdio.h>
#include <iostream>
#include <stdlib.h>
#include <math.h>
#include <cstring>
#include <fstream>
#include "myfunctions3.h"  // include the header files with the functions

using namespace std;  // for the strings

int main(int argc, char *argv[])   // allows to pass the arguments by command line
{
   FILE *ofile;   // file pointer to output file;
   char outfile[35]="";   // stores the output name of the dat file
   char inpfile[35]="";   // store the input file of the text file
```

```
  if(argc != 2) {  // check whether the file name is provided
    cout <<" Usage: sk <filename>" <<endl;
    exit(1);
  }  // end of if

  sprintf(inpfile, "%s.PRN", argv[1]);   // generate the input file name
  sprintf(outfile, "%s.dat", argv[1]);   // generate output file name

  ifstream in(inpfile);  // open the input file
  if(!in) {  // check whether the input file is present in the directory
    cout <<" Cannot open the input file." <<endl;
    exit(1);
  }  // end of if

  ofstream out(outfile);  // open the output file
  if(!out) {
    cout <<" Cannot open the output file." <<endl;
    exit(1);
  }

  char str[200];
  while(in) {   // until all data is read run the loop
    in.getline(str,200);     // read one line at a time from the input file
    if((str[0] == '1') || (str[0] == '2')) { // only get the data with lane information
      if(str[11] != '#') {  // strip all the data without any values
        out <<str <<endl;
      } // end of inner if
    } // end of if
  } // end of while

  cout <<endl;
  cout <<" Completed generating the " <<outfile <<" after stripping unwanted info. " <<endl;
  in.close();  // close input file
  out.close();  // close output file

return 1;   // ansi c requires the main to return a value

} // end of main program
```

Sk4.cpp

```
//--------------------------------------------------- sk4.cpp--------------------------------------
// The main program for the atr file manipulation of Siskiou in Oregon
// The program strips the ATR file with unwanted data and missing information
//  The functions used here are available in the myfunctions3.h file
//  coded by: Deepu philip; 09/10/2004


#include <stdio.h>
#include <iostream>
#include <stdlib.h>
#include <math.h>
#include <cstring>
#include <fstream>
#include "myfunctions3.h"  // include the header files with the functions

using namespace std;  // for the strings

int main(int argc, char *argv[])   // allows to pass the arguments by command line
{
    FILE *ofile;   // file pointer to output file;
    char outfile[35]="";   // stores the output name of the dat file
    char inpfile[35]="";   // store the input file of the text file

   if(argc != 2) {  // check whether the file name is provided
      cout <<" Usage: sk <filename>" <<endl;
      exit(1);
   }  // end of if

   sprintf(inpfile, "%s.PRN", argv[1]);   // generate the input file name
   sprintf(outfile, "%s.dat", argv[1]);   // generate output file name

   ifstream in(inpfile);  // open the input file
   if(!in) {  // check whether the input file is present in the directory
      cout <<" Cannot open the input file." <<endl;
      exit(1);
   }  // end of if

   ofstream out(outfile);  // open the output file
   if(!out) {
      cout <<" Cannot open the output file." <<endl;
      exit(1);
   }

   char str[200];
   while(in) {   // until all data is read run the loop
```

```
    in.getline(str,200);     // read one line at a time from the input file
    if((str[0] == '1') || (str[0] == '2') || (str[0] == '3') || (str[0] == '4')) { // only get the data with
lane information
      if(str[11] != '#') {  // strip all the data without any values
        out <<str <<endl;
      } // end of inner if
    } // end of if
  } // end of while

  cout <<endl;
  cout <<" Completed generating the " <<outfile <<" after stripping unwanted info. " <<endl;
  in.close();  // close input file
  out.close();  // close output file

return 1;   // ansi c requires the main to return a value

} // end of main program
```

APPENDIX B: OREGON ATR DATA STRUCTURE

Data	Columns
Lane Number	1-3
Direction	5
Day of Month	7-8
Day of Week	10
Volume, Hour 1	11-15
Volume, Hour 2	16-20
Volume, Hour 3	21-25
Volume, Hour 4	26-30
Volume, Hour 5	31-35
Volume, Hour 6	36-40
Volume, Hour 7	41-45
Volume, Hour 8	46-50
Volume, Hour 9	51-55
Volume, Hour 10	56-60
Volume, Hour 11	61-65
Volume, Hour 12	66-70
Volume, Hour 13	71-75
Volume, Hour 14	76-80
Volume, Hour 15	81-85
Volume, Hour 16	86-90
Volume, Hour 17	91-95
Volume, Hour 18	96-100
Volume, Hour 19	101-105
Volume, Hour 20	106-110
Volume, Hour 21	111-115
Volume, Hour 22	116-120
Volume, Hour 23	121-125
Volume, Hour 24	126-130

Code	Day of Week
0	Sunday
1	Monday
2	Tuesday
3	Wednesday
4	Thursday
5	Friday
6	Saturday

Code	Direction
1	Northbound
2	Eastbound
3	Southbound
4	Westbound

```
000001500700 497800000000 01 'SISKIYOU JCT.       'JACKSON             'GREEN SPRINGS HWY #21 @ MP 6.61          2    6342
1-1 4 01 3 0000 0001 0000 0000 0005 0009 0025 0043 0043 0070 0041 0054 0051 0058 0058 0044 0062 0049 0032 0040 0029 0015 0007 0009
2-2 2 01 3 0001 0001 0003 0000 0006 0010 0015 0027 0030 0039 0043 0047 0038 0043 0041 0055 0049 0073 0059 0040 0043 0029 0014 0010
1-1 4 02 4 0002 0002 0000 0002 0003 0007 0025 0045 0065 0040 0036 0049 0055 0063 0035 0048 0040 0041 0035 0033 0031 0032 0014 0012
2-2 2 02 4 0002 0002 0001 0000 0009 0011 0020 0014 0041 0037 0051 0042 0060 0047 0036 0044 0077 0065 0055 0041 0051 0031 0019 0011
1-1 4 03 5 0007 0004 0003 0001 0002 0010 0022 0040 0047 0054 0053 0057 0049 0044 0049 0069 0058 0041 0037 0038 0024 0015 0008 0008
2-2 2 03 5 0006 0002 0001 0003 0008 0012 0015 0026 0038 0044 0034 0045 0048 0043 0050 0057 0064 0060 0070 0051 0031 0025 0015 0018
1-1 4 04 6 0007 0000 0003 0004 0001 0005 0005 0016 0034 0034 0056 0052 0060 0041 0058 0058 0053 0064 0045 0052 0033 0027 0011 0008
2-2 2 04 6 0009 0006 0001 0005 0005 0005 0008 0023 0026 0047 0055 0063 0050 0057 0055 0062 0061 0057 0043 0031 0026 0024 0022 0009
1-1 4 05 0 0005 0003 0002 0001 0002 0006 0008 0007 0034 0042 0044 0063 0058 0080 0064 0068 0077 0059 0058 0056 0047 0024 0015 0010
```

```
2-2 2 05 0 0005 0004 0003 0002 0001 0004 0006 0018 0031 0054 0062 0078 0067 0069 0056 0061 0054 0063 0039 0027 0037 0014 0010 0011
1-1 4 06 1 0005 0003 0003 0001 0004 0009 0032 0045 0061 0063 0050 0056 0064 0065 0048 0054 0054 0041 0027 0032 0028 0029 0016 0016
2-2 2 06 1 0006 0001 0001 0002 0008 0007 0021 0021 0042 0048 0047 0046 0050 0047 0047 0046 0058 0053 0042 0048 0034 0030 0010 0008
1-1 4 07 2 0002 0001 0001 0001 0005 0006 0026 0045 0064 0069 0062 0064 0082 0061 0062 0065 0058 0050 0037 0028 0039 0027 0009 0005
2-2 2 07 2 0001 0002 0002 0003 0010 0006 0018 0024 0026 0048 0041 0049 0033 0043 0033 0046 0074 0059 0048 0054 0031 0025 0021 0015
1-1 4 08 3 0001 0005 0001 0002 0003 0012 0023 0050 0055 0052 0051 0052 0046 0057 0052 0046 0056 0051 0047 0029 0031 0031 0010 0004
2-2 2 08 3 0003 0002 0000 0006 0011 0012 0017 0024 0026 0027 0037 0046 0042 0055 0045 0044 0061 0063 0064 0044 0027 0022 0018 0010
1-1 4 09 4 0005 0001 0000 0002 0004 0013 0023 0039 0072 0042 0050 0042 0054 0056 0048 0056 0054 0040 0036 0030 0034 0020 0006 0010
2-2 2 09 4 0006 0001 0001 0004 0007 0011 0007 0021 0033 0033 0051 0046 0048 0044 0046 0051 0052 0074 0052 0048 0034 0024 0018 0014
1-1 4 10 5 0004 0001 0002 0004 0006 0009 0024 0043 0055 0051 0051 0050 0048 0054 0056 0053 0038 0042 0040 0025 0028 0030 0013 0004
2-2 2 10 5 0005 0001 0003 0002 0010 0013 0013 0024 0028 0035 0041 0032 0039 0055 0036 0038 0056 0068 0055 0049 0031 0020 0019 0013
1-1 4 11 6 0005 0012 0004 0004 0004 0009 0009 0026 0024 0050 0046 0050 0059 0055 0053 0057 0038 0042 0042 0033 0034 0034 0013 0008
2-2 2 11 6 0007 0006 0002 0006 0002 0004 0008 0014 0033 0027 0056 0065 0048 0045 0060 0054 0067 0047 0046 0037 0023 0015 0008 0008
1-1 4 12 0 0004 0006 0002 0000 0001 0005 0005 0009 0024 0039 0056 0044 0051 0080 0069 0060 0050 0067 0043 0048 0031 0021 0009 0004
2-2 2 12 0 0008 0007 0000 0003 0001 0006 0007 0013 0021 0025 0043 0045 0048 0044 0070 0062 0049 0039 0042 0029 0021 0015 0012 0012
1-1 4 13 1 0003 0002 0001 0000 0005 0013 0029 0048 0046 0048 0049 0051 0045 0066 0055 0052 0039 0043 0032 0022 0026 0017 0009 0009
2-2 2 13 1 0006 0002 0001 0002 0009 0022 0021 0021 0030 0031 0048 0048 0036 0033 0043 0062 0055 0049 0045 0036 0022 0027 0017 0011
1-1 4 14 2 0004 0000 0001 0001 0003 0010 0030 0047 0056 0047 0054 0059 0055 0048 0061 0034 0061 0053 0025 0028 0025 0026 0008 0005
2-2 2 14 2 0004 0001 0000 0001 0020 0014 0012 0022 0034 0041 0044 0036 0039 0046 0035 0050 0054 0049 0051 0031 0025 0017 0017 0013
1-1 4 15 3 0001 0001 0001 0000 0006 0012 0033 0057 0054 0049 0043 0047 0046 0058 0051 0043 0053 0043 0035 0027 0026 0011 0003 0007
2-2 2 15 3 0007 0002 0001 0000 0014 0018 0015 0015 0038 0034 0035 0053 0049 0044 0044 0034 0048 0062 0042 0043 0028 0035 0016 0009
1-1 4 16 4 0003 0000 0000 0003 0004 0009 0026 0051 0060 0045 0056 0054 0059 0048 0052 0047 0065 0039 0030 0023 0030 0019 0011 0007
2-2 2 16 4 0006 0001 0002 0002 0009 0018 0014 0012 0031 0040 0035 0044 0048 0045 0037 0040 0047 0074 0055 0048 0033 0023 0014 0013
1-1 4 17 5 0002 0001 0001 0000 0004 0015 0032 0043 0050 0049 0053 0050 0056 0057 0063 0051 0066 0047 0038 0029 0027 0026 0010 0004
2-2 2 17 5 0004 0001 0001 0005 0009 0014 0022 0027 0035 0043 0056 0045 0042 0046 0050 0042 0060 0070 0054 0044 0022 0038 0018 0014
1-1 4 18 6 0004 0004 0001 0001 0001 0005 0005 0023 0028 0039 0042 0051 0064 0047 0058 0069 0051 0051 0049 0043 0059 0035 0015 0010
2-2 2 18 6 0008 0003 0001 0001 0003 0006 0008 0017 0034 0044 0053 0058 0060 0063 0070 0059 0049 0063 0040 0025 0036 0019 0016 0011
1-1 4 19 0 0006 0004 0000 0000 0000 0006 0008 0017 0037 0044 0057 0053 0061 0065 0085 0060 0053 0064 0052 0049 0034 0024 0014 0005
2-2 2 19 0 0005 0003 0002 0000 0002 0003 0009 0018 0034 0027 0056 0056 0060 0055 0045 0057 0050 0038 0041 0034 0023 0022 0009 0010
1-1 4 20 1 0002 0002 0002 0003 0007 0014 0028 0047 0056 0046 0048 0057 0060 0043 0046 0062 0049 0040 0024 0018 0018 0012 0006 0002
2-2 2 20 1 0004 0003 0001 0004 0013 0024 0012 0023 0028 0030 0043 0038 0044 0046 0047 0048 0038 0064 0036 0029 0028 0011 0014 0009
1-1 4 21 2 0000 0001 0001 0001 0006 0014 0030 0054 0064 0054 0057 0047 0057 0057 0043 0059 0049 0040 0035 0025 0028 0008 0004 0003
2-2 2 21 2 0006 0004 0001 0003 0020 0026 0016 0021 0035 0043 0039 0058 0026 0043 0037 0054 0041 0061 0050 0038 0025 0018 0012 0005
1-1 4 22 3 0002 0001 0003 0001 0008 0009 0026 0047 0066 0047 0043 0048 0039 0055 0048 0048 0040 0042 0029 0025 0032 0015 0010 0007
2-2 2 22 3 0007 0000 0000 0004 0017 0016 0012 0024 0016 0033 0043 0042 0038 0039 0043 0048 0050 0063 0044 0023 0028 0020 0015 0009
1-1 4 23 4 0002 0000 0001 0000 0007 0008 0030 0040 0057 0044 0038 0045 0048 0062 0047 0073 0045 0029 0030 0018 0022 0006 0006 0001
2-2 2 23 4 0000 0001 0000 0007 0012 0016 0012 0023 0036 0029 0036 0035 0034 0031 0044 0048 0045 0050 0054 0033 0024 0019 0011 0005
1-1 4 24 5 0000 0000 0001 0002 0003 0008 0023 0038 0065 0056 0045 0051 0043 0050 0057 0071 0040 0054 0027 0016 0029 0014 0010 0006
2-2 2 24 5 0004 0005 0002 0001 0009 0019 0010 0019 0030 0040 0040 0045 0041 0051 0044 0051 0040 0063 0051 0037 0048 0024 0014 0008
       .
       .

1-1 4 29 3 0004 0000 0000 0003 0005 0010 0027 0051 0051 0054 0047 0056 0052 0049 0042 0061 0050 0048 0034 0020 0031 0014 0005 0004
2-2 2 29 3 0001 0000 0001 0002 0017 0017 0010 0024 0029 0046 0046 0044 0044 0045 0045 0046 0051 0053 0048 0044 0039 0032 0012 0007
1-1 4 30 4 0003 0002 0001 0002 0003 0010 0028 0046 0052 0047 0042 0054 0055 0063 0053 0045 0050 0036 0031 0027 0030 0017 0006 0005
2-2 2 30 4 0007 0002 0001 0006 0010 0015 0021 0014 0040 0043 0037 0070 0039 0037 0026 0045 0048 0069 0046 0045 0019 0023 0009 0011
1-1 4 31 5 0002 0000 0003 0003 0004 0012 0016 0045 0050 0042 0059 0062 0052 0067 0062 0054 0040 0035 0032 0027 0022 0017 0013 0016
2-2 2 31 5 0004 0002 0004 0007 0010 0013 0010 0016 0038 0025 0045 0036 0042 0033 0043 0066 0067 0055 0063 0051 0034 0031 0030 0039
```

APPENDIX C: MONTANA ATR VOLUME DATA STRUCTURE

```
HESTIA                            1 Site Code
0162  01 00 00 000103             2 aaaa bcd ef gh iiiiiii
00 02 04 06 01 03 05 07           3 V1 V2 V3 V4 V5 V6 V7 V8
                                  4
0000 0000 0000 4440 2             5 jjjj kkkk llll mmmm n
                                  6
                                  7
                                  8
0001 0019 01 01 31 23 59 48       9 pppp qqqq yy mm dd hr mn sc
00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000
00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000
00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000
00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000
00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000
00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000
00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000
00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000
00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000
00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000
00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000
00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000
00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000
00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000
00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000
```

KEY:

```
1. Site Code( e.g. HESTIA)
2. aaaa : Statistical Version( V01.62)
   b: Data separator(period or a space)
   c: 0 = No classification(i.e. weight classification)
      1 = Classification on 8 lanes
      2 = Classification on more than 8 lanes
   d: 0 = No speed data
      1 = Speed data on 8 lanes
      2 = Speed data on more than 8 lanes
   e: 0 = No weight data
      1 = Weight data on 8 lanes
      2 = Weight data on more than 8 lanes
   f: Not Used
   gh: 00 = Statistics per lane
       11 = Statistics in all directions
       22 = Statistics per direction
   iiiiii:  iiii= Number of Table(1 table per bit) Each variable contains 16
                  tables
            ii = Number of variable(CHOIXT1, CHOIXT2,.......)
3. Number of lanes in order
4. jjjj = Start of class( Speed)
   kkkk = End of class ( Speed)
   llll = Class Interval (Speed)
   mmmm = Value of the CHOIXPA variable
   n = Quart used with CHOIXPA
9. pppp = Section
   qqqq = Number of a station
   yy   = year
   mm   = month
  dd   = day
  hr   = hour
  mm   = minutes
  sc   = seconds
```

DATA:

```
DVSH: Distribution of Vehicle Speed By Hour File

Lane 0

Time    00-35 36-40 41-45 46-50 51-55 56-60 61-65 66-70 71-75 76-80 81-85 >85
0-1     00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000
1-2     00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000
2-3     00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000
3-4     00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000
4-5     00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000
5-6     00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000
6-7     00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000
***     00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000
***     00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000
***     00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000
***     00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000
20-21   00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000
21-22   00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000
22-23   00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000
23-24   00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000

Lane 2
Time    00-35 36-40 41-45 46-50 51-55 56-60 61-65 66-70 71-75 76-80 81-85 >85
0-1     00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000
1-2     00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000
2-3     00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000
3-4     00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000
***     00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000
***     00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000
***     00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000
21-22   00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000
22-23   00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000
23-24   00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000

Lane 4 ....
Lane 6 ....
Lane 1 ....
Lane 3 ....
Lane 5 ....

Lane 7

Time    00-35 36-40 41-45 46-50 51-55 56-60 61-65 66-70 71-75 76-80 81-85 >85
0-1     00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000
1-2     00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000
2-3     00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000
3-4     00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000
***     00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000
***     00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000
***     00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000
21-22   00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000
22-23   00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000
23-24   00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000
```

APPENDIX D: MONTANA ATR SPEED DATA STRUCTURE

```
        HESTIA                           1 Site Code
        0162  01 00 00 000103            2 aaaa bcd ef gh iiiiii
        00 02 04 06 01 03 05 07          3 V1 V2 V3 V4 V5 V6 V7 V8
                                         4
        0000 0000 0000 4440 2            5 jjjj kkkk llll mmmm n
                                         6
                                         7
                                         8
              0001 0019 01 09 04 23 59 11      9 pppp qqqq yy mm dd hr mn sc
                                                        Lane
Hour 00       00000 00000 00000 00000 00000 00000 00000 00   Flow Class 01 to Class 07
              00000 00000 00000 00000 00000 00000 00000      Flow Class 08 to Class 14
              00000 00000 00000 00000 00000 00000 00000 02
              00000 00000 00000 00000 00000 00000 00000
              00000 00000 00000 00000 00000 00000 00000 04
              00000 00000 00000 00000 00000 00000 00000
              00000 00000 00000 00000 00000 00000 00000 06
              00000 00000 00000 00000 00000 00000 00000
              00001 00039 00022 00000 00002 00000 00000 01
              00000 00014 00000 00000 00000 00005 00002
              00000 00002 00002 00000 00000 00000 00000 03
              00000 00001 00000 00000 00000 00000 00000
              00000 00000 00000 00000 00000 00000 00000 05
              00000 00000 00000 00000 00000 00000 00000
              00000 00000 00000 00000 00000 00000 00000 07
              00000 00000 00000 00000 00000 00000 00000
Hour 01       00000 00000 00000 00000 00000 00000 00000 00
              00000 00000 00000 00000 00000 00000 00000
              00000 00000 00000 00000 00000 00000 00000 02
              00000 00000 00000 00000 00000 00000 00000
              00000 00000 00000 00000 00000 00000 00000 04
              ...
              ...
```

KEY:

```
      1. Site Code( e.g. HESTIA)
      2. aaaa : Statistical Version( V01.62)
         b: Data separator(period or a space)
         c: 0 = No categories
            1 = categories on 8 lanes
            2 = categories on more than 8 lanes
         d: 0 = No speed data
            1 = Speed data on 8 lanes
            2 = Speed data on more than 8 lanes
         e: 0 = No weight data
            1 = Weight data on 8 lanes
            2 = Weight data on more than 8 lanes
         f: Not Used
         gh: 00 = Statistics per lane
             11 = Statistics in all directions
             22 = Statistics per direction
         iiiiii:  iiii= Number of tableau(1 table per bit)
                  ii = Number of variable(CHOIXT1, CHOIXT2,.......)
                  Each variable contains 16 tables.
                  Ex: 000203: 03 = CHOIXT3
                              0002 = Tale 2 : FI28
      3. Number of lanes in order
      5. jjjj = Start of class( Speed)
         kkkk = End of class ( Speed)
```

```
    llll = Class Interval (Speed)
    mmmm = Value of the CHOIXPA variable
    n = Quart used with CHOIXPA
 9. pppp = Section
    qqqq = Number of a station
    yy   = year
    mm   = month
    dd   = day
    hr   = hour
    mm   = minutes
    sc   = seconds
```

APPENDIX E: TRAFFIC VOLUME DATA CONVERSION

Vehicle Classification List

With the Hestia units it is an error bin. The diamond files had a *.bin extension and was run through TRAFMAN®.

	Vehicle Classification	PCU Equivalents
1	Motorcycles	1
2	Cars	1
3	Pickup trucks	1
4	Buses	1.2
5	Two axle six tire Single Unit trucks	1.2
6	Three axle Single Unit trucks	1.2
7	Four or more axle Single Unit trucks	1.2
8	Four or fewer axle single trailer trucks	1.2
9	Five axle single trailer trucks	1.2
10	Six or more axle single-trailer trucks	1.2
11	Five or fewer axle multi-trailer trucks	1.2
12	Six axle multi-trailer trucks	1.2
13	Seven or more axle multi-trailer trucks	1.2
14	With the Diamond files this bin is for vehicles that do not fit any other bin	1.2

APPENDIX F: TEST OF SIGNIFICANCE OF HOLIDAYS ON HOURLY TRAFFIC VOLUMES FOR GRAVE CREEK SITE

```
mlk_day=January 21, 2002
pres_day=February 18, 2002
dst_beg=April 7, 2002
mem_day=May 27, 2002
ind_day=July 4, 2002
lab_day=September 2, 2002
col_day=October 14, 2002
dst_end=October 27, 2002
elec_day=November 5, 2002
vet_day=November 11, 2002
thks_day=November 28, 2002
xmas_day=December 25, 2002
```

dn	DATE	_TYPE_	_FREQ_	SumV	MeanV
1	1/1/2002	0	24	16772	698.8333
2	1/2/2002	0	24	21261	885.875
3	1/3/2002	0	24	21341	889.2083
4	1/4/2002	0	24	21938	914.0833
5	1/5/2002	0	24	19767	823.625
6	1/6/2002	0	24	18375	765.625
7	1/7/2002	0	24	15459	644.125
8	1/8/2002	0	24	17048	710.3333
9	1/9/2002	0	24	17354	723.0833
10	1/10/2002	0	24	17833	743.0417
11	1/11/2002	0	24	17902	745.9167
12	1/12/2002	0	24	15752	656.3333
13	1/13/2002	0	24	15280	636.6667
14	1/14/2002	0	24	15140	630.8333
15	1/15/2002	0	24	16778	699.0833
16	1/16/2002	0	24	16708	696.1667
17	1/17/2002	0	24	17228	717.8333
18	1/18/2002	0	24	19343	805.9583
19	1/19/2002	0	24	15359	639.9583
20	1/20/2002	0	24	14508	604.5
22	1/22/2002	0	24	15801	658.375
23	1/23/2002	0	24	16800	700
24	1/24/2002	0	24	17779	740.7917
25	1/25/2002	0	24	17986	749.4167
26	1/26/2002	0	24	13693	570.5417
27	1/27/2002	0	24	12537	522.375
28	1/28/2002	0	24	14226	592.75
29	1/29/2002	0	24	16339	680.7917
30	1/30/2002	0	24	16678	694.9167
31	1/31/2002	0	24	17147	714.4583
32	2/1/2002	0	24	18800	783.3333
33	2/2/2002	0	24	16216	675.6667
34	2/3/2002	0	24	14824	617.6667

21	1/21/2002	0	24	16280	678.3333
49	2/18/2002	0	24	19811	825.4583
151	5/27/2002	0	24	27355	1139.792
190	7/4/2002	0	24	17295	720.625
250	9/2/2002	0	24	26627	1109.458
293	10/14/2002	0	24	18696	779
306	10/27/2002	0	24	20517	854.875
315	11/5/2002	0	24	19337	805.7083
321	11/11/2002	0	24	19284	803.5
338	11/28/2002	0	24	21338	889.0833
366	12/25/2002	0	24	13606	566.9167

F-Test Two-Sample for Variances

	Variable 1	*Variable 2*
Mean	851.265	833.8864
Variance	21622.36	28610.38
Observatio	283	11
df	282	10
F	0.755752	
P(F<=f) on	0.217429	
F Critical o	0.536376	

t-Test: Two-Sample Assuming Unequal Variances

	Variable 1	Variable 2
Mean	851.2650177	833.8863636
Variance	21622.36221	28610.37711
Observations	283	11
Hypothesized Mean Differe	0	
df	11	
t Stat	0.335864241	
P(T<=t) one-tail	0.371646111	
t Critical one-tail	1.795884814	
P(T<=t) two-tail	0.743292222	
t Critical two-tail	2.200985159	

There is a significant difference in variances between holiday and non-holiday hourly traffic volume in 2002.

There is no significant deference in mean hour volume between holiday and non-holiday traffic volume in 2002.

APPENDIX G: ESTIMATED PERCENTAGE CHANGE IN VOLUME USING VOLUME METHODOLOGY ONE

%Delta V	
Mean	4.41
Standard Error	3.24
Median	-0.77
Mode	#N/A
Standard Deviation	19.43
Sample Variance	377.39
Kurtosis	9.32
Skewness	2.82
Range	99.19
Minimum	-23.25
Maximum	75.94
Sum	158.76
Count	36.00

It should be noted that the mean percent change in volume during weather events was found to be about positive 4 percent (i.e. the volume increased by 4 percent during weather events). The overall traffic growth between 2003 and 2003 was found to be less than 2 percent.

APPENDIX H: REGRESSION ANALYSIS

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.014253558
R Square	0.000203164
Adjusted R Square	-0.001479996
Standard Error	0.142869444
Observations	596

ANOVA

	df	SS	MS	F	ignificance F
Regression	1	0.002464	0.002464	0.120704	0.728395
Residual	594	12.12454	0.020412		
Total	595	12.127			

	Coefficients	tandard Err	t Stat	P-value	Lower 95%	Upper 95%	ower 95.0%	Ipper 95.0%
Intercept	-0.030529014	0.018635	-1.638285	0.101892	-0.067127	0.006069	-0.067127	0.006069
R_S	0.000142323	0.00041	0.347425	0.728395	-0.000662	0.000947	-0.000662	0.000947

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