Impact of Winter Road Conditions on Highway Speed and Volume

by

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Author's Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Abstract

Several past studies have attempted to quantify the impact of winter weather conditions on highway mobility in terms of traffic volume, speed, and capacity. While consistent in their general findings, these studies have shown considerably different results in terms of effect size and contributing factors. More importantly, most of these studies have not attempted to model the effects of winter maintenance operations on mobility or isolate these effects from those due to snowstorm characteristics, rendering their results and the proposed methods of limited use for estimating the benefits of maintenance activities. This research attempts to address this gap through a statistical analysis of a data set that is unique in terms of spatial and temporal coverage and data completeness. The data set includes both event based and hourly observations of road weather and surface conditions, maintenance operations, traffic volume and speed, as well as several other measures, from 21 highway sections across the province of Ontario.

Event based information is available for six winter seasons (2000 to 2006) at 19 of the sites. For this event based data a matched pair technique was employed to determine the changes in traffic volumes and speeds under matched conditions with and without snow events. A regression analysis was subsequently performed to relate the changes in traffic volume and speed over an event to changes in various contributing factors such as highway type, snow event characteristics and road surface conditions. A case study was conducted to illustrate the application of the developed models for quantifying the mobility impact of road surface condition and the mobility benefit of winter maintenance operations.

Complete hourly records were available for all 21 sites for three winter seasons. This was used to perform the evaluation on an hourly basis. A matching technique is employed to assign hour-by-hour median speeds observed under typical weather and road surface conditions to each hour of a snowstorm event. A regression analysis is subsequently performed to relate changes from average hourly speed to various contributing factors such as highway type, weather conditions and maintenance operations. Effects of maintenance operations are represented by an intermediate variable called road surface condition index (RSI). A case study is conducted to illustrate the application of the developed models for quantifying the mobility impact of winter snowstorms and the mobility benefit of maintenance operations.

The models developed in these analyses confirmed the relationships between weather variables and traffic volume and speed described in the literature. In addition a strong association between road surface condition and traffic volumes and speed was identified.

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List of Abbreviations

ARIMA	Autoregressive Integrated Moving Average
ASOS	Automated Surface Observing System
ATR	Automatic Traffic Recorder
AWOS	Automated Weather Observation System
EC	Environment Canada
HCM	Highway Capacity Manual
RSC	Road Surface Condition
RSI	Road Surface Index
RWIS	Road Weather Information System
TDM	Transportation Demand Management
WAF	Weather Adjustment Factor
WRM	Winter Road Maintenance

1 Introduction

Ontario receives a widely varying amount of snow each year. Typically, Southwestern Ontario receives the lowest annual average snowfalls e.g., Chatham-Kent at 79.2 cm, while Northeastern Ontario receives some of the largest annual average snowfalls e.g., Timmins at 313.4 cm [1].

These snowfalls have a variety of impacts on day to day life in Ontario. One of which is their impact on our transportation systems. Over $1 billion is spent annually in Canada on winter road maintenance (WRM) operations [2].

The benefits of WRM are intuitively clear to most of us. They keep our roadways in safe and reliable driving condition by minimizing weather-induced disruptions to our daily lives. They ensure that emergency services are continually delivered where and when we need. Moreover, they enable sustained health of our modern society and productivity of our economy through continued mobility.

However, what is not clear is the magnitude of these benefits. How much safer can WRM operations make a roadway? How much travel time can be saved with WRM? What is the effect of WRM on people’s travel decisions? What is the end economic value of WRM?

Many attempts have been made in the past to address some of these questions related to the safety and mobility benefits of WRM [3] [4] [5] [6] [7]. Past efforts have focused on the safety related issues and benefits [8] [9]. In addition, some studies have been conducted on the impact to highway mobility resulting from winter storms. However, for these efforts the focus has typically been on the effects of various atmospheric factors with little consideration of the effects of WRM activities. As a result, there lacks a general methodology, or reliable model, that can be used to quantify the mobility effects of winter storms and benefits of WRM.

Without sound benefit-estimation methods, WRM cannot be placed within the same framework for the assessment of other types of transportation investments such as construction of new roads and rehabilitation and maintenance of the existing roads, and receive the funding priority that it warrants. This knowledge gap makes it difficult to develop communication materials to convey the justification for consistent and adequate funding for winter maintenance operations.

1.1 Research Objective

The objective of this research is twofold:

1. to quantify the mobility impact of winter storms in terms of impact to volume and speed; and,
2. to explore applications of these findings including to quantify potential mobility benefits of WRM activities.

This study makes use of a data set that comprises atmospheric, road surface and traffic conditions at 21 highway sites throughout Ontario, Canada totaling nearly 60,000 snow storm hours and 4,800 site-event pairs. (Site-event pairs are defined as a winter weather event (e.g., a snow storm) at a particular site.) The site-event pairs form an event based data set while the hourly records form an hourly data set.

Two separate approaches are taken to satisfy these objectives. First, using the event based data set a regression analysis estimates average reduction in volume and median speed over the course of a snow event as a function of temperature, wind speed, visibility, total precipitation over the event, road surface index (RSI) and time of day.

Second, using the hourly data set, regression analysis is employed to estimate average reduction in median speed for each hour of a snow event as a function of temperature, wind speed, visibility, precipitation, RSI, highway type and time of day.

While the bulk of the data includes only free flow conditions (15 “rural” sites), some data does span congested conditions (4 “urban” sites). This distinction between urban and rural sites used throughout this paper but is more a convenient descriptor of the traffic patterns observed than a strict definition of the site location.

1.2 Organization

The remainder of this paper is organized into the following seven chapters:

- Chapter 2 explores the existing literature on how adverse weather and road surface conditions affect highway volume and speed.
- Chapter 3 reviews the basic methodology used and describes the sources of data assembled for this research
- Chapter 4 describes the data processing performed to develop the research data sets and outlines the contents of those datasets
- Chapter 5 investigates the impact of winter road conditions on highway volume
- Chapter 6 investigates the impact of winter road conditions on highway speed
- Chapter 7 considers the overall mobility impact of the volume and speed effects from Chapters 5 and 6
- Chapter 8 provides the final conclusions and commentary

2 Literature Review

Several past studies have investigated the relationship between winter weather and highway volume or speed. Some of these studies have explicitly considered road surface condition as a contributing factor to volume or speed reduction. This has typically been done with the use of an indicator variable to specify snow covered or not snow covered.

The review below summarizes key industry reference material and several relevant studies conducted over the past 20 years.

2.1 Effect of Winter Conditions on Traffic Volume

2.1.1 Hanbali and Kuemmel

Hanbali and Kuemmel studied 11 rural and suburban highways in the United States. Each of the highways was equipped with an automatic traffic recorder (ATR) and was classified according to average daily traffic and by weekday or weekend. These study sites were chosen randomly for an earlier research project. [3]

TABLE 1 Automated Continuous Count Stations

State	County	Highway	Station#	Location
NewYork	Wayne	STH 104	3732	0.9 Mile E. of RT 14 (Sodus Bay)
NewYork	Monroe	STH 590	4342	0.6 Mile N. of RT 286 (Seabreeze)
NewYork	Onondaga	I - 81	3311	0.8 Mi. N. of Cortland-Onondaga C.L.
NewYork	Steuben	STH 17	6441	NE of S. JCT. of RT 415
Wisconsin	Walworth	USH 12	64-0002	Lake Geneva
Wisconsin	Kenosha	STH 50	30-6109	0.2 Mile W. of USH 45 (Salem)
Wisconsin	Waukesha	I - 43	67-0010	Crowbar RD overpass (Crowbar)
Minnesota	Olmsted	TH 14	212	E. CR 104 Rochester
Minnesota	Olmsted	TH 52	188	S. of ORONOCO
Illinois	Ogle	I - 39	205	S. of CH 20 (Lindenwood)
Illinois	Lee	Ill 38	280	W. of Ashton

Figure 1: Study Sites, Reproduced from Hanbali and Kuemmel Table 1

Snowfall was categorized by total amount and snow storms were divided based on whether or not they occurred in a peak or off peak period. Normal conditions during an analogous period were established and the difference in volume between normal and snow event periods were evaluated using a “snow reduction factor”. [3]

Snow (mm)	Time of Day	Average Traffic Reductions (%)					
		(a)	(b)	(c)	(d)	Range	
< 25	1	8	10	11	12	8-12	Rural & Suburb:
	2	7	8	9	10	7-10	
	3	12	15	16	17	12-17	- Freeways:
	4	7	8	9	11	7-11	(a)11,000-20,000
	5	11	12	13	13	11-13	(b)21,000-30,000
	6	27	29	31	31	27-31	
	7	23	23	21	19	19-23	- Highways:
25-75	1	14	16	21	23	14-23	(c) 3,000- 6,000
	2	11	13	17	18	11-18	(d) 7,000-10,000
	3	13	15	22	25	13-25	
	4	12	12	14	15	12-15	Temperature Range:
	5	23	25	28	31	23-31	
	6	32	35	38	41	32-41	-13°C to +10°C
	7	30	32	35	36	30-36	
75-150	1	28	30	31	31	28-31	
	2	18	20	19	21	18-21	
	3	36	38	38	39	36-39	
	4	21	23	25	25	21-25	
	5	40	42	43	43	40-43	
	6	42	43	45	47	42-47	
	7	39	41	41	42	39-42	
150-225	1	43	44	45	45	43-45	
	2	36	37	38	39	36-39	
	3	42	44	44	46	42-46	
	4	35	37	38	40	35-40	
	5	47	48	49	49	47-49	
	6	49	50	50	51	49-51	
	7	41	42	44	46	41-46	
225-375	1	52	53	51	52	51-53	
	2	42	42	41	41	41-42	
	3	47	49	48	49	47-49	
	4	42	43	43	44	42-44	
	5	50	49	51	51	49-51	
	6	55	56	55	55	55-56	
	7	44	47	48	50	44-50	

<u>Weekdays (Monday - Friday):</u>

(1) Off-Peak Hours (Early AM)
(2) AM Peak Hours
(3) Off-Peak Hours (Mid-Day)
(4) PM Peak Hours
(5) Off-Peak Hours (Late PM)

<u>Weekends (Saturday+Sunday):</u>

(6) Off-Peak Hours (Variable)
(7) Peak Hours (Variable)

* Holidays and days with special events are not included in this study.

Figure 2: Traffic Volume Reduction Results, Reproduced from Hanbali and Kuemmel Table 4

Weekday traffic was found to fall 7% to 17% for a light snowfall (<25mm) and up to 41% to 53% for a heavy snowfall (225mm to 375mm). Peak hour were less susceptible to volume reduction than off peak hours. [3]

While this paper demonstrates a clear relationship between volume reductions and winter storms it fails to quantify that relationship and distinguish the contributing factors. For example, while it states that depth of snow was available it does not attempt to understand the possible effects of snow covered highways versus snowfall amount.

2.1.2 Knapp et al.

Using data from three winter seasons in Iowa, Knapp et al investigated the mobility and safety impacts of winter storms. Seven sites along access controlled interstate highways were selected to minimize the impact of other traffic flow characteristics on the relationships being investigated. Additionally, the sites selected were chosen based on proximity of RWIS and ATR installations. [7]

Interstate RWIS Location	Time Period Data Available (Month/Year)	Winter Season[2] Available (Years)
#133 – I-235, Des Moines, Iowa (MP 6)	4/1996 to 7/1998	1996/1997 and 1997/1998
#512 – I-35, Ames, Iowa (MP 113)	12/1995 to 10/1998	1995/1996, 1996/1997, and 1997/1998
#606 – I-380, Cedar Rapids, Iowa (MP 21)	9/1995 to 6/1998	1995/1996, 1996/1997, and 1997/1998
# 615 – I-80, Grinnell, Iowa (MP 183)	9/1995 to 3/1997, 12/1997 to 4/1998, and 6/1998	1995/1996, 1996/1997, and 1997/1998
#619 – I-35, Mason City, Iowa (MP 187)	11/1996 to 6/1998	1996/1997 and 1997/1998
#620 – I-80, Adair, Iowa (MP 70)	6/1996 to 6/1998	1996/1997 and 1997/1998
#624 – I-35, Leon, Iowa (MP 13)	12/1994 and 9/1995 to 4/1998	1995/1996, 1996/1997, and 1997/1998

[1]MP = milepost, approximate location
[2]Winter season in this table is defined from December to April

Figure 3: RWIS Sites Celected, Reproduced from Knapp et al Table 2

Winter storm events were defined based on four criteria including precipitation, air and surface temperature, and wet pavement. Further, events were tested to combine data when separated by only a one hour gap and to only consider events that had a duration of four or more hours with an average snowfall of at least 0.2 inches per hour.

Assessing a total of 64 events the overall reduction in volume observed during winter storms was roughly 29% with a range from 16% to 47%. They also identified a relationship between snowfall intensity, the square of wind speed and reduction in traffic volume and concluded that each additional inch of snowfall is correlated with a drop of about 2.3% in traffic volume [7].

Unfortunately, despite designing the study to collect many more environmental factors, this study did not assess the impact of any other variables, including road surface condition, against change in traffic volume.

2.1.3 Kumar and Wang

Kumar and Wang studied highways in Oregon and Montana to investigate volume impacts during severe weather events. Two methodologies were used to investigate the impact. The first method involved an hourly dataset that was combined with traffic data from one year earlier as a baseline. The second method was essentially the same except an ARIMA (Autoregressive Integrated Moving Average) model was used to estimate the normal volume. Both methods then modelled the percent change in traffic volume relative to a variety of variables including precipitation, temperature and event duration.

Data used spanned eight years (1997 to 2004 in Oregon and 2000 to 2004 in Montana). It was collected from achieved RWIS and ATR stations. These stations were selected based on data availability and proximity between station pairs. For example, only RWIS and ATR stations within 10 miles of each other were considered as pairs.

Data varied between the Oregon and Montana sites, in Montana RWIS data included air and surface temperature, surface conditions and wind speeds in addition to the air temperature and precipitation data available in both states.

This investigation of two highway sections in Oregon found that rain and snow events reduced traffic volume on average by 2% to 7%, but with such large variability that a confident relationship could not be established. Proximity between RWIS and ATR locations was identified as a major possible source of error in this assessment. [10]

This study does not appear to have a strong baseline condition from which to base its conclusions. There is no evidence that the previous year's data was during normal conditions and change in volume that would be expected year over year does not appear to be factored in to the analysis. In the second approach the baseline volume is simulated through the time series model ARIMA. Essentially the baseline data is model data and relies on the accuracy of that model process to produce accurate results.

2.1.4 Datla and Sharma

To test the effects of cold and snowfall on traffic volume Datla and Sharma used a data set based on permanent count stations on provincial highways in Alberta, Canada. This traffic data spanned 11 years (1995 to 2005) and was classified into road types including "commuter, regional commuter, rural long distance and recreational roads." The traffic data was paired with Environment Canada records for two weather stations within 15 miles (24 km). Five sites from each of the four road classifications were ultimately selected.

This study estimated a model for daily volume as a ratio of AADT based on the expected ratio, the total snow on a given day, and the categorized temperature.

The study found that as temperature drops, so does highway volume with very cold temperatures (below -25°C) showing 30% less highway traffic on recreational roads. As shown in Figure 4, the study found volume reductions between 7% and 17% per 10 cm of snowfall. Reductions on regional commuter roads were found to be less. Conversely, recreational roads had the highest volume reduction with weekday periods dropping the most. [11]

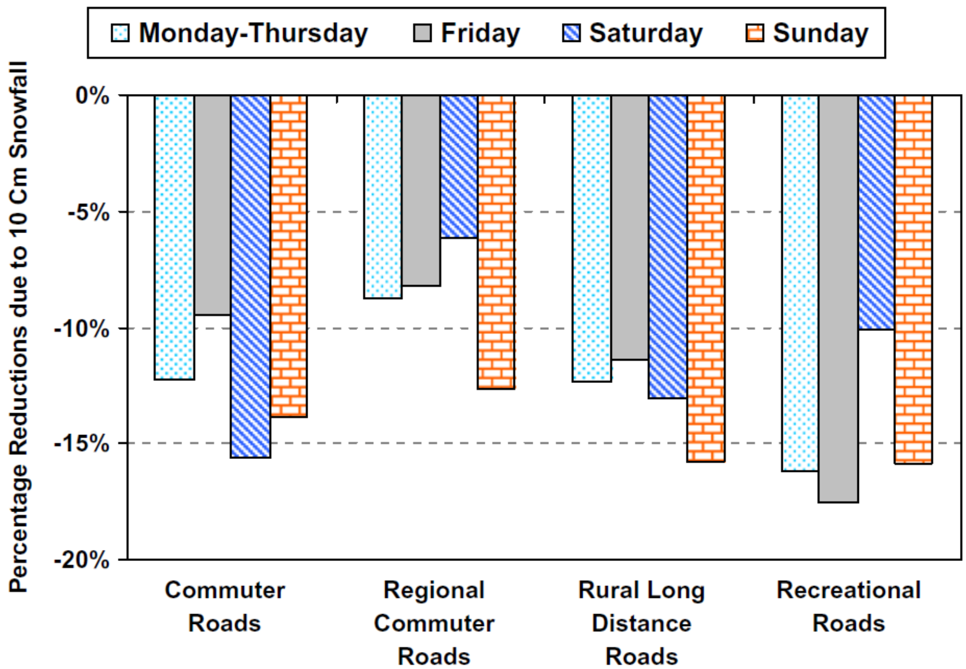


Figure 4: Volume Impact Summary, Reproduced from Datla and Sharma (2008) Fig. 5

Further study by Datla and Sharma investigated the interaction between cold and snowfall by introducing an interaction variable in the regression model. In Figure 5 below, the coefficients B_{RS} show the strength of the interaction effect on the overall model. This study found that the volume suppressing effect of snowfall was higher with colder temperatures for recreational routes while there was not a strong relationship for commuter roads. [12] However, the interaction between cold and snow does only appear to hold strong during the Friday to Sunday period suggesting a very strong influence of discretionary trips.

	Commuter Road				Recreational Road			
	Sun.	Mon.–Thurs.	Fri.	Sat.	Sun.	Mon.–Thurs.	Fri.	Sat.
B_a	1.0284	1.0239	1.0229	1.0364	1.0543	1.0212	1.0375	1.0523
B_s	−0.0102	−0.0126	−0.0170	−0.0127	−0.0131	−0.0090	−0.0053	−0.0110
Coefficients B_R								
B_1	−0.0140	−0.0097	−0.0152	−0.0090	−0.0194	−0.0134	−0.0029	−0.0083
B_2	−0.0222	−0.0226	−0.0254	−0.0178	−0.0369	−0.0229	−0.0212	−0.0261
B_3	−0.0401	−0.0339	−0.0489	−0.0293	−0.1065	−0.0376	−0.0712	−0.0975
B_4	−0.0630	−0.0404	−0.0617	−0.0530	−0.1797	−0.0543	−0.1086	−0.1475
B_5	−0.0770	−0.0737	−0.0767	−0.0865	−0.2612	−0.0735	−0.1281	−0.2175
B_6	−0.1076	−0.1000	−0.1362	−0.1053	−0.3234	−0.1196	−0.1991	−0.2378
Coefficients B_{RS}								
B_{1S}	−0.0019	−0.0048	—	—	—	0.0111	0.0068	—
B_{2S}	−0.0040	0.0009	0.0069	−0.0026	0.0009	0.0011	−0.0065	0.0072
B_{3S}	−0.0017	−0.0029	0.0036	−0.0012	−0.0127	−0.0014	−0.0081	−0.0060
B_{4S}	−0.0023	0.0050	0.0094	0.0018	−0.0155	−0.0053	−0.0170	−0.0112
B_{5S}	−0.0023	−0.0031	0.0067	−0.0004	−0.0161	−0.0093	−0.0190	−0.0121
B_{6S}	—	−0.0022	—	—	—	−0.0120	−0.0260	—
R^2	.997	.998	.998	.997	.992	.996	.996	.993
Data size	492	1,971	492	492	413	1,653	414	414
F-statistic	11,574	67,830	15,071	11,268	2,642	19,960	5,012	2,932

Figure 5: Interaction Summary, Reproduced from Datla and Sharma (2010) Table 1

By considering effects only at the daily traffic level Datla and Sharma miss the opportunity to consider effects related to more disaggregate conditions.

2.1.5 Andrey et al.

Andrey et al. studied driver adaptation to inclement weather using data from 23 cities across Canada with a focus on safety. A dataset for four defined areas: London Urban, London Rural, Toronto Urban and Toronto Rural was assessed for days with snow or rain during the November to April in 2003 to 2007.

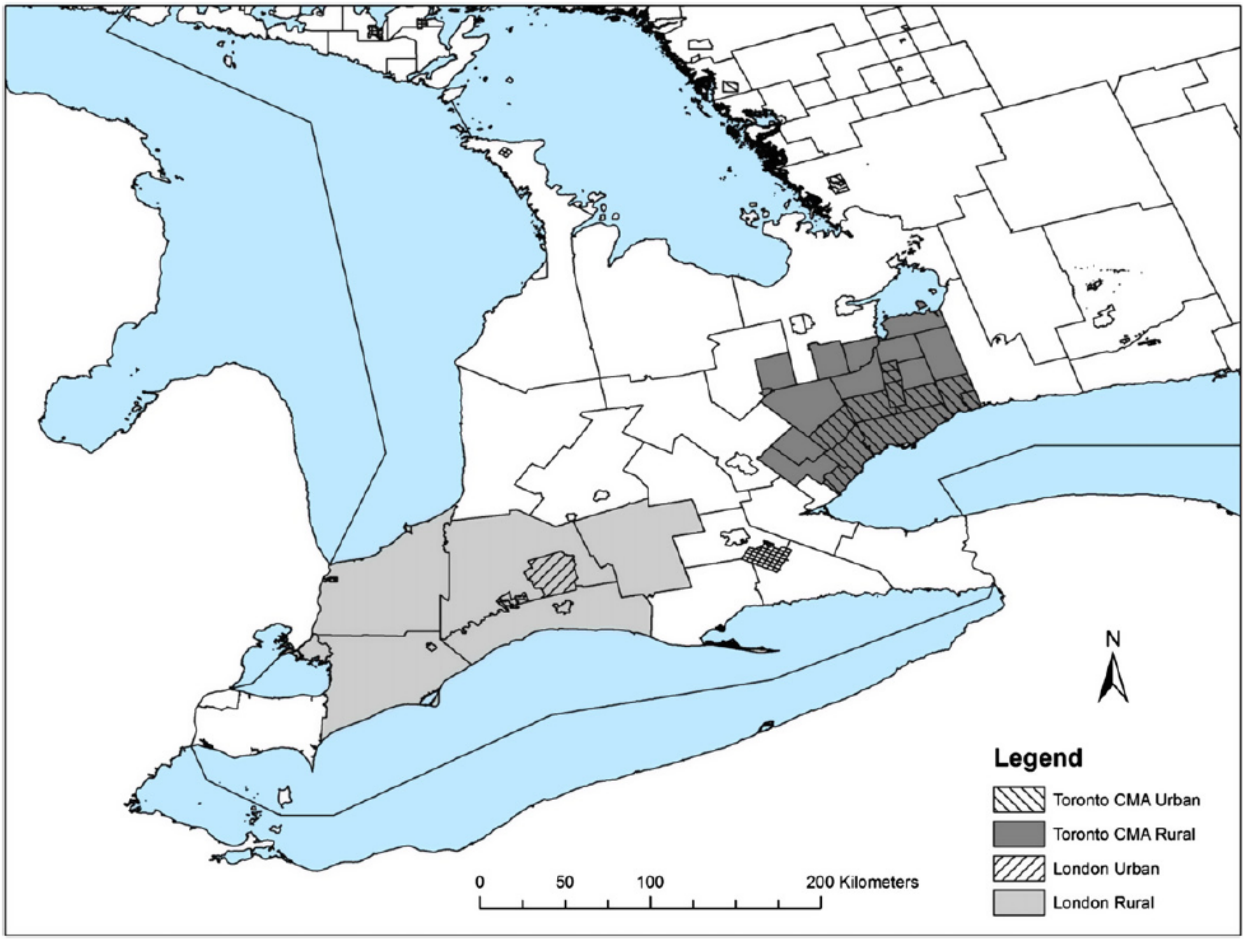


Fig. 8. Location of the study areas.

Figure 6: Study Locations, Reproduced from Andrey et al. Fig. 8

A threshold of at least 0.4 mm liquid equivalent snowfall was used to identify winter events. Events were only included if stations in all four study regions showed precipitation. This resulted in a total of 70 events to be assessed. In the Toronto areas, 58 of these had acceptable control days while in the London areas 49 had control days identified. Controls were filtered based on a lack of precipitation, good visibility and lack of holidays that would result in an obvious volume impact.

When these events occurred on a Monday through Thursday they were found to have 1.8% to 3.9% less traffic compared to days without precipitation. [13]

While these results are consistent with other observations, the focus of this study elsewhere means that the analysis that led to these results is not as robust as it might otherwise be.

2.1.6 Bartlett et al.

Bartlett et al. compared a base case and an inclement weather case for hourly traffic volumes collected on highways in Buffalo, New York. These data were matched with a combination of hourly and daily weather data from the Automated Surface Observing System (ASOS) and the

Automated Weather Observing System (AWOS). The data was cleaned and data from Friday through Monday was removed to reduce the impact of natural traffic volume variation on the analysis. Inclement weather was then identified based on the presence of precipitation, high winds and poor visibility. Temperature was also converted to a binary variable indicating whether it was above or below freezing. Weather type was index based on a conversion of descriptive categories as shown in Figure 7 and a cumulative precipitation parameter was calculated.

Weather Type	Description	WeatherType_Index
RA	RAIN	-3
DZ	DRIZZLE	-1
SN	SNOW	-3
SG	SNOW GRAINS	-1
GS	SMALL HAIL &/OR SNOW PELLETS	-3
PL	ICE PELLETS	-5
FG+	HEAVY FOG (FG & LE.25 MILES VISIBILITY)	-5
FG	FOG	-3
BR	MIST	-3
FZ	FREEZING	-2
HZ	HAZE	-2
BL (SN)	BLOWING (SNOW)	-3
BCFG	PATCHES FOG	-3
TS	THUNDERSTORM	-2
Modifiers	**Description**	
-	LIGHT	+2
+	HEAVY	-2
"NO SIGN"	MODERATE	0

Figure 7: Weather Index Mapping, Reproduced from Bartlett et al. Table 2

This study found a volume reduction of 13.3% to 33.9%. Bartlett et al. also found that the type of weather and the cumulative precipitation were the two factors with the largest impact on volume reduction [14]

Interestingly, the largest drop in volume was found during peak periods contradicting the results found in Hanbali and Kuemmel [3]and Datla and Sharma [11].

2.1.7 Call

In another study from New York, Call investigated Interstate 90 (a toll highway) which receives over 225cm of snow fall most winters. Data used spanned 8 years from 2003 to 2010. Traffic data for this study was aggregated to the daily level from toll station records and only the month of January was assessed.

This small study found a correlation between snowfall amount and reduced volume for most types of personal vehicles. However, large vehicles experienced less volume reduction due to snowfall. [15]

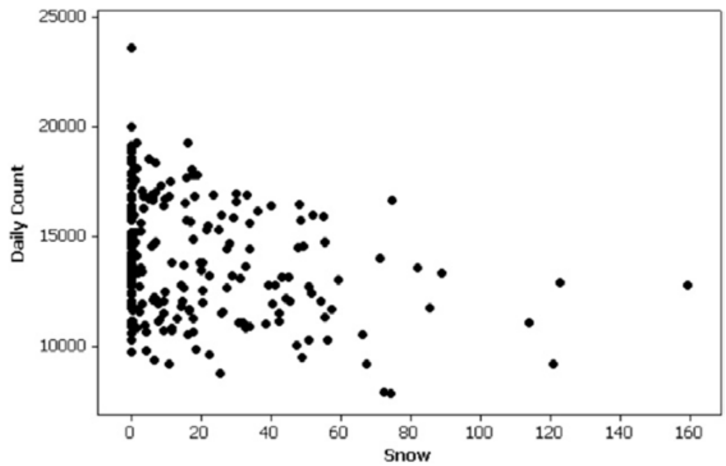


Figure 8: Representative Scatterplot, Reproduced from Call Fig. 2

2.2 Effect of Winter Conditions on Traffic Speed

2.2.1 Knapp et al.

The study by Knapp et al. discussed above also investigated the impact on speed of winter storms. Additional data was manually collected for many environmental factors via video record (including speed, headway, volume, visibility and snow cover). These detailed data sets spanned 27.25 hours during winter storm events.

Due to limitations in the amount of data collected and the additional factors involved in peak hour travel, this study chose to focus on off-peak only traffic flow. This study was also careful to exclude speed records from periods with fewer than 30 vehicles from which to estimate average speed. Ultimately only 83 periods (15 minute intervals) were considered to have sufficient quality data during the off-peak condition to be included in the analysis.

In this study by Knapp et al. a reduction in average speed of 16.7% due to winter storms was found. A drop in free flow speed of approximately 11% was also identified. A binary indicator for visibility (less than ¼ mile) was used to identify a 3.88 mph (6.25 km/h) reduction due to low visibility. The regression in Knapp et al. also used a binary variable for road condition and found a 7.23 mph (11.64km/h) average speed reduction when the road surface was snow covered. [7]

Despite a high quality data collection design the analysis in this study suffered from few data points and use of binary variables to represent continuous conditions.

2.2.2 Kumar and Wang

Kumar and Wang studied highways in Oregon and Montana to investigate speed impacts during severe weather events. This was assessed by modelling the percent change in speed between the observed speed during the storm and a baseline speed.

The baseline speed was developed based on one of two methods. The first method developed a typical speed profile for a 24hour period based on annual data. The second method was essentially the same except the baseline speeds were developed based on data from the same day. These two methods did not produce statistically different results and, as such, the annual average speed was used.

Speed data was not available from the regular ATD data and was supplemented by one week of speed data collected for each of three Montana sites during each of the four seasons.

As shown in Figure 9 the data showed average speed reductions of 6.09 to 11.76 mph (9.8 km/h to 18.9 km/h) from an average speed of approximately 72 mph (116 km/h) or 8.5% to 16% due to snow events on three rural highways in Montana.

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

Figure 9: Speed Impact Summary, Reproduced from Kumar and Wang Table 5-6

When performing a regression analysis Kumar and Wang had difficulty identifying a consistent relationship between the variables tested and average speed. In the end it was concluded that wind speed and surface temperature played a significant role. [10]

Using only 250 total data points, a lack of simultaneous data appears to have negatively impacted the ability of this study to identify consistent results among the inherently variable nature of traffic data.

2.2.3 Liang et al.

Liang et al. assessed the impact of visibility and snow conditions on vehicle speed using an instrumented section of highway 25 km long near the Idaho Utah border. Three separate sensors were installed along this stretch of highway to collect traffic, visibility and weather data. The data collection period ran from December 1995 to April 1996. During this period 16 “problem” days were recorded and assessed as part of this study.

The typical speeds on this stretch of highway were found to be between 95 km/hr and 112 km/hr (much in excess of the posted limit of 88.5 km/h). This section of highway is also fairly low in volume, an average daily traffic of about 4,500 vehicles.

Based on five minute average data the study included a regression analysis that considered visibility, wind speed, temperature, time of day, and a binary variable for RSC. The regression found a 3.5 km/h reduction in average speed when the road surface was snow covered. The log of visibility distance (km) was also significant with a coefficient of about 2.5 with no snow and about 4.6 during a snow event. Daylight and temperature increased average speeds while wind speed reduced speeds. [16]

	Visibility Threshold (km)	Intercept	Visibility	Snow Floor	Day/Night	Temperature	Wind Speed	Adjusted R^2
Fog Events								
All vehicles	10.0	98.72 0.0001	2.55 0.0001	---	2.12 0.0001	2.83 0.0001	---	0.52
Passenger car	10.0	104.83 0.0001	2.56 0.0001	---	1.27 0.024	1.74 0.0137	---	0.28
Truck	10.0	94.95 0.0001	2.09 0.0001	---	1.98 0.0001	*0.35* *0.44*	---	0.48
Snow Events								
All vehicles	10.0	89.13 0.0001	4.61 0.0001	-3.49 0.0001	2.58 0.0001	2.58 0.0001	-1.09 0.0001	0.384
Passenger car	10.0	92.78 0.0001	4.79 0.0001	-4.05 0.0001	1.32 0.0034	3.23 0.0001	-1.24 0.0001	0.373
Truck	10.0	86.78 0.0001	3.23 0.0001	-3.39 0.0001	1.34 0.0005	3.43 0.0001	-1.21 0.0001	0.396

Note: The first value in each cell is the regression coefficient. The second value is the p-value. Italic figures are statistically insignificant.

Figure 10: Regression Results, Reproduced from Liang et al. Table 1

The binary variable for RSC "snow floor" was found to have a strong negative correlation with speed in this study. However, despite having video records as part of the highway instrumentation a more precise study of road surface conditions and their impact was not conducted.

2.2.4 Agarwal et al.

Agarwal et al. used a robust data set from the Twin Cities in Minnesota to investigate reductions in speed and capacity due to rain and snow. The data set used included traffic data from approximately 4,000 detectors, RWIS data from 5 stations and weather data from 3 AWOS stations. This data spanned two to four years.

As the detectors in this study did not collect traffic speed data, it was back calculated based on the theoretical speed = flow / density relationship. The equation used is shown in Eq 1.

$$Speed = \frac{Vehicles}{10\ minutes} * 6 \bigg/ \frac{5{,}280 * Occupancy}{Field\ length * 100} \qquad \text{Eq 1}$$

Collected data was aggregated in 10 minute intervals and pair with ASOS data based on timestamp. Based on regression analysis their analysis found that heavy snow (>0.5 inches per hour) was correlated with a speed reduction of 11% to 15%. Light snow, by comparison, was associated with a 7% to 9% speed reduction. [17]

2.2.5 Cao et al.

Four rural sites in Iowa equipped with road weather information system (RWIS) stations were assessed by Cao et al. These RWIS stations collected weather, road surface and traffic condition data. Road surface condition was reported based on surface monitors and included six categories that ran from “dry” through “wet” to “ice warning. Though sensor data was recorded at a variety of different time intervals it was standardized to a consistent baseline of 15 minute intervals. The rural nature of the sites and the low volumes recorded led to the conclusion that conditions observed were contained within the free flow regime.

Using a random 90% sample of the data collected a regression analysis was undertaken to investigate the relationship between the environmental factors and speed. This regression analysis found that RSC had a large impact on travel speed. A “chemically wet” road surface resulted in a 4.38 km/h drop in speed and an “ice watch” or “ice warning” resulted in an 8.5 km/h to 11.42 km/h drop in speed. Precipitation, wind speed and vehicle mix were also found to significantly influence traffic speed. For example heavy snow resulted in a 20.47 km/h to 22.19 km/h drop in speed.

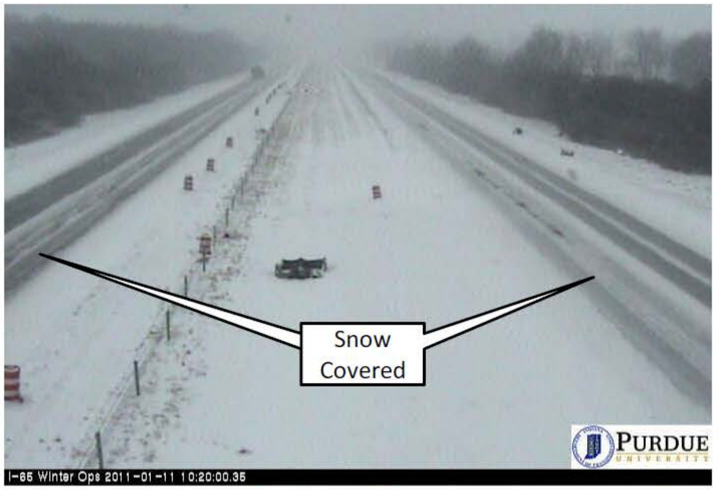
A second approach was taken to estimating the relationship between environmental variables and speed using a Multilayer Perceptron Artificial Neural Network (MLP-NN) architecture. The results of this analysis show similar fit to the data as with the linear regression.

Finally, a time series (ARIMA) model was used to estimate the relationship of interest. This approach resulted in a slightly better model fit than the two previous methods. At a lag of zero, a “chemically wet” facility was correlated with a drop in speed of 2.8 km/h to 4.6 km/h. “Ice watch” and “Ice warning” were correlated with drops in speed of between 2.8 km/h and 3.6 km/h. [18]

2.2.6 Hainen et al.

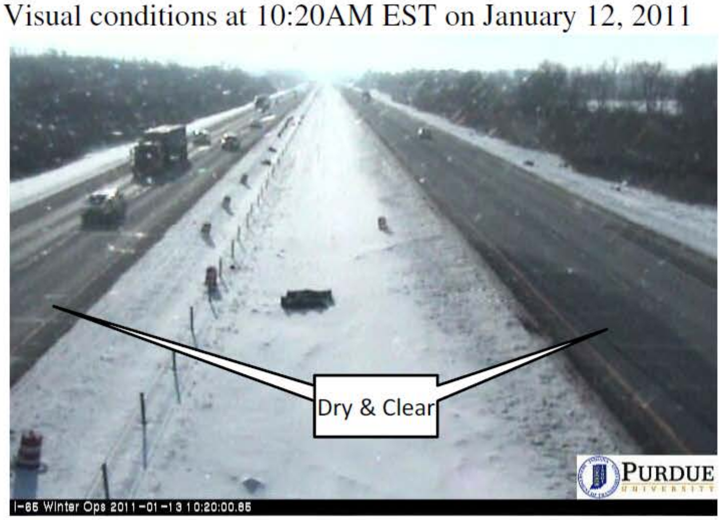
Using Bluetooth readers on the I-65 highway in Indiana, Hainen et al. evaluated the impact of winter conditions on space mean speed. This 62 mile (100 km) highway segment was assessed over the course of both clear weather and during a winter storm. A unique aspect of this study was that through the use of Bluetooth readers the estimates of speed are based on space mean speed rather than time mean speed. In this way the average conditions over the length of a highway facility, such as those inferred from automated weather stations should be much more reflective of the true experience of drivers reflected in the speed data.

This study performed a variety of visual analysis to classify conditions (see Figure 11) and estimate effects. The results showed that during the winter storm space mean speed fell by approximately 20 mph (32 km/h) from a baseline of roughly 65mph (105 km/h), see Figure 12, which equates to about a 31% decrease in space mean speed. [19]



a. Visual conditions at 10:20AM EST on January 11, 2011

b. Visual conditions at 10:20AM EST on January 12, 2011



c. Visual conditions at 10:20AM EST on January 13, 2011

Figure 11: Surface condition classification, Reproduced from Hainen et al. Fig. 4

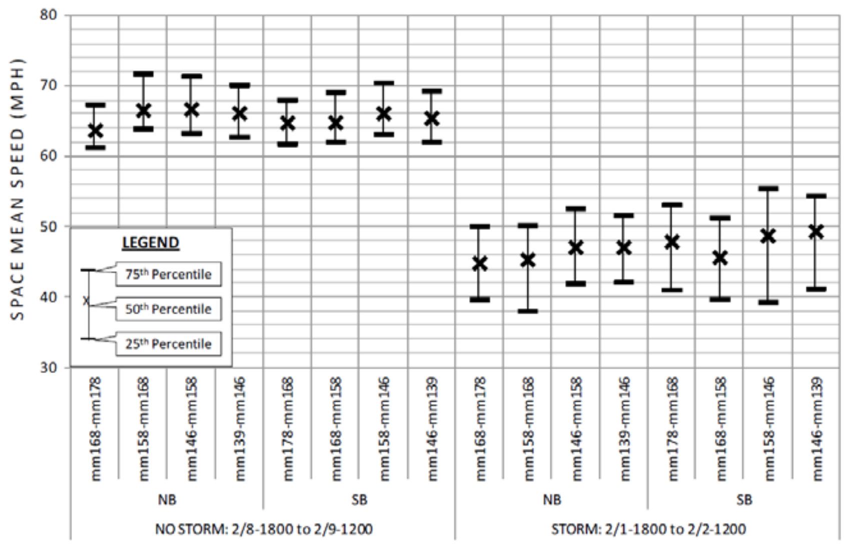


Figure 12: Speed results, Reproduced from Hainen et al. Fig. 7

2.2.7 Islam and Qiu

Islam and Qiu studied free flow speeds under inclement weather on Whitemud Drive an urban freeway in Edmonton, Canada. This section of freeway carries very high volumes and experiences congested conditions during peak hours. Over the 2010-2011 winter season seven in every ten days experienced precipitation.

Snowfall intensity is categorized into three groupings based on daily accumulation. Less then 3.12 cm in a day is considered "light" while greater than 6cm in a day is considered "heavy".

A "weather adjustment factor" (WAF) was developed to represent the ratio of free flow speed achieved during event conditions as compared to the baseline condition. Baseline speed was estimated based on data from preceding days. This weather adjustment factor was the dependant variable tested in a regression analysis including snow intensity, temperature, and visibility based on the model form in Eq 2

$$\begin{aligned} WAF = a + b(Snow\ Intensity) + c(Temperature) \\ + d(Snow\ Intensity * Visibility) \end{aligned} \quad \text{Eq 2}$$

Based on this approach this study established the relationships shown in Figure 13. These results show a 0.9% to 1.6% drop in vehicle speed per cm of daily accumulation. For a snowfall categorized as light this could be typically 2% total speed reduction to a 19% drop in free flow speed associated with a heavy snowfall. [20]

Location	Parameter	Estimate	Standard Error	T-Statistics	P-Value	R^2	R^2 Adjusted
VDS 1017	a	0.996	0.013	126.287	0.000	0.554	0.540
n=77	b	-0.016	0.002	-7.438	0.000		
	c	0.003	0.001	4.648	0.000		
	d	---*	---	---	---		
VDS 1016	a	0.976	0.009	106.715	0.000	0.641	0.624
n=77	b	-0.009	0.003	-2.680	0.009		
	c	0.002	0.001	4.295	0.000		
	d	-0.001	0.000	-2.964	0.004		
VDS 1007	a	0.970	0.009	111.977	0.000	0.623	0.605
n=77	b	-0.010	0.003	-3.059	0.003		
	c	0.002	0.001	3.837	0.000		
	d	-0.001	0.000	-2.427	0.018		
VDS 1008	a	0.967	0.012	78.636	0.000	0.425	0.407
n=77	b	0.016	0.003	-6.276	0.000		
	c	0.002	0.001	2.614	0.011		
	d	---*	---	---	---		

Note: * means parameter was found insignificant at 95% confidence level

Figure 13: Regression results, Reproduced from Islam and Qiu Table 2

This study takes a new approach to including visibility in the analysis by adding an interaction term between snowfall and visibility. Although it is concluded that it is significant, the results show that the significance is not strong as it fails in two of the four study sites. Beyond the anecdotal note that these variables would be correlated there is no evidence to support a linear interaction of the nature tested.

2.2.8 Rakha et al.

Rakha et al. in a study of inclement weather impacts on traffic flow assessed data from three cities: Minneapolis-St. Paul, Baltimore and Seattle. Looking at the basic parameters of free flow speed, speed at capacity and capacity they calibrate a Van Aerde traffic flow model to observed conditions under different weather regimes.

The study used two years worth of data in each of the three study locations all of which fell between 2002 and 2004. Inductive loops and microwave detectors were used to collect traffic data while ASOS data supplied the weather data. Visibility data was classified into four bins (<0.8km, <1.6km, <4.8km and >4.8km). Snowfall was categorized into three bins (<0.127cm/h, <0.254cm/h, >0.254cm/h). This data was combined and aggregated to five minute intervals.

Each grouping of data (based on a cross classification of visibility and precipitation) was used to calibrate a Van Aerde traffic flow model. This was then compared to the base case (high visibility, no precipitation) and the ratio of the key parameters (free flow speed, speed at capacity and capacity) between the two established weather adjustment factors as summarized in Figure 14.

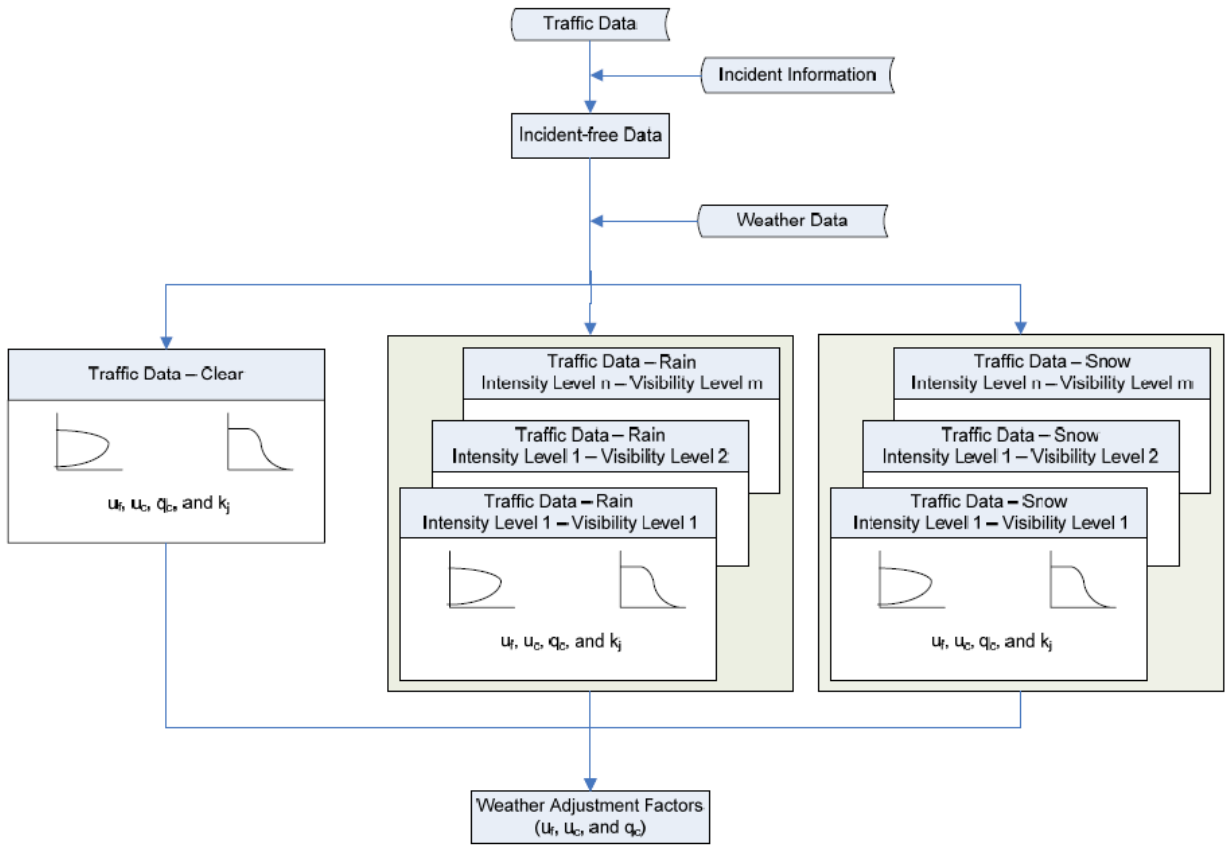


Figure 14: WAF workflow, Reproduced from Rakha et al. Figure 4.2

Once this set of WAFs was established a linear regression model was estimated based on the functional form shown in

$$\begin{aligned} WAF = a + b(Snow\ Intensity) + b\left(Snow\ Intensity^2\right) \\ +d(Visibility) + e(Visibility^2) \\ +f(Snow\ Intensity * Visibility) \end{aligned} \qquad \text{Eq 3}$$

Based on this regression, the interaction term was found to be insignificant in all cases. Rakha et al. found that free flow speed fell by about 9% per increase in snowfall category. This leads to speed falling by 5% to 19% as a result of snow in excess of 0.3cm/h. [21]

This study is entirely based on categorized variables which may mask the effect of continuous variables in the data set. It also fails to consider any more than two environmental factors: precipitation and visibility.

2.3 Other Effects of Winter Conditions on Traffic Parameters

2.3.1 Agarwal et al.

In this study, described in more detail above, capacity was estimated by taking the average of the highest 5% of observed flow rates. Figure 15 demonstrates this for a subset of the data used in this study.

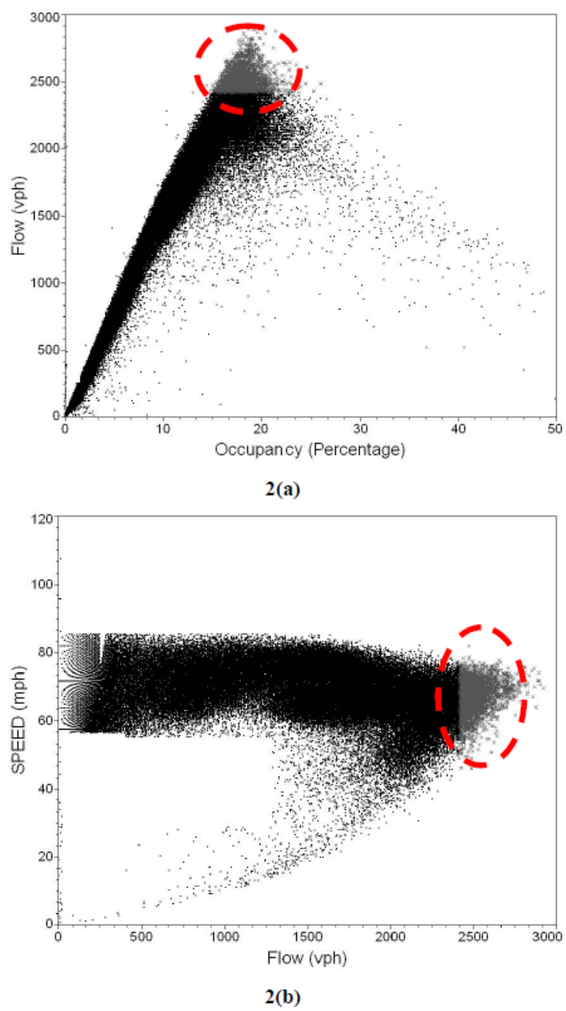


Figure 15: Capacity estimation, Reproduced from Agarwal et al. Figure 2

Their analysis found that light snow was correlated with 6% to 11% capacity reduction and heavy snow (>0.5 inches per hour) was correlated with a highway capacity reduction of 19% to 27% [17]

2.3.2 Rakha et al.

As described above Rakha et al. included the change in capacity associated with winter conditions in their study of traffic stream models. They found that capacity fell by 12% to 20% with snow and did not vary based on snowfall intensity. This drop in capacity is evident in the traffic stream model shown in Figure 16. [21]

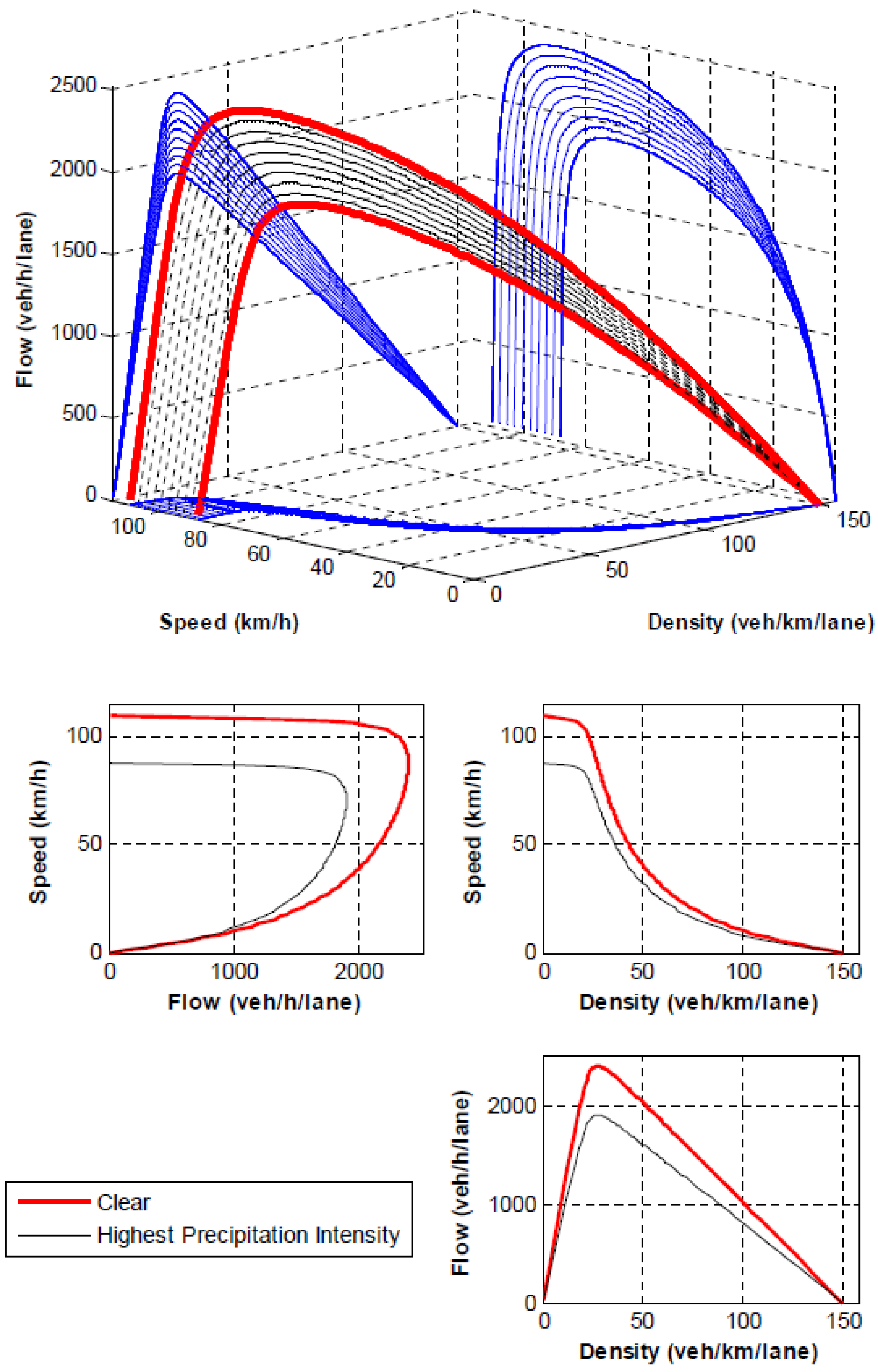


Figure 16: Traffic Stream Model Example Result, Reproduced from Rakha et al. Figure 5.10

2.3.3 Highway Capacity Manual

The 2010 Highway Capacity Manual (HCM 2010) is an industry standard reference on calculating capacity and quality of service for a variety of transportation facility types [22]. Chapter 10 of the

HCM 2010 includes a discussion on the implications of weather on capacity. Several factors common to the academic literature are shown to play a role in highway capacity including rain, snow, temperature, wind and visibility. The reduction in capacity for each of these factors is shown in Table 1.

Table 1: Capacity Reductions due to Weather and Environmental Conditions in Iowa, Reproduced from HCM 2010 Exhibit 10-15

Type of Condition	Intensity of Condition	Percent Reduction in Capacity	
		Average	Range
Rain	>0 ≤ 0.10 in./h	2.01	1.17–3.43
	>0.10 ≤ 0.25 in./h	7.24	5.67–10.10
	>0.25 in./h	14.13	10.72–17.67
Snow	>0 ≤ 0.05 in./h	4.29	3.44–5.51
	>0.05 ≤ 0.10 in./h	8.66	5.48–11.53
	>0.10 ≤ 0.50 in./h	11.04	7.45–13.35
	>0.50 in./h	22.43	19.53–27.82
Temperature	<50°F ≥ 34°F	1.07	1.06–1.08
	<34°F ≥ −4°F	1.50	1.48–1.52
	<−4°F	8.45	6.62–10.72
Wind	>10 ≤ 20 mi/h	1.07	0.73–1.41
	>20 mi/h	1.47	0.74–2.19
Visibility	<1 ≥ 0.50 mi	9.67	One site
	<0.50 ≤ 0.25 mi	11.67	One site
	<0.25 mi	10.49	One site

Original Source: Adapted from Agarwal et al.

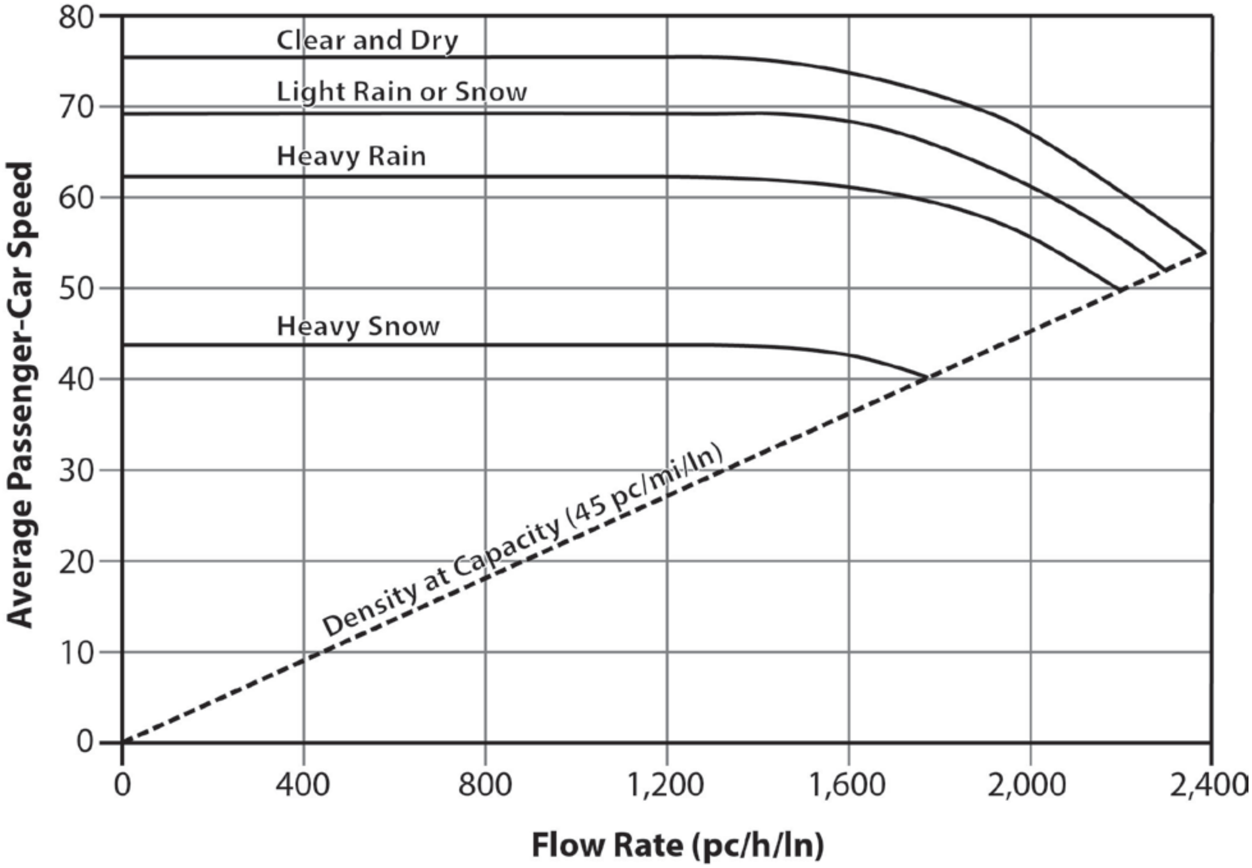
Road surface conditions measured as the difference between wet and dry, Table 2, are also highlighted in the HCM 2010 as having an effect on highway capacity [22].

Table 2: Capacities on German Autobahns Under Various Conditions (veh/h/ln), Reproduced from HCM 2010 Exhibit 10-16

Freeway Lanes	Weekday or Weekend	Daylight Dry	Dark Dry	Daylight Wet	Dark Wet
6	Weekday (% change*)	1,489	1,299 (13%)	1,310 (12%)	923 (38%)
6	Weekend (% change*)	1,380	1,084 (21%)	1,014 (27%)	— —
4	Weekday (% change*)	1,739	1,415 (19%)	1,421 (18%)	913 (47%)
4	Weekend (% change*)	1,551	1,158 (25%)	1,104 (29%)	— —

Note: *Percent change from daylight, dry conditions for the same day of week.
Original Source: Adapted from Brilon and Ponzlet.

Finally, the HCM 2010 references drops in free flow speed relative to environmental conditions as shown in Figure 17 [22]. This graph shows a free flow speed reduction of approximately 8% with light snow and approximately 41% with heavy snow.



Note: Free-flow speed = 75 mi/h (base conditions).

Figure 17: Illustration of Speed-Flow Curves for Different Weather Conditions, Reproduced from HCM 2010 Exhibit 10-18

2.3.4 Ye et al.

Using a series of 828 highway segments across the state of Minnesota, Ye et al. estimated the travel time savings during winter storms of the existing highway winter road maintenance program. It was assumed that, on average, speeds would be 16% below the speed limit with no WRM. This is equivalent to assuming that the highways were snow covered during winter storms. It was also estimated that, on average, speeds are 10% below the speed limit during winter storms with the current WRM program. A final value of $10.9 million was calculated as the travel time savings value for the existing state WRM program. [23]

2.4 Summary of Literature

Table 3 summarizes the general findings of the academic literature reviewed above. While the magnitude of effects varies from study to study, this shows that there is agreement that the effects being considered do exist.

Table 3: Summary of Literature

Source	Drop in Volume	Drop in Speed	Drop in Speed due to RSC
Hanbali and Kuemmel [3]	7% to 53%		
Knapp et al. [7]	16% to 47%	16.7%	11.57km/h (snow covered)
Kumar and Wang [10]	2% to 7%	8.5% to 16%	
Datla and Sharma [11]	7% to 17% per cm		
Andrey et al. [13]	1.8% to 3.9%		
Bartlett et al. [14]	13.3% to 33.9%		
Liang et al. [16]		~18%	3.5 km/h (snow covered)
Agarwal et al. [17]		11% to 15%	
Cao et al. [18]			8.5 km/h to 11.42 km/h (ice watch / warning)
Hainen et al. [19]		27%	
Islam and Qiu [20]		2% to 19%	
Rakha et al. [21]		5% to 19%	

Unfortunately, no study was found that covered highways in Ontario while investigating the same relationships that formed the basis of this research.

2.5 Problem Statement

There is consensus in the literature that winter weather conditions, particularly snowfall have an impact on highway volume. Assuming that the highways studied, which were primarily rural in nature, were not experiencing capacity constraints, the most obvious rationale is that during snow events people choose to shift their travel to another time, or cancel their trip entirely. No correlation has yet been shown in the literature between volume and RSC.

As with volume, there is general agreement in the literature that winter weather and RSC have an effect on average travel speeds. However, the effect of RSC has been limited to a binary variable describing only if a highway is snow covered or not.

As such there remains a gap in the current literature as to the effect of RSC on volume and speed.

3 Methodology

This empirical study builds on a very large and dispersed set of available data to model the effects of weather and road surface condition on highway volume and speed. Figure 18 shows the process followed starting from collection of data through model development and on to conclusions.

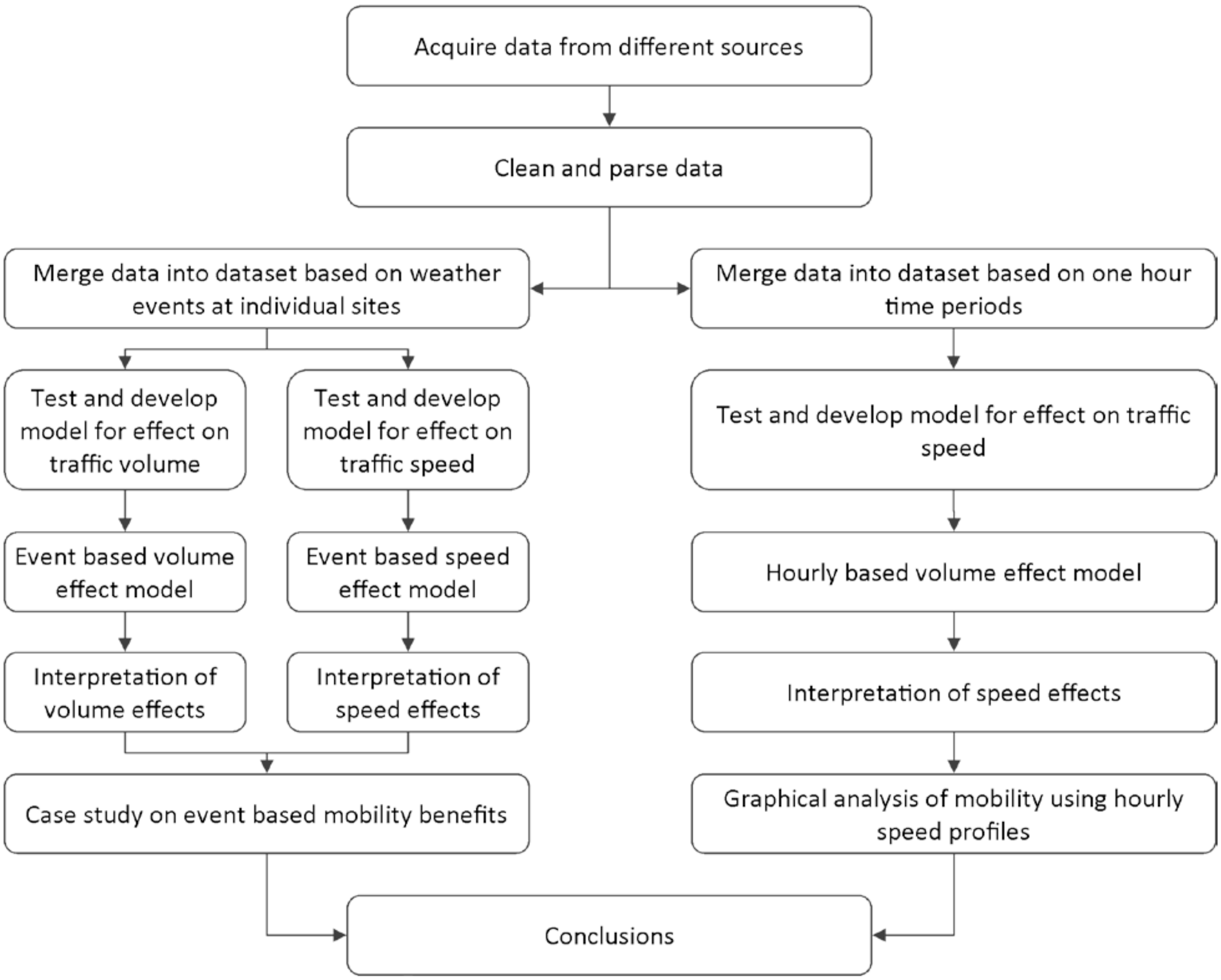


Figure 18: Study process flow chart

3.1 Study Sites

Twenty-one maintenance patrol routes were selected from different regions of Ontario, Canada, as shown in Figure 1 (different line colours serve only to facilitate differentiation of patrol routes). These sites were selected based on traffic, weather and RSC data availability. The selected road sections belong to different highway classes, including low volume rural two lane sections through to high volume multi-lane urban freeways.

Figure 19: Study sites

3.2 Data sources

Due to varying data availability 19 sites were grouped to create a data subset spanning six winter seasons (2000 – 2006) with available event based information. For the hourly evaluation 21 sites had complete data spanning three winter seasons (from 2003 – 2006). All data was compiled from several different sources. A description of each data source is given below.

3.2.1 Road Weather Information System (RWIS) Data

All of the study sites selected for this research have at least one road weather information system (RWIS) station installed along the route, which provides real-time climatic data such as temperature, precipitation type, visibility, wind speed and road surface condition. All data except precipitation intensity were available on an hourly basis. Hourly precipitations from RWIS sensors were either not available or unreliable. As a result, we derive this information from the daily precipitation amount reported by Environment Canada (EC). Daily precipitation amount was averaged over periods with precipitation to estimate precipitation intensity. RWIS stations record data every 20 minutes. Data from 45 RWIS stations were used in this research. In the case that multiple stations covered a maintenance route, average values from all the stations were used.

3.2.2 Environment Canada (EC) Data

Weather data from Environment Canada includes temperature, precipitation type and intensity, visibility and wind speed. With the exception of precipitation intensity, all data given are in an hourly format. Data from most EC stations were incomplete; for this reason, EC data were obtained from 217 stations for the study routes. This data set was processed in three steps. In the first step, a 60 km arbitrary buffer zone was assumed around each route and all stations within this boundary were assigned to the particular route. In the next step, EC stations near the routes were identified and filtered based on a t-test to remove EC stations that showed significantly different weather. In the last step, data from different EC stations around a route were converted into a single dataset by taking their arithmetic mean. It was found that arithmetic means provide better results than weighted averages.

3.2.3 Road Condition Weather Information System (RCWIS) Data

Data on road surface conditions and maintenance activities were extracted from MTO's road condition and weather information system (RCWIS). RCWIS contains information about road surface conditions, maintenance operations, precipitation type, accumulation, visibility and temperature. The data in RCWIS are collected by MTO and contract maintenance personnel, who patrol the maintenance routes during snow events, 3~4 times on the average. Information from all patrol routes is conveyed to a central system six times a day. One of the most important pieces of information in this data source is the description of the overall road surface conditions of the highway section at the time of observation. This description is used as a basis for determining a scalar variable called road surface index (RSI) as described in the Section 3.3.

3.2.4 Traffic Volume Data

The data on the response variables of our main concern, namely, traffic volume and speed, were obtained from MTO's permanent count stations (PDCS). The original PDCS data included traffic counts and binned speed measurements for each lane over each hour. The binned speed measurements cannot be used to obtain good estimate on the average hourly speed because of the large bin size at the low speed range (e.g., the lowest speed bin is from 0 to 60 km/h). For this reason, the sample median speed is estimated from the binned speed measurements and is used as the response variable for evaluating the effect on speed in the subsequent analysis. It should be noted that the mean speed should be close to the median speed because traffic speed commonly follows a symmetrical distribution.

3.2.5 Event definition

Throughout this research events are identified based on the definition used in the database prepared by Taimur Usman as part of his review on the safety impact of winter maintenance. Each event spans a period from the time when precipitation is first observed and ends when road surface condition of bare has been recovered. In order to qualify as a winter event the temperature must also have been below 5°C and the road surface condition must drop below the level of bare surface.

3.3 Models used

The Stata (9.2) software package was used to perform the statistical work for this analysis. Two types of regression models were used to answer the research questions.

3.3.1 Poisson regression

Highway volume for a given period is not fixed. It varies from hour to hour, day to day and month to month [24]. The natural variation in traffic volumes can be represented using a Poisson distribution [25].

As such, Poisson regression was used to estimate the effects of a variety of independent variables on highway volume.

3.3.2 Linear regression

All research questions surrounding highway speed were tested using multiple linear regressions. This approach allowed the wide variety of available independent variables to be tested for significance within the context of predicting traffic volume and speed.

Datla and Sharma [12] found statistically significant second order effects in estimating highway speeds in adverse weather. However, this investigation focused only on first order effects.

3.4 Data Processing

At first, all the data sources, except traffic data, were combined to form an integrated data set for each site treating location, date and time as the common basis for merging. In the next step data from all the sites were pooled into a single dataset with each site assigned a unique identifier (site-specific variables) to retain its identity.

3.4.1 Inclusion of road surface condition

Road surface condition (RSC) is an important variable in this research, representing the joint effect of weather, winter road maintenance and traffic. As described previously, the raw data on RSC are from patrol reports, which are descriptive in nature including 7 major categories and 486 subcategories. This variable was therefore mapped into a continuous road surface index. The resulting road surface index (RSI) decreases with increasingly difficult operating conditions as shown in Figure 2. A detailed description on the rationale behind this mapping is given in [8].

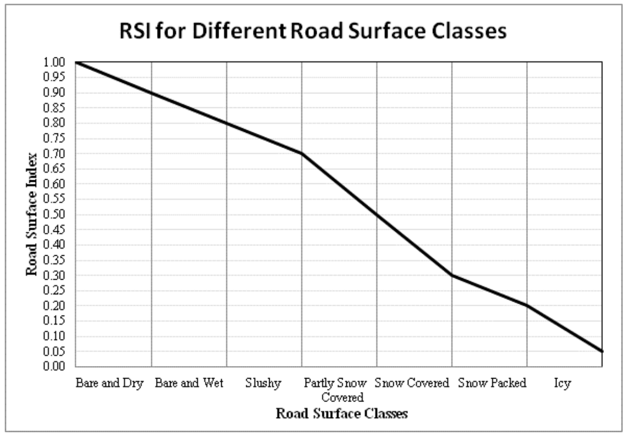


Figure 20: RSI for different RSC classes

3.4.2 Event based data subset

The lane traffic volumes and speeds were aggregated into hourly volumes and median speeds by direction and then merged with the atmospheric and surface condition data set. Snow events were then identified and the hourly data were subsequently merged into an event-based data set by highway and by direction [8], which yielded 4822 records of directional highway-event pairs. A few sample rows of this dataset are shown in Appendix A.

This data set is directly used for traffic speed analysis. For traffic volume analysis, however, the total traffic volume of a highway over an event is considered. As a result, the data set is further aggregated to form a non-directional data set, including 2411 records.

For each snow storm in the event data set described previously, the same period (day of week and time of day), a week either before or after the snow event, is identified as the control of the analysis. The control period must have normal road weather condition with good road surface conditions (RSI>0.9). In case a control period could not be identified for a given event, the event was dropped from the analysis. Table 2 and 3 give the summary statistics of the two data sets.

Table 4: Characteristics of Volume Analysis Dataset (2411 Observations)

Variables	Min	Max	Avg	StDev
Temperature (°C)	-29.99	5.00	-4.519	4.886
Wind Speed (km/h)	0.00	60.50	12.849	8.876
Visibility (km)	0.00	26.82	10.478	6.944
Total Precipitation (cm)	0.00	40.00	2.341	3.161
RSI	0.12	1.00	0.761	0.156

Site1	4%
Site2	3%
Site3	5%
Site4	5%
Site5	6%
Site6	4%
Site7	3%
Site8	9%
Site9	5%
Site10	5%
Site11	5%

Site12	5%
Site13	4%
Site14	8%
Site15	4%
Site16	4%
Site17	2%
Site18	5%
Site19	5%
Site20	4%
Site21	3%

Table 5: Characteristics of Median Speed Analysis Dataset (4822 Observations)

Variables	Min	Max	Avg	StDev
Temperature (°C)	-29.99	5.00	-4.464	4.878
Wind Speed (km/h)	0.00	60.50	12.991	8.856
Visibility (km)	0.00	26.82	10.488	6.941
Hourly Precipitation (cm)	0.00	13.80	0.503	0.761
RSI	0.12	1.00	0.763	0.156
V/C	0.00023	0.35189	0.046	0.060

Posted Speed Limit (80 km/hr)	33%
Posted Speed Limit (90 km/hr)	35%
Posted Speed Limit (100 km/hr)	31%

Site1	4%
Site2	3%
Site3	6%
Site4	5%
Site5	7%
Site6	5%
Site7	3%
Site8	10%
Site9	6%
Site10	6%
Site11	5%

Site12	6%
Site13	5%
Site14	9%
Site15	5%
Site16	5%
Site17	2%
Site18	3%
Site19	3%
Site20	2%
Site21	2%

3.4.3 Hourly data subset

The data obtained from all the data sources were extracted in hourly format. As such, when the traffic data was merged with the atmospheric and surface condition dataset it was directly used to complete the hourly analysis.

With the event based data, events were identified and paired with non-event periods to enable a pair wise analysis. For the hourly analysis however, snow events were then identified within the hourly data. The resultant data set contained over 400,000 hourly observations on speed data, of which almost 60,000 were complete records identified as occurring during an event.

This data set is directly used for traffic speed analysis. Descriptive statistics for four key sub groups of this data set are shown in Table 6 through Table 9.

.

Table 6: Data Description for Rural – No Snow Storm

Variable	Obs	Mean	Std. Dev.	Min	Max
Temperature	367060	-0.33	9.34	-42.15	29.17
Wind Speed	364716	10.21	8.09	0.00	69.00
Visibility	323966	19.24	7.45	0.00	40.20
Precipitation	367610	0.80	2.13	0.00	31.65
RSI	367610	0.92	0.13	0.05	1.00
V/C	333187	0.05	0.06	0.00	1.47
Median Speed	323703	99.80	9.95	60.00	135.00
Base Speed	367610	100.84	8.97	78.27	122.43

Table 7: Data Description for Urban – No Snow Storm

Variable	Obs	Mean	Std. Dev.	Min	Max
Temperature	111762	2.20	8.08	-32.00	29.35
Wind Speed	109588	12.13	8.45	0.00	61.00
Visibility	111816	19.51	6.81	0.10	40.20
Precipitation	111894	0.55	1.54	0.00	20.41
RSI	111894	0.92	0.13	0.07	1.00
V/C	82504	0.57	0.56	0.00	4.28
Median Speed	82422	107.94	11.99	60.00	135.00
Base Speed	111894	109.44	5.61	93.27	117.35

Table 8: Data Description for Rural – With Snow Storm

Variable	Obs	Mean	Std. Dev.	Min	Max
Temperature	54758	-5.48	5.50	-33.50	11.50
Wind Speed	54568	14.18	9.32	0.00	67.00
Visibility	48220	11.31	7.97	0.00	40.20
Precipitation	54884	3.82	3.90	0.00	31.65
RSI	54884	0.70	0.21	0.05	1.00
V/C	50168	0.04	0.05	0.00	0.66
Median Speed	49048	93.47	11.38	60.00	135.00
Base Speed	54884	100.34	8.30	78.27	122.43

Table 9: Data Description for Urban – With Snow Storm

Variable	Obs	Mean	Std. Dev.	Min	Max
Temperature	15346	-4.10	4.73	-26.00	12.95
Wind Speed	15216	17.15	9.98	0.00	58.00
Visibility	15388	12.37	7.72	0.10	32.20
Precipitation	15388	2.80	3.01	0.00	20.41
RSI	15388	0.75	0.21	0.07	1.00
V/C	10121	0.49	0.49	0.00	4.31
Median Speed	10115	100.68	15.77	60.00	125.00
Base Speed	15388	109.67	5.66	93.27	117.35

In the tables above the number of observations for each variable varies. This is due to gaps in the associated data sets. For any model testing the relationships between variables, only records containing all variables included in that model are used.

Base speeds were developed to represent the average speed during each hour of the day for each day of the week. The base speeds were taken from the average of all records for a given hour that were not identified as occurring during a snowstorm and had a RSI of 0.8 or greater. Rural sites did not demonstrate a significant variation in average speeds from day to day, therefore the base speeds were all established from a single average 24 hour period. See Figure 21 for a typical average speed profile from a rural site.

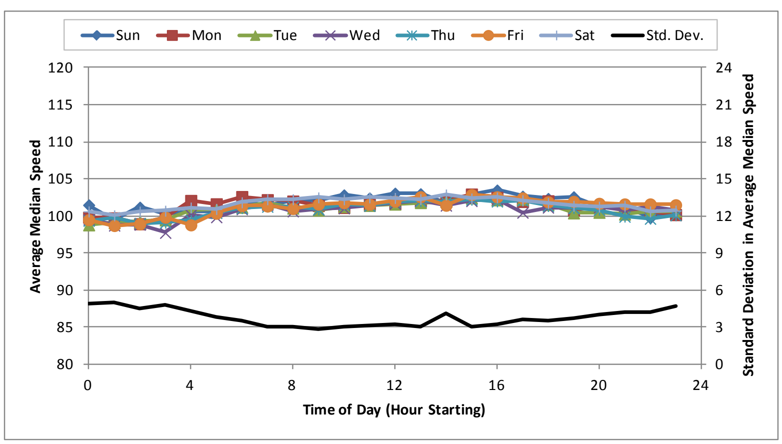


Figure 21: Typical Week Speed Profile – Rural Site

For urban sites, the weekday average speed profile exhibited peak hour slowing, as such the base speeds were established from an average weekday 24-hour period as well as an average Saturday and Sunday. This pattern can be seen in the typical speed profile for an urban site shown in Figure 22. Much greater variation is also present in the urban speeds during peaks.

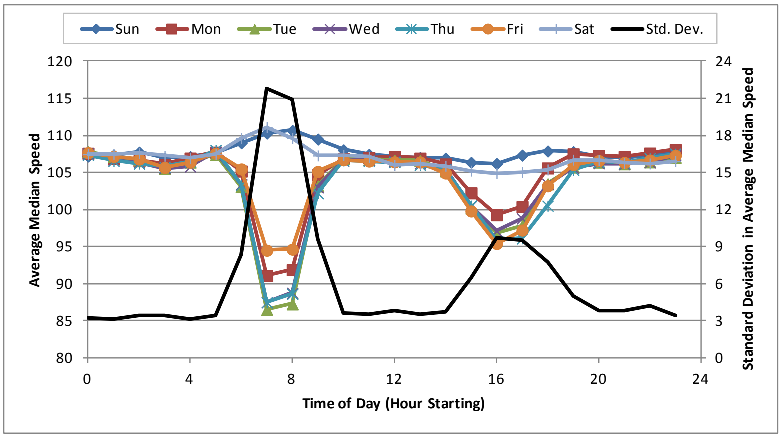


Figure 22: Typical Week Speed Profile – Urban Site

4 Analysis of Effects on Traffic Volume

4.1 Chapter Overview

This section details the first aspect of this research: the relationship between winter storms and traffic volume. It investigates the effects of winter storms, and specifically the effect of RSI, on traffic volume over the course of a winter storm.

The results discussed in this chapter clearly demonstrate that road surface condition, as measured by RSI, is one of the most significant factors in the correlation between winter storm conditions and traffic volume.

4.2 Factors influencing traffic volume

Many factors influencing traffic volume can be intuitively grouped into two broad categories. The first, and simplest, of these categories is demand for travel. The second category is supply of highways on which to travel.

4.2.1 Demand

Demand for travel is driven by the need to complete activities in any given day and the location at which we can complete those activities. For example, the need to purchase groceries and the location of the grocery store relative to or home or, the need to work and the location of our workplace. Many different activities can require travel including social and recreational purposes.

Demand can be affected in many different ways. Typical four step models used by transportation authorities across North America recognise the impact that factors such as age, income, family composition, automobile ownership and employment status have on the number of trips an individual may wish to make in the course of a day.

The field of transportation demand management (TDM) recognises that a variety of other factors will influence the demand for travel at peak times. TDM strategies attempt to reduce five dimension of travel:

1. Whether a trip is performed at all: for example online shopping or telecommuting may reduce the need to make a shopping or work trip in the first place.
2. When that trip is performed: shift work or flexible work hours may mean that travel for work during the peak hours is reduced.
3. How the trip is performed: a variety of options including transit, walking, cycling and carpooling will lower the overall volume of traffic while still accomplishing the desired trip.
4. Where a trip is destined: by enabling a mix of land uses in close proximity it is possible to reduce longer distance trips which encourages alternate modes of travel and reduces total vehicle kilometers.
5. Can more than one need be accomplished in this trip: similar to the previous dimension, a mix of co-located land uses can enable a single trip to accomplish more than one need, for example, picking up your dry cleaning at the grocery store.

Affecting these five dimensions is not always done intentionally. New technology enabling telecommuting was not created to reduce traffic volume. However, encouraging a telecommuting policy may be part of the role of a TDM practitioner.

One thing that may affect the demand for travel is weather conditions [11]. Controlling for this effect is important as this analysis attempts to understand if there is a relationship between RSC and volume in addition to the effects of weather.

4.2.2 Supply

Similar to demand, there are several different aspects of highway supply that will influence volume. Other than the requisite need to provide access to the origins and destinations of travellers, the two most intuitively obvious factors are convenience and capacity.

Capacity of a highway acts as an upper bound to the volume measured. A higher capacity highway has the potential to serve more demand.

Convenience is intuitively obvious as an influence on how many drives will choose to use a particular facility. Many different factors might play in to convenience: expected speed on a facility, directness, comfort of the design (vertical and horizontal curves, lane width, superelevations).

As shown in the Highway Capacity Manual, weather can have a significant impact on highway capacity [22]. This research attempts to distinguish between the effect of weather on highway volume and the effect of RSC.

4.3 Event based analysis of traffic volume

4.3.1 Research Question

This research focuses on the mobility effects of WRM which is assessed through the surrogate measure of highway RSC. In this section the effect on volume is investigated. As such, the specific question being asked in this section is:

> *Do WRM activities affect mobility in terms of trip making?*

4.3.2 Approach

In the event based dataset described above, each winter storm event has been summarized according to the average conditions over the duration of the event. Each event is also paired with a clear weather period in the week before or after of the same duration. The average conditions during the paired “clear weather” are used as a baseline from which to perform a pair wise comparison.

In this way the change in volume between “snow event” and “clear weather” is modeled as dependant on the relative change in independent variables such as hourly precipitation and RSI.

The modeled effect of RSI on volume is interpreted as an indicator of the potential impact of WRM activities.

4.3.3 Exploratory Data Analysis

For this model the dependant variable is taken as the total volume on a highway over the course of a snow storm. The total volume during the paired clear weather period is included in the model. As a result, the coefficients estimated will show the variable effect on volume change during a winter storm event. Each of the five key variables being tested was plotted against volume change below. To simplify interpretation the range of changes from -1,000 vehicles to +1,000 vehicles was plotted. This results in over 80% of the data being presented. Each of these exploratory plots only considers the effects of a single variable; as such any interaction between effects is masked.

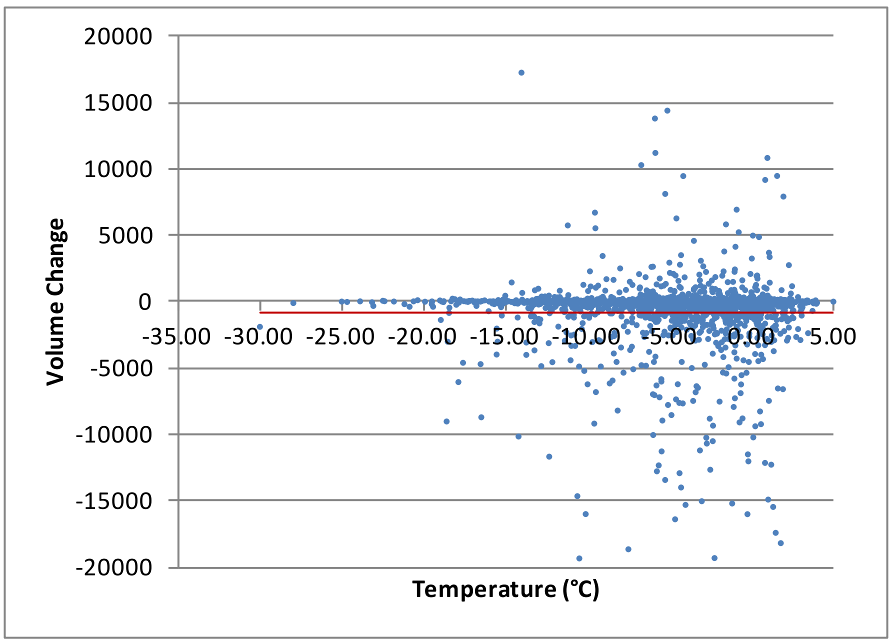


Figure 23: Temperature vs. Volume Change

When temperature is plotted against volume change there is no obvious trend observed. A linear trend shows only a small effect though it does demonstrate that volume change, in general is negative in the data set (i.e., storm have less traffic). The considerable noise within the data is also evident in the plot.

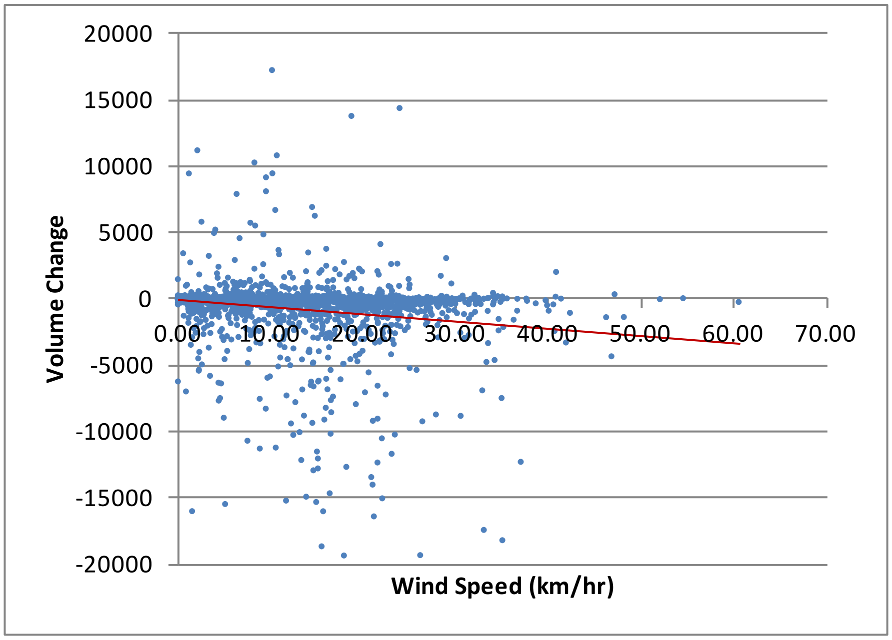


Figure 24: Wind Speed vs. Volume Change

Little trend is obvious when comparing wind speed to volume change. A linear trend line does suggest that higher wind speeds is correlated with lower volumes during storms.

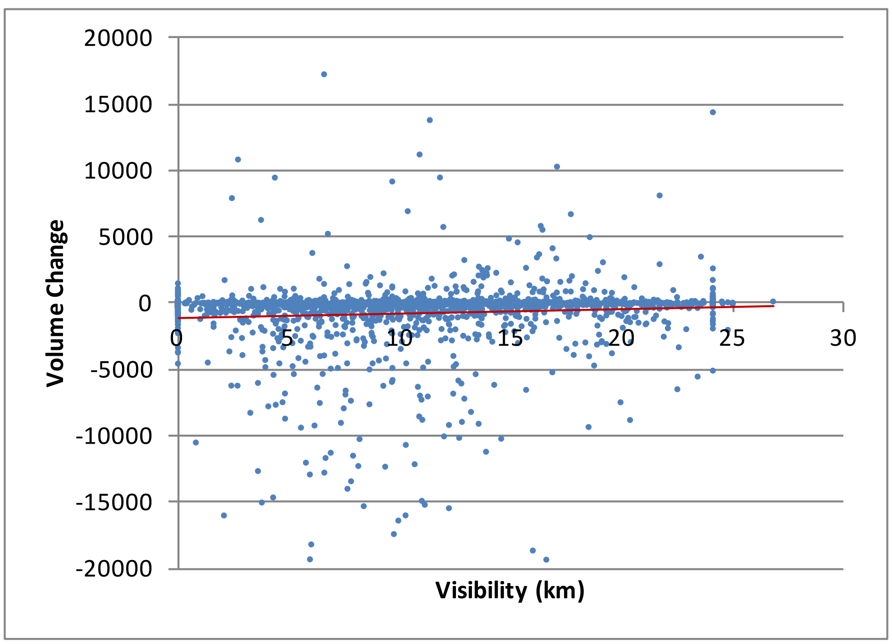


Figure 25: Visibility vs. Volume Change

Plotting visibility against volume change appears to reveal a reporting bias: significant groups of data are reported at the 0km/hr and 24km/hr visibility levels. The linear trend does suggest that low visibilities are correlated with lower traffic volumes.

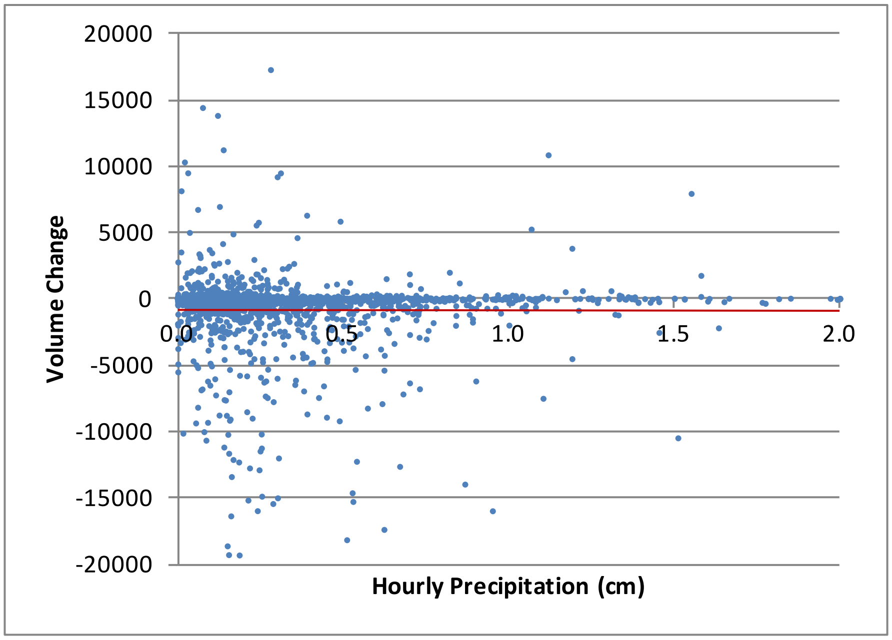


Figure 26: Precipitation vs. Volume Change

Despite the noise in the data this plot clearly shows a volume reduction when there is precipitation occurring. This is expected as precipitation was used as a factor in identifying storm events. However, a relationship between the intensity of precipitation and volume change is less obvious.

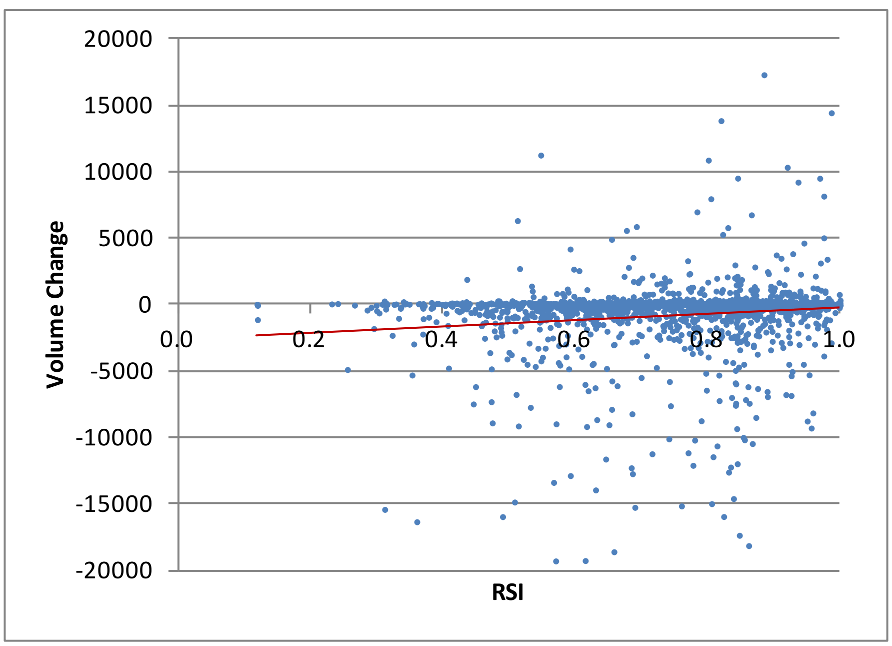


Figure 27: RSI vs. Volume Change

When comparing RSI to volume reduction the linear trend clearly indicates a strong correlation between lower RSI and lower volume. This is also visible by observing the shift in data away from the horizontal axis with lower RSI. However, the noise in the data masks this trend to some degree.

4.3.4 Event Based Model for Traffic Volume

Traffic volume on highways generally varies over space and time due to the inherent variation in the decisions made by individual travelers. For the same reason, traffic volume also varies randomly, that is: different volumes could be observed by the same time of day, day of week and month and under the external conditions (e.g. weather). The randomness of traffic counts can be reasonably captured by Poisson distribution. Let $Y_{h,k}$ represent the total traffic volume on highway *h* over a given snow storm *k.* Assume $Y_{h,k}$ follows a Poisson distribution with its mean, denoted by $Q_{h,k}$, being a function of some independent variables, representing factors such as highway characteristics and road weather conditions. The relationship between $Q_{h,k}$, and the influencing factors is assumed to take the form shown in Eq 4.

$$\ln\left(Q_{h,k}\right) = \ln(\bar{Q}_{h,k}) + \beta_0 + Site_h + \sum \beta_i \mathrm{x}_{\mathrm{k,i}} \qquad \text{Eq 4}$$

where

$\bar{Q}_{h,k}$ = an offset term representing the expected total traffic volume for the event period if the event had not occurred. This value is approximated using the observed traffic volume for the same period one week before or after the event day, as discussed previously.

$x_{k,i}$ = attribute related to weather and road conditions

$Site_h$ = constant term that varies by site

Eq 4 can be calibrated using Poisson regression with the dataset described in Section 3.4.2. The independent variables tested for significance include temperature (°C), wind speed (km/h), visibility (km), total precipitation over the event (cm), RSI (unitless) and site variation indicators (binary variable).

After testing a variety of options, it was found that all variables except temperature were statistically significant in improving the explanatory power of the traffic volume model. The final regression result that was found to best fit the full data set is given in Table 3 along with the elasticity (marginal effect) of each significant factor. Eq 5 shows the resulting model.

$$\ln\left(Q_{h,k}\right) = \ln(\bar{Q}_{h,k}) - 0.264 - 0.004 * WindSpeed - 0.005 * Visibility - 0.007 * Precipitation + 0.265 * RSI + \sum_{1}^{\mathrm{n}} (y_{\mathrm{i}} * Site_{\mathrm{i}}) \qquad \text{Eq 5}$$

Table 10: Modeling Results for Traffic Volume of a Highway over a Storm Event

Variable	Coef.	Sig	Std. Err.	z	Elasticity
Constant	-0.264	0.000	0.002	-158.830	
Wind Speed	-0.004	0.000	0.000	-146.060	-0.048
Visibility	0.005	0.000	0.000	113.460	0.052
Precipitation	-0.007	0.000	0.000	-89.030	-0.015
RSI	0.265	0.000	0.002	153.840	0.201
Site 1	0.041	0.000	0.006	6.320	0.040
Site 2	-0.129	0.000	0.016	-8.230	-0.137
Site 3	-0.019	0.000	0.003	-7.310	-0.019
Site 4	0.041	0.000	0.004	11.120	0.040
Site 5	0.071	0.000	0.003	27.960	0.068
Site 6	-0.017	0.000	0.003	-6.280	-0.017
Site 7	0.068	0.000	0.004	18.470	0.066
Site 8	-0.008	0.000	0.002	-4.740	-0.008
Site 9	0.025	0.000	0.001	20.060	0.024
Site 10	0.063	0.000	0.003	21.830	0.062
Site 11	-0.021	0.000	0.003	-7.340	-0.022
Site 12	0.084	0.000	0.001	66.330	0.080
Site 13	0.006	0.006	0.002	2.730	0.006
Site 14	0.0003	0.827	0.001	0.220	0.000
Site 15	-0.0003	0.875	0.002	-0.160	0.000
Site 16	-0.069	0.000	0.002	-36.990	-0.072
Site 17	-0.025	0.000	0.002	-16.170	-0.026
Site 18	-0.031	0.000	0.001	-45.120	-0.032
Site 19	-0.003	0.000	0.001	-5.630	-0.004
Site 20	0.043	0.000	0.001	54.160	0.042
Site 21					
Observations	2411				
LL(null)	-312547				
LL(model)	-247673				
df	25				
AIC	495396				
BIC	495541				
Pseudo R2	0.2076				

4.3.5 Interpretation of the Event Based Volume Model

Observations on each of the modeled variables and an examination of effects on volume reinforce several intuitive relationships. Results of the volume-based analysis indicate impacts on trip making decisions affecting trip making utility.

4.3.5.1 Temperature

The average temperature during an event was not a significant variable affecting traffic volume. This indicates that temperature does not play an important role in travelers' trip-making decisions.

4.3.5.2 Wind Speed

Wind speed was found to be significant however, with a small effect. A 10% increase in wind speed is expected to result in 0.48% drop in volume. This relatively small impact on speed is supportive of literature findings that wind speed was only a strong factor when very high wind speeds were reached [10] [16]. Despite the small coefficient, very strong winds could still result in large traffic volume reductions.

4.3.5.3 Visibility

Visibility had only a modest impact on volume reduction in the models. A 10% drop in visibility is correlated with a 0.52% drop in volume.

4.3.5.4 Precipitation

Precipitation has the anticipated impact on volume. This has one of the smallest observed effects on volume with a 10% increase in precipitation is correlated with a 0.15% drop in volume.

4.3.5.5 Site Variation

The variation by site could be interpreted in several ways. Some of the possible contributions to this variation are:

- More or fewer discretionary trips in different areas;
- More or less tolerance for winter conditions in different areas;
- Merging/weaving, curves, interchange density or other operational characteristics.

More extensive research is needed to identify the causes of the variation and quantify the exact impacts of these factors.

In the hourly based analysis presented below the locations were divided into urban and rural sites and separate models developed. The coefficients of the site specific constants were compared to this division between urban and rural to explore if this relationship appeared. In Table 10 sites 18 through 21 are "urban" while the remaining sites are "rural". Comparing the differences between site specific coefficients does not reveal a trend based on this urban/rural distinction. Nor is there another obvious pattern that could identify a source of variation between sites. Many other factors that could be captured by this site specific coefficient have not been tested. These include driver population (familiarity, behaviour, vehicle mix), geometric design, location and site context, and variation in how well the data collected matches actual conditions between sites.

4.3.5.6 RSI

Road surface index was shown to be a significant factor in volume models. A 10% drop in RSI was correlated with a 2% drop in volume. A large drop in RSI, for example from 0.90 to 0.45 (or 50%

drop) is correlated with a significant reduction in volume: on the order of 10%. This suggests a strong relationship between road conditions and an individual's decision to travel.

5 Analysis of Effects on Traffic Speed

5.1 Chapter Overview

This section details two key aspects of this research related to the relationship between winter storms and speed. It investigates the effects of winter storms, and specifically the effect of RSI, on median speed based on two data sets. The first set contains records of event long average conditions (the "event based" data set. The second set contains records at a one hour resolution.

The results discussed in this chapter clearly demonstrate that road surface condition, as measured by RSI, is one of the most significant factors in the correlation between winter storm conditions and median speed.

5.2 Factors influencing traffic speed

Factors influencing speed can intuitively be grouped into two categories: first, the vehicle and driver; second, the highway facility itself.

5.2.1 Vehicle and driver

The performance characteristics of each vehicle will obviously play a role in how fast that vehicle can travel. More importantly for this research is the behaviour of the driver. How a driver reacts to the other vehicles on the highway and how the driver reacts to adverse conditions are key to determining whether or not a driver will choose a different speed in response to poor RSC.

5.2.2 Highway facility

Several aspects of the highway facility design will influence how comfortable it is to travel at any given speed. For example, wider lanes shallower curves, appropriate superelevation and long sight distances all allow, and to some extent encourage, higher travel speeds. A smooth flat surface also makes travelling at higher speeds more comfortable. It seems likely that the converse of this is also true: that poor surface conditions lead to lower speeds.

5.3 Event Based analysis of traffic speed

5.3.1 Research question

This research focuses on the mobility effects of WRM which is assessed through the surrogate measure of highway RSC. In this section the effect on speed is investigated. As such, the specific question being asked in this section is:

Do WRM activities affect mobility in terms of delay to drivers?

5.3.2 Approach

In the event based dataset described above, each winter storm event has been summarized according to the average conditions over the duration of the event. Each event is also paired with a clear weather period in the week before or after of the same duration. The average conditions during the paired "clear weather" are used as a baseline from which to perform a pair wise comparison.

In this way the change in speed between "snow event" and "clear weather" is modeled as dependant on the relative change in independent variables such as hourly precipitation and RSI.

The modeled effect of RSI on speed is interpreted as an indicator of the potential impact of WRM activities.

5.3.3 Exploratory Data Analysis

For this model the dependant variable is taken as the median speed on a highway over the course of a snow storm. Each of the six key variables being tested was plotted against median speed below. Each of these exploratory plots only considers the effects of a single variable; as such any interaction between effects is masked. The data for median speed is originally binned in 5km/hr increments. These increments show up in the plots below as areas of concentrated data. Points between these 5km/hr bands are the result of averaging median speed across the duration of an event.

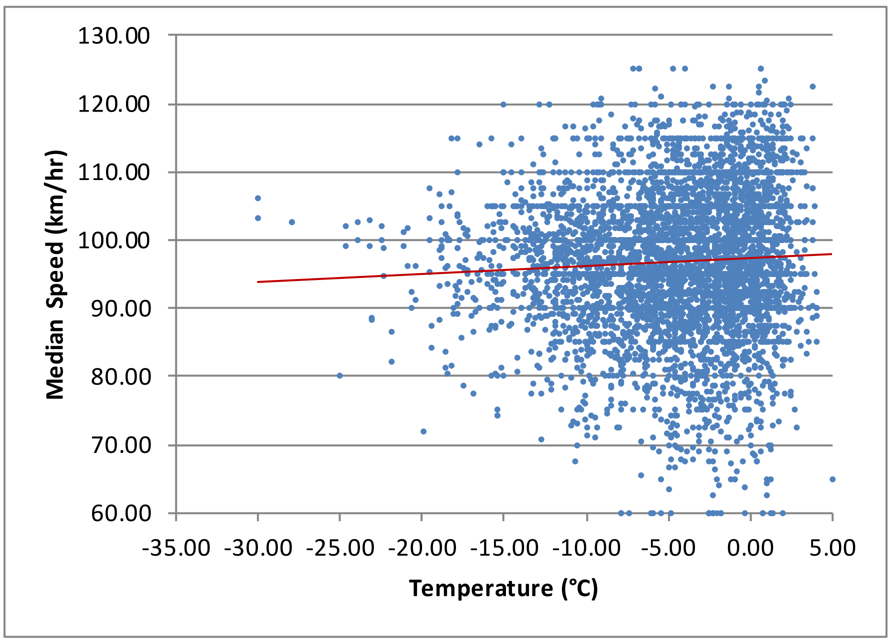


Figure 28: Temperature vs. Median Speed

As with the exploratory analysis of volume change, there is not really an obvious trend in the relationship between temperature and speed.

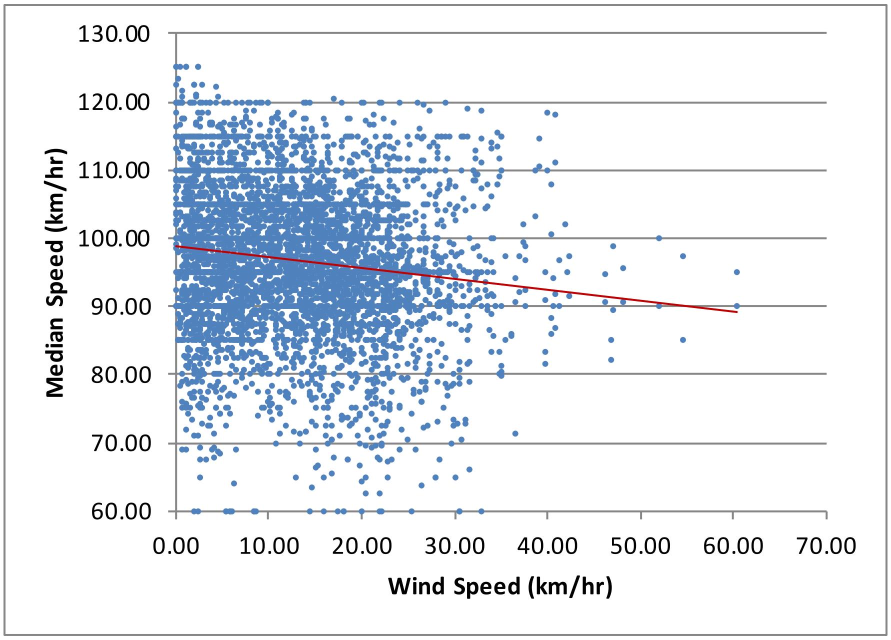


Figure 29: Wind Speed vs. Median Speed

Wind speed does appear to be correlated with lower speeds based on this linear trend line.

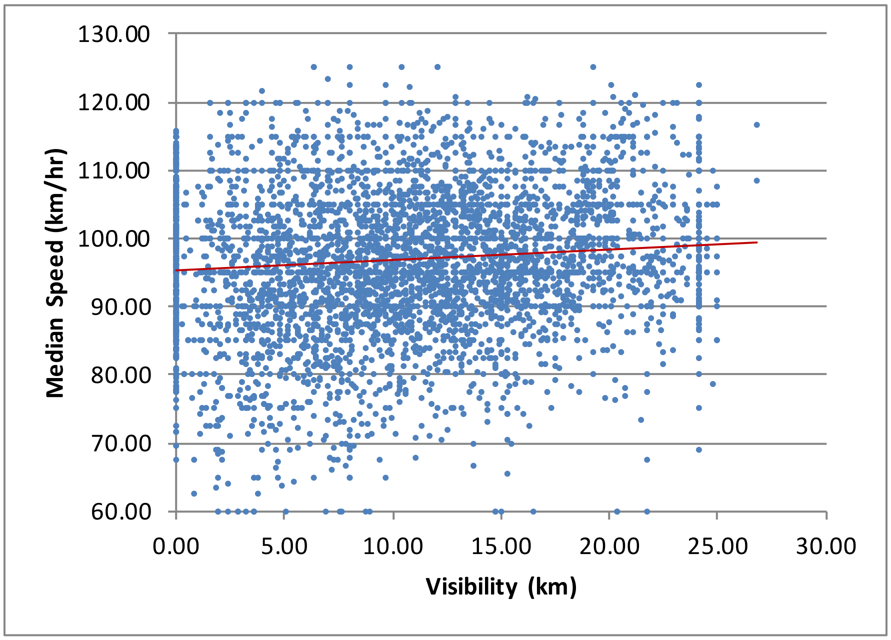


Figure 30: Visibility vs. Median Speed

The reporting bias discussed when exploring the volume change plots is evident again here. Again, a lower visibility appears to be correlated with lower visibility.

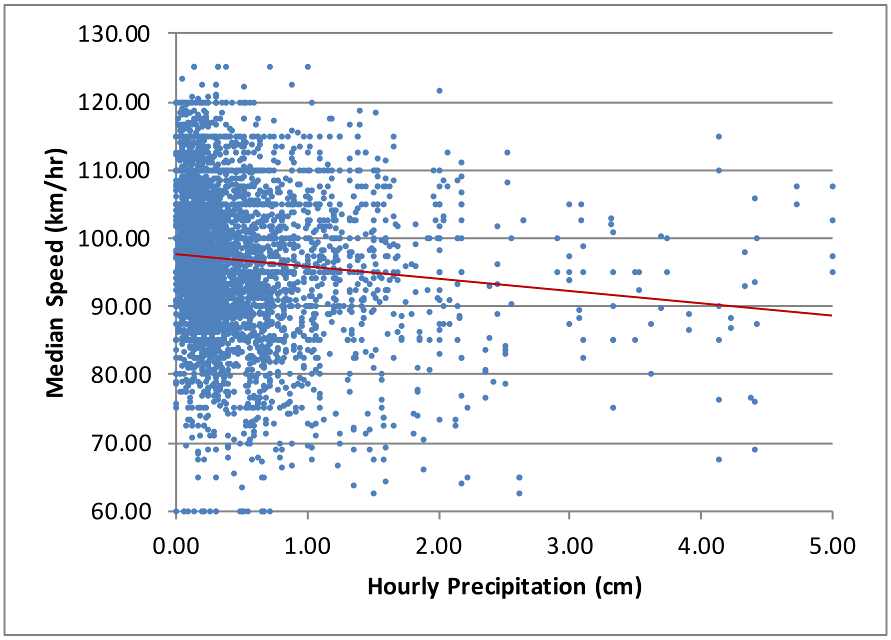


Figure 31: Precipitation vs. Median Speed

While the data is quite noisy the linear trend appears to indicate a strong relationship between speed and precipitation.

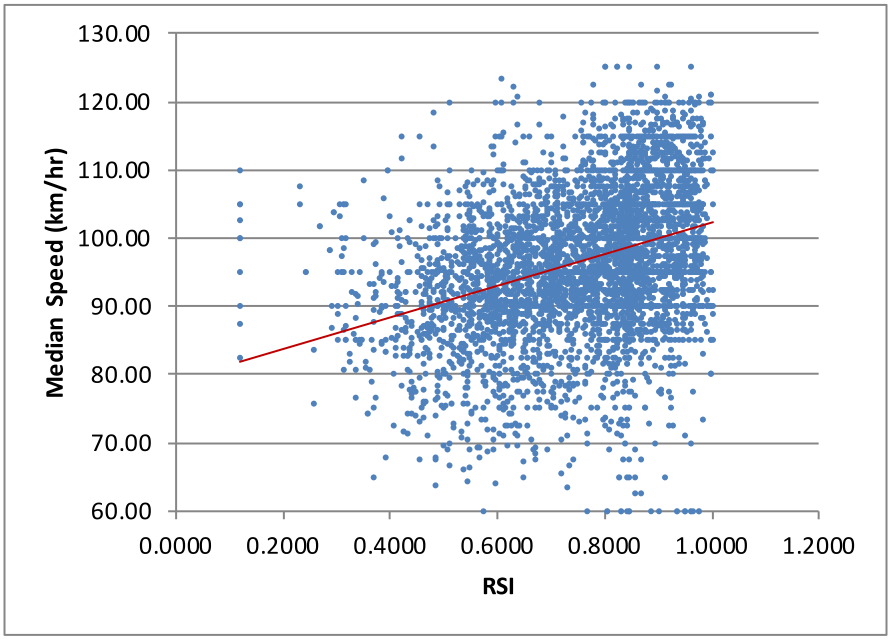


Figure 32: RSI vs. Median Speed

RSI, the primary factor of interest in this research, shows the most obvious correlation with speed of the variables tested.

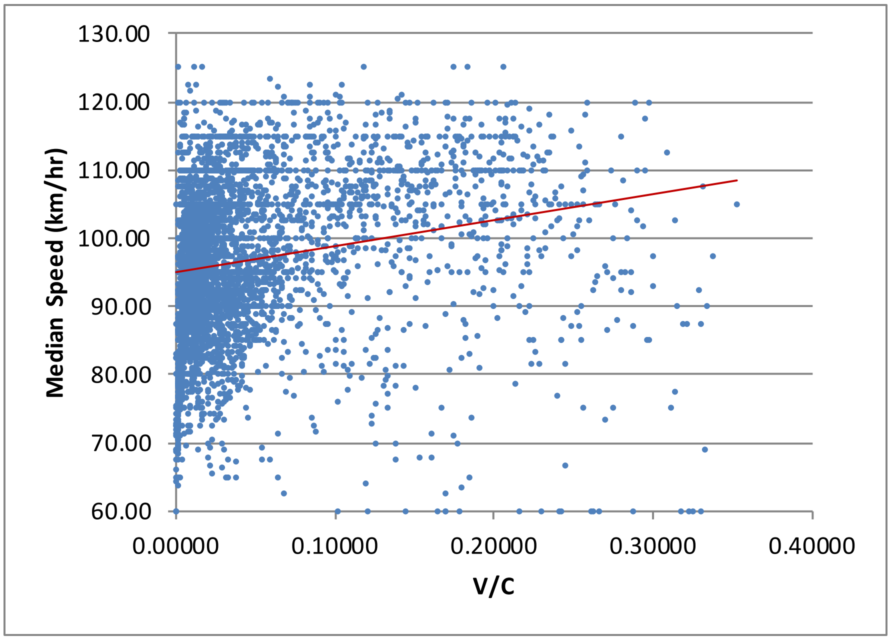


Figure 33: V/C vs. Median Speed

An increase in volume to capacity ratio appears to be correlated with an increase in speed. This counterintuitive result is likely due to the large proportion of the sample that is drawn from rural sites which have lower speeds and lower V/C ratios than urban sites. Exploratory analysis of the hourly dataset shows this question persists in the rural only data while the urban data follows the expected pattern of lower speeds with high V/C.

5.3.4 Event Based Model for Traffic Speed

The median speed during a snow event is modeled differently than volume. It is assumed to be a normally distributed random variable with its mean assumed to be a linear function of various influencing factors. Independent variables tested for significance include posted speed (categorical), temperature (°C), wind speed (km/h), visibility (km), hourly precipitation over the event (cm), RSI (unitless), average volume to capacity ratio (unitless) and site variation indicators (binary variable). A standard capacity of 2200 vehicles per lane per hour is assumed for all highways. Table 4 gives the modeling results with the final linear model that was found to best fit the full data set. The resulting model is given in Eq 6.

$$\mathrm{V} = 69.082 + 0.089 * Temperature - 0.078 * WindSpeed + 0.310 * Visibility - 1.258 * Precipitation + 16.974 * RSI - 4.325 * \frac{v}{c} + \sum_{1}^{\mathrm{n}} (x_{\mathrm{i}} * Speed_{\mathrm{i}}) + \sum_{1}^{\mathrm{n}} (y_{\mathrm{i}} * Site_{\mathrm{i}})$$ Eq 6

Table 11: Modeling Results for Median Speed

Variable	Coef.	Sig	Std. Err.	z	Elasticity
Constant	69.082	0.000	0.787	87.790	
Temperature	0.089	0.000	0.022	3.980	-0.004
Wind Speed	-0.078	0.000	0.013	-6.060	-0.010
Visibility	0.310	0.000	0.019	16.380	0.034
Hourly Precipitation	-1.258	0.000	0.140	-8.960	-0.007
RSI	16.974	0.000	0.708	23.970	0.133
Volume to Capacity Ratio (V/C)	-4.325	0.004	2.966	-2.920	-0.004
Posted Speed Limit (80 km/hr)					
Posted Speed Limit (90 km/hr)	1.951	0.007	0.718	2.720	0.020
Posted Speed Limit (100 km/hr)	12.621	0.000	0.818	15.430	0.130
Site1					
Site2	-4.521	0.000	0.807	-5.600	-0.047
Site3	7.664	0.000	0.664	11.530	0.079
Site4	12.023	0.000	0.704	17.080	0.124
Site5	12.459	0.000	0.658	18.920	0.129
Site6	12.812	0.000	0.718	17.850	0.132
Site7	7.825	0.000	0.857	9.130	0.081
Site8	10.295	0.000	0.791	13.010	0.106
Site9	17.189	0.000	0.716	24.010	0.178
Site10	11.380	0.000	0.690	16.500	0.118
Site11	10.031	0.000	0.672	14.930	0.104
Site12	7.244	0.000	0.662	10.950	0.075
Site13					
Site14	8.408	0.000	0.600	14.010	0.087
Site15	9.897	0.000	0.807	12.270	0.102
Site16	8.411	0.000	0.817	10.300	0.087
Site17	15.273	0.000	0.926	16.490	0.158
Site18	0.740	0.276	0.679	1.090	0.008
Site19	13.331	0.000	0.676	19.720	0.138
Site20	8.230	0.000	0.720	11.430	0.085
Site21					
Observations	4822				
R-squared	0.5879				
Adj R-squared	0.5857				

5.3.5 Interpretation of the Event Based Speed Model

Observations on each of the modeled variables and an examination of effects on median speed reinforce several intuitive relationships. Results of the median speed analysis indicate driving behaviour factors resulting in travel time impacts.

5.3.5.1 Temperature

The average temperature during an event had a small impact on median speed indicating that driving speed in winter conditions is only influenced by temperature by a small amount; not a surprise given most vehicles are able to control cabin temperature. The effect found may also be related to an unexplored higher order effect.

5.3.5.2 Wind Speed

Wind speed was found to be significant though the effect on traffic speed is relatively small. Each 10km/h increase in wind speed is correlated with a 0.8km/h drop in median speed. This relatively small impact on speed is supportive of literature findings that wind speed was only a strong factor when very high wind speeds were reached [10] [16]. Despite the small coefficient, strong winds could still result in large traffic volume and median speed reductions.

5.3.5.3 Visibility

Visibility had a strong effect on median speed. Each 10km drop in visibility could lead to a 3.1km/h drop in median speed. This is an intuitive result and supports the literature findings related to fog [16].

5.3.5.4 Precipitation

Precipitation has the anticipated impact on median speed. Each additional centimeter of precipitation is expected to result in a 1.3 km/h drop in median speed. Similar effects of precipitation are well documented in the literature [3] [7] [10] [11].

5.3.5.5 Volume

The impact of average volume (or volume to capacity ratio) on median speed was found to be relatively small, which is consistent with the general traffic stream patterns. A 0.1 increase in volume to capacity ratio would lead to 0.4 km/h reduction in median speed. It should be noted that traffic volume is expected to have a nonlinear effect on traffic speed, which needs to be examined in future research.

5.3.5.6 Site Variation

The variation by site could be interpreted in several ways. Some of the possible contributions to this variation are:

- More or less tolerance for winter conditions in different areas;
- Merging/weaving, curves, interchange density or other operational characteristics.

As discussed in Section 4.3.5.5 there is no obvious pattern that explains what may be contributing to the site specific constant. More extensive research is needed to identify the causes of the variation and quantify the exact impacts of these factors.

5.3.5.7 RSI

Road surface index was shown to be a significant factor in the median speed models. A 10% drop in RSI was correlated with a 1.7km/h drop in median speed. A reduction value of approximately 6.8km/h in median speed was found for a 0.4 drop in RSI. This drop in RSI roughly corresponds to the difference between bare pavement and snowy roads (see Figure 20). Higher drops, such as 0.6 to 0.8 that might be typical of the difference between bare pavement and snow packed or ice covered roads, are associated with larger speed and volume reductions: on the order of 10.2km/h to 13.6km/h.

5.4 Hourly based analysis of traffic speed

5.4.1 Research question

The question asked for this analysis is the same as that asked when investigating speed using the event based dataset. For this analysis however, the effects are considered on a much shorter time scale. Rather than looking at the average speed over an entire event, this analysis evaluates hour by hour changes in speed.

Do WRM activities affect mobility in terms of delay to drivers?

5.4.2 Approach

For this analysis the dataset was divided into two groups as discussed in Section 3.4.3. The first group consisted of "rural" highways and the second group coasted of "urban" highways. This was done to isolate the effect of volumes approaching capacity on speed experienced in "urban" locations.

Each event hour was paired with the typical median speed established based on non-event data. The difference between the observed median speed and the typical median speed was used as the dependant variable for regression modelling. This change in median speed at a point in time (1 hour resolution) was used as a measure of mobility and RSI as an indicator of the effect of WRM activities.

5.4.3 Exploratory Data Analysis

For this model the dependant variable is taken as the median speed on a highway over the course of a snow storm. Each of the six key variables being tested was plotted against median speed below. Data for rural sites and urban sites are shown separately. Each of these exploratory plots only considers the effects of a single variable; as such any interaction between effects is masked. The data for median speed is originally binned in 5km/hr increments. These increments show up in the plots below as bands of data. Due to a limitation on the number of points that can be simultaneously plotted each of the plots below contains a set of approximately 32,000 randomly selected records.

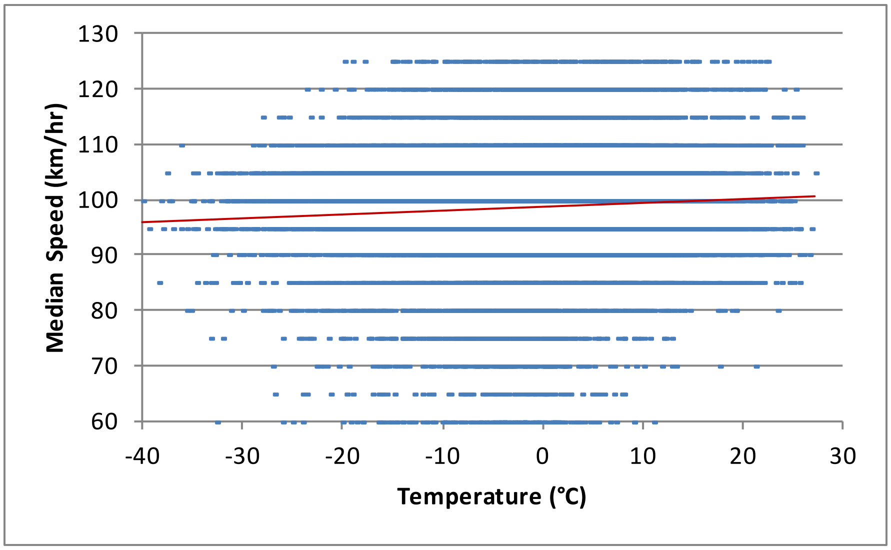


Figure 34: Rural Sites - Temperature vs. Median Speed

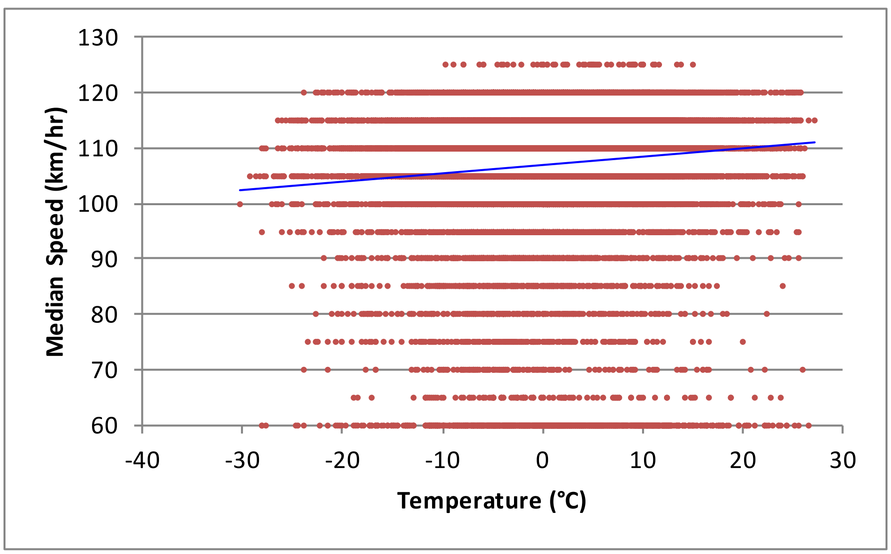


Figure 35: Urban Sites - Temperature vs. Median Speed

As with the previous analysis, plotting temperature against median speed does not demonstrate a clear relationship. The linear trend lines do appear to indicate a stronger effect of cold temperatures in urban environments.

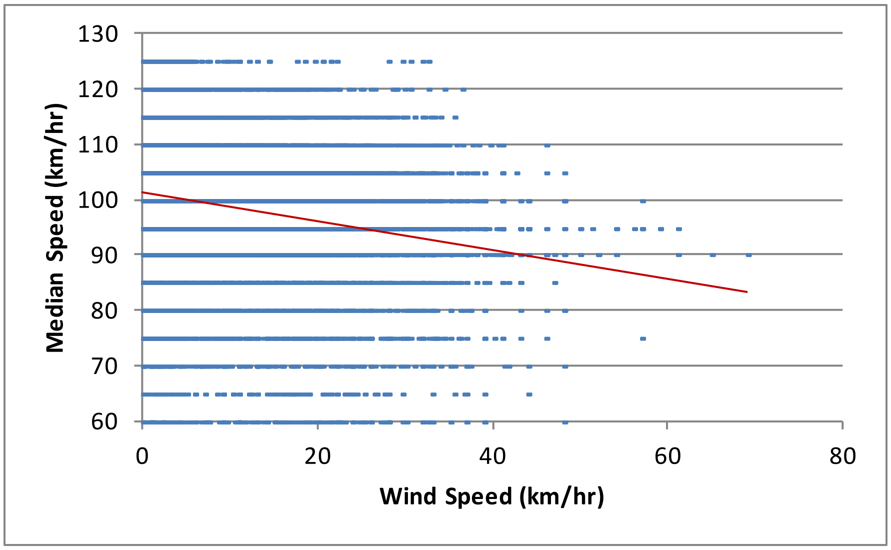


Figure 36: Rural Sites - Wind Speed vs. Median Speed

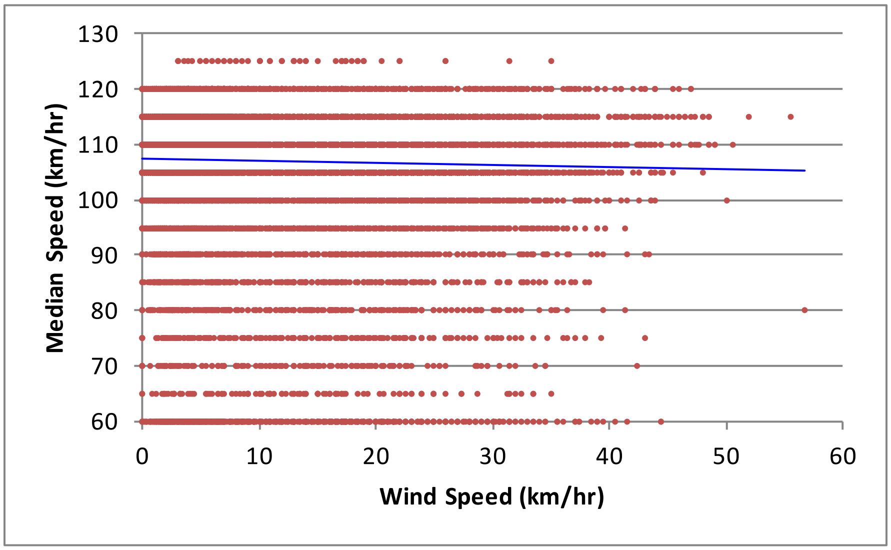


Figure 37: Urban Sites - Wind Speed vs. Median Speed

While no trend in the data plots is obvious, the linear trend of rural data shows a correlation between wind speed and a drop in speed.

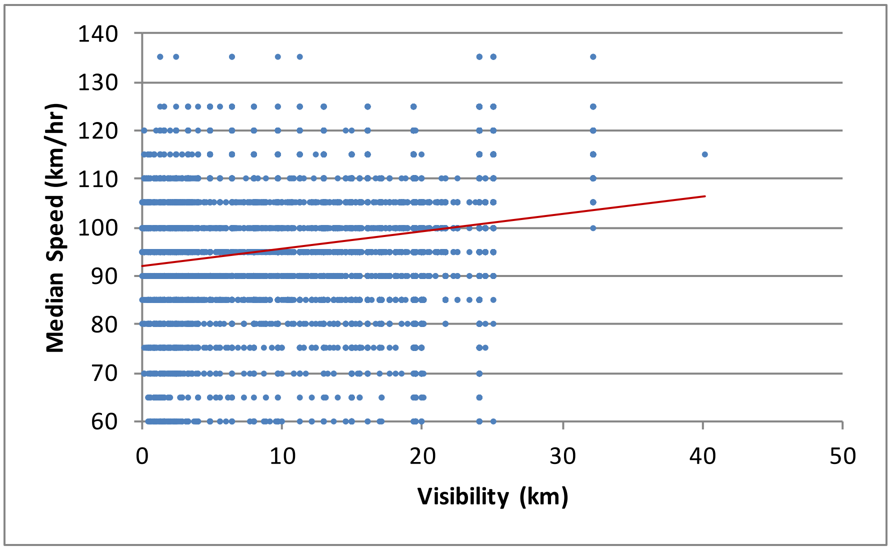


Figure 38: Rural Sites - Vivibility vs. Median Speed

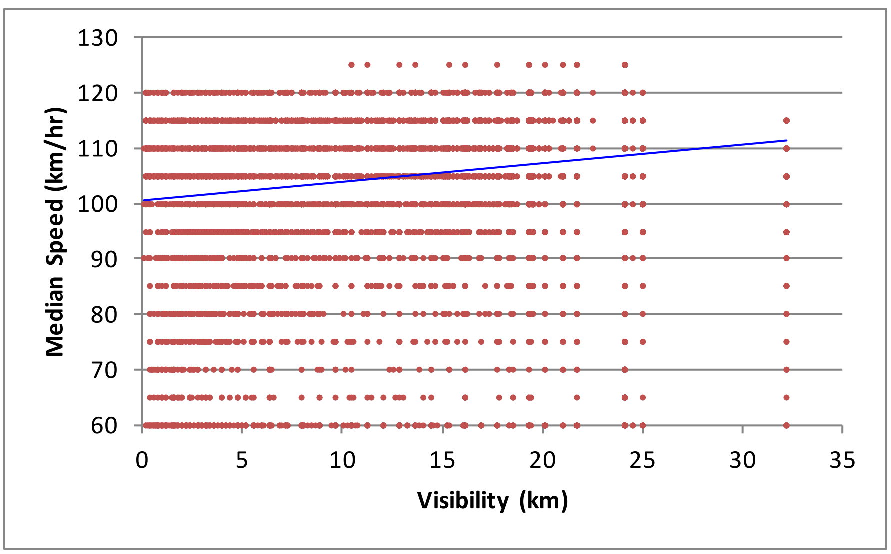


Figure 39: Urban Sites - Vivibility vs. Median Speed

Slower speeds at very low visibility are evident in these plots. This supports the linear trend showing the same correlation for both urban and rural sites.

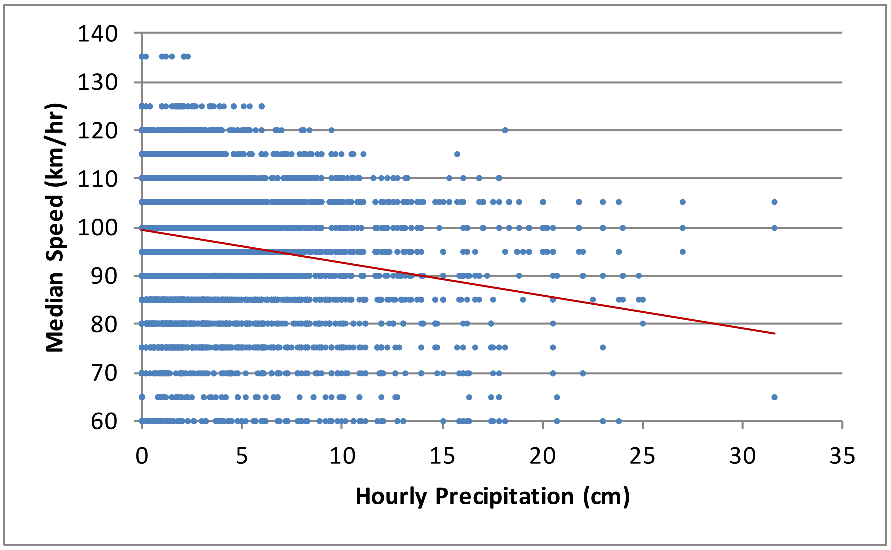


Figure 40: Rural Sites - Precipitation vs. Median Speed

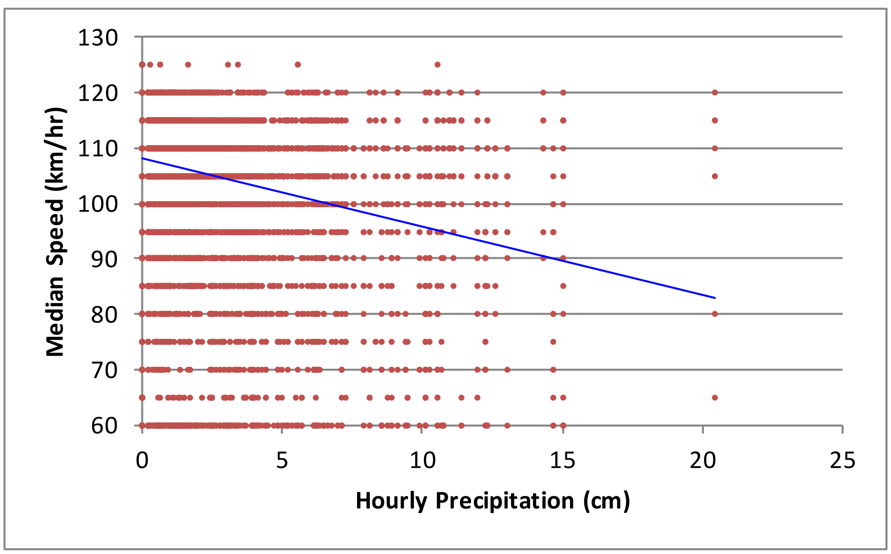


Figure 41: Urban Sites - Precipitation vs. Median Speed

A significant amount of noise in the data masks any visible trend relating speed and precipitation. However, the linear trend line shows a clear correlation for lower speeds with heavy precipitation for both urban and rural sites.

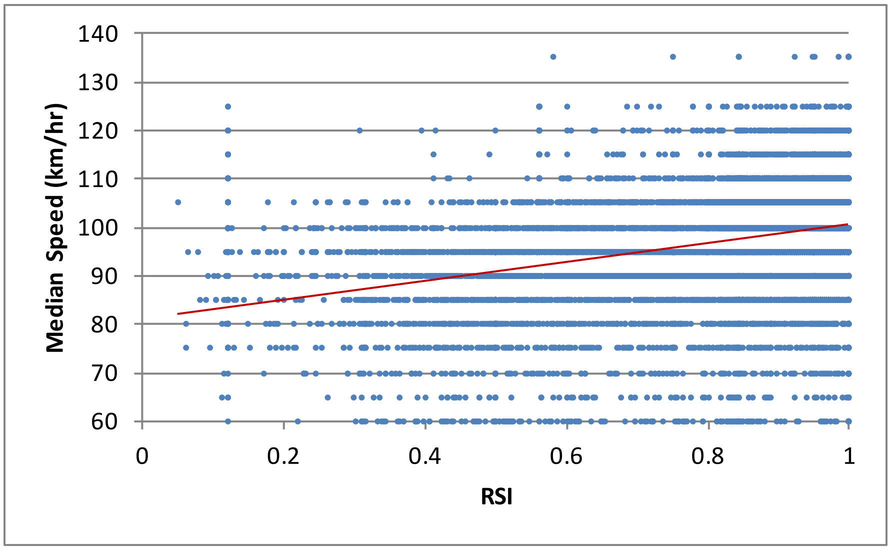


Figure 42: Rural Sites - RSI vs. Median Speed

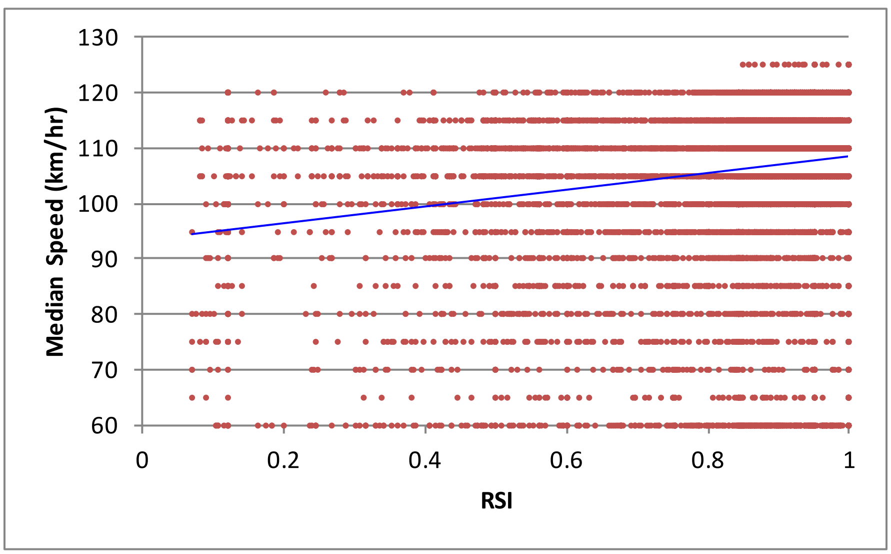


Figure 43: Urban Sites - RSI vs. Median Speed

The linear trend line shows that low RSI is correlated with lower speeds as is expected for this variable. This trend is clearly visible in the rural data set but less so in the urban data plot.

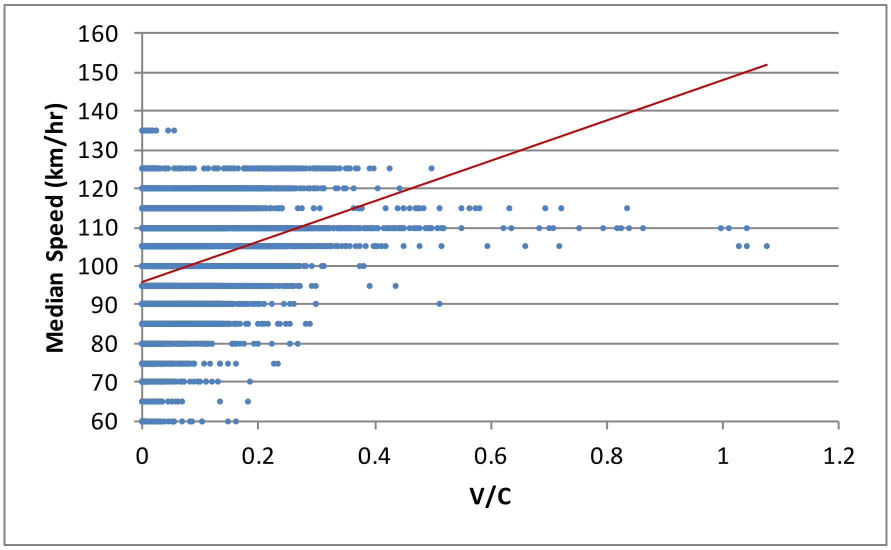


Figure 44: Rural Sites - V/C vs. Median Speed

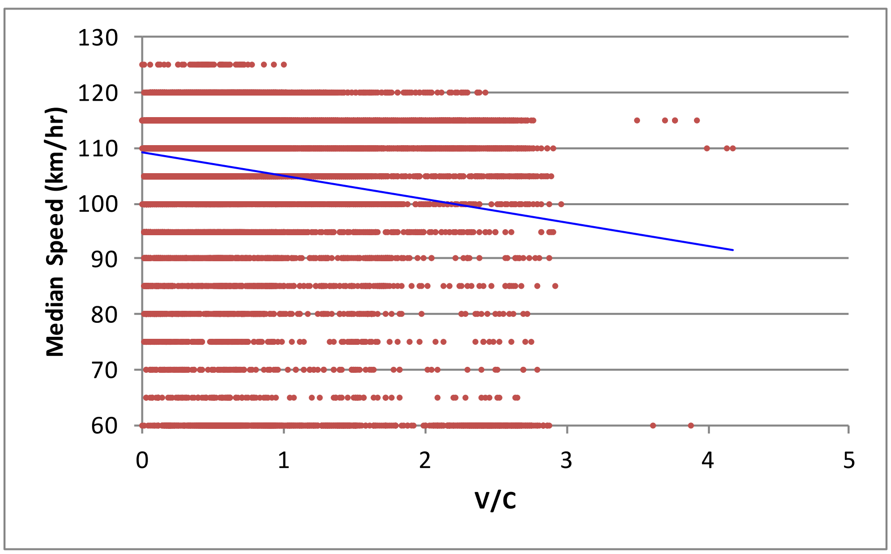


Figure 45: Urban Sites - V/C vs. Median Speed

Urban sites demonstrate the expected trend for lower speeds with higher V/C. However, for rural sites a non-intuitive result is shown where high V/C appears to be correlated with higher speed. The distributions of speed and V/C in this data (Appendix C) show that urban sites have a higher speed profile and higher volumes than do rural sites. This leads to a possible explanation of the non-intuitive result: it is possible that this result is a confounding effect of higher volume roads (and therefore higher V/C) having typically higher speeds which holds true during the low V/C regime that dominates at rural sites.

5.4.4 Hourly Model for Traffic Speed

The median speed on a highway, whether during a snow event or not is assumed to be a normally distributed random variable. As such the change in median speed between typical and event conditions will follow the same distribution and its mean will be assumed to be a linear function of various influencing factors. Independent variables tested for significance include temperature (°C), wind speed (km/h), visibility (km), hourly precipitation over the event (cm), volume (per hour), RSI (unitless), facility type (categorical), daylight (binary) and site variation indicators (binary variable).

Through a process of testing various models, see Figure 46, the most significant variables were identified. In the case of the "hour" variable, the results achieved led to the creation of the "daylight" variable. Ultimately, separate models were developed for speeds on both rural and urban highways. These final models are highlighted in Figure 46.

Physically intuitive (sign of coefficient)		+		-		+		-		+		-		-		+		+		+				
		Independant Variables																				
Model Test	Sites Included	TEMP		WIND		VIS		PRECIP_CM		RSI		VOLUME		V/C		HOUR		STORMHOUR		DAYLIGHT		_CONS		Adj. R^2
		Coef.	Sig.	Coef.	Sig.	Coef.	Sig.	Coef.	Sig.	Coef.	Sig.	Coef.	Sig.	Coef.	Sig.	Coef.	Sig.	Coef.	Sig.	Coef.	Sig.	Coef.	Sig.	
1	Combined	0.060	0.000	-0.023	0.000	0.296	0.000	-0.516	0.000	12.927	0.000	-0.001	0.000			0.036	0.000	0.013	0.011			-16.07	0.000	0.246
2	Combined	0.058	0.000	-0.022	0.000	0.297	0.000	-0.516	0.000	12.827	0.000	-0.001	0.000			0.036	0.000					-15.92	0.000	0.245
3	Combined	0.062	0.000	-0.023	0.000	0.296	0.000	-0.504	0.000	13.052	0.000	-0.001	0.000					0.014	0.005			-15.80	0.000	0.245
4	Combined	0.024	0.002	-0.030	0.000	0.293	0.000	-0.477	0.000	11.973	0.000											-15.89	0.000	0.213
5	Rural	-0.015	0.037	-0.017	0.000	0.241	0.000	-0.477	0.000	11.711	0.000											-14.54	0.000	0.253
	Urban	0.391	0.000	-0.045	0.000	0.521	0.000	-0.881	0.000	15.371	0.000											-22.35	0.000	0.263
	Combined	0.060	0.000	-0.022	0.000	0.298	0.000	-0.504	0.000	12.945	0.000	-0.001	0.000									-15.63	0.000	0.245
6	Rural	-0.026	0.000	-0.016	0.000	0.241	0.000	-0.482	0.000	11.528	0.000	0.002	0.000									-14.85	0.000	0.257
	Urban	0.425	0.000	-0.039	0.002	0.522	0.000	-0.896	0.000	17.702	0.000	-0.001	0.000									-21.49	0.000	0.284
	Combined			-0.019	0.000	0.292	0.000	-0.501	0.000	13.231	0.000	-0.001	0.000									-16.14	0.000	0.244
7	Rural			-0.017	0.000	0.244	0.000	-0.484	0.000	11.405	0.000	0.002	0.000									-14.61	0.000	0.257
	Urban			-0.036	0.005	0.496	0.000	-0.916	0.000	19.723	0.000	-0.001	0.000									-24.54	0.000	0.265
	Combined			-0.028	0.000	0.290	0.000	-0.476	0.000	12.095	0.000											-16.09	0.000	0.213
8	Rural			-0.018	0.000	0.243	0.000	-0.478	0.000	11.636	0.000											-14.41	0.000	0.253
	Urban			-0.042	0.001	0.497	0.000	-0.901	0.000	17.395	0.000											-25.12	0.000	0.247
	Combined	0.056	0.000			0.295	0.000	-0.509	0.000	12.981	0.000	-0.001	0.000									-15.96	0.000	0.244
9	Rural	**-0.029**	0.000			0.240	0.000	-0.486	0.000	11.568	0.000	0.002	0.000									-15.10	0.000	0.257
	Urban	0.423	0.000			0.514	0.000	-0.914	0.000	17.578	0.000	-0.001	0.000									-21.86	0.000	0.283
	Combined	0.053	0.000	-0.034	0.000	0.306	0.000	-0.519	0.000	12.396	0.000	-0.001	0.000							3.441	0.000	-16.56	0.000	0.273
10	Rural	**-0.027**	0.000	-0.028	0.000	0.249	0.000	-0.487	0.000	11.019	0.000	0.000	0.178							3.129	0.000	-15.45	0.000	0.286
	Urban	0.416	0.000	-0.052	0.000	0.523	0.000	-0.916	0.000	17.989	0.000	-0.001	0.000							3.112	0.000	-22.10	0.000	0.294
	Combined	0.014	0.072	-0.040	0.000	0.299	0.000	-0.486	0.000	11.412	0.000									2.819	0.000	-16.68	0.000	0.232
11	Rural	**-0.026**	0.000	-0.028	0.000	0.249	0.000	-0.486	0.000	11.029	0.000									3.163	0.000	-15.43	0.000	0.286
	Urban	0.385	0.000	-0.049	0.000	0.521	0.000	-0.886	0.000	15.247	0.000									0.951	0.000	-22.62	0.000	0.264
12	Rural	-0.007	0.331	-0.032	0.000	0.245	0.000	-0.470	0.000	10.929	0.000			4.473	0.000					2.901	0.000	-15.37	0.000	0.277
	Urban	***0.420***	***0.000***	***-0.048***	***0.001***	***0.527***	***0.000***	***-0.938***	***0.000***	***17.143***	***0.000***			***-4.472***	***0.000***					***2.364***	***0.000***	***-22.19***	***0.000***	***0.287***
13	Rural	-0.003	0.698	-0.033	0.000	0.246	0.000	-0.468	0.000	11.005	0.000									3.109	0.000	-15.28	0.000	0.276
	Urban	0.389	0.000	-0.047	0.001	0.519	0.000	-0.911	0.000	15.241	0.000									0.963	0.000	-22.47	0.000	0.267
14	***Rural***			***-0.033***	***0.000***	***0.246***	***0.000***	***-0.472***	***0.000***	***10.887***	***0.000***			***4.378***	***0.000***					***2.903***	***0.000***	***-15.29***	***0.000***	***0.276***
	Urban			-0.046	0.001	0.496	0.000	-0.938	0.000	19.442	0.000			-4.107	0.000					2.470	0.000	-25.52	0.000	0.268
15	Rural			-0.033	0.000	0.246	0.000	-0.469	0.000	10.986	0.000									3.107	0.000	-15.24	0.000	0.276
	Urban			-0.045	0.001	0.491	0.000	-0.913	0.000	17.529	0.000									1.167	0.000	-25.55	0.000	0.251

Figure 46: Regression Model Testing

Eq 7 shows the best fit linear model for the overall rural data set. Note that volume is not a significant variable in this model. The adjusted R^2 value for this model is 0.2764. As expected there is a significant amount of unexplained variation in speed using only environmental variables. Table 12 shows the regression results for this model.

$$\Delta V = -15.287 - 0.033 * WindSpeed + 0.246 * Visibility - 0.472 * Precipitation + 10.887 * RSI + 4.378 * V/C + 2.903 * Daylight \quad \text{Eq 7}$$

Table 12: Rural Sites Regression Results

Variable	Coef.	P>t	[95% Conf. Interval]	
Wind Speed	-0.03307	<0.001	-0.0414	-0.02473
Visibility	0.246235	<0.001	0.235756	0.256713
Precipitation	-0.47158	<0.001	-0.49304	-0.45012
RSI	10.88714	<0.001	10.49855	11.27572
V/C	4.37801	<0.001	2.85159	5.904431
Daylight	2.902785	<0.001	2.729091	3.07648
Constant	-15.2866	<0.001	-15.6276	-14.9456

Similarly, Eq 8 shows the best fit linear model for the overall urban data set. Temperature now has a significant effect on change in speed. More importantly, the magnitude of effects found in the rural model has been magnified; presumably by the increased density found in the urban conditions. Again, there is a significant amount of unexplained variation in speed; the adjusted R^2 value for this model is 0.2871. Table 13 shows the regression results for this model.

$$\Delta V = -22.192 + 0.420 * Temperature - 0.048 * WindSpeed + 0.527 * Visibility - 0.938 * Precipitation + 17.143 * RSI - 4.472 * \frac{V}{C} + 2.364 * Daylight \quad \text{Eq 8}$$

Table 13: Urban Sites Regression Results

Variable	Coef.	P>t	[95% Conf. Interval]	
Temperature	0.419885	<0.001	0.363988	0.475783
Wind Speed	-0.04763	<0.001	-0.07479	-0.02048
Visibility	0.527471	<0.001	0.491232	0.56371
Precipitation	-0.93832	<0.001	-1.03512	-0.84152
RSI	17.14269	<0.001	15.79233	18.49306
V/C	-4.47154	<0.001	-5.05009	-3.89299
Daylight	2.364446	<0.001	1.804025	2.924867
Constant	-22.192	<0.001	-23.452	-20.932

5.4.5 Model Validation

In order to validate the models, data from both the urban and rural groups were randomly divided in 80% (calibration data) and 20% (validation data). Models obtained from the calibration data were then applied to the validation data to validate the models. Figure 47 and Figure 48 show plots of modeling results versus observed values from the validation data for both rural and urban sites respectively.

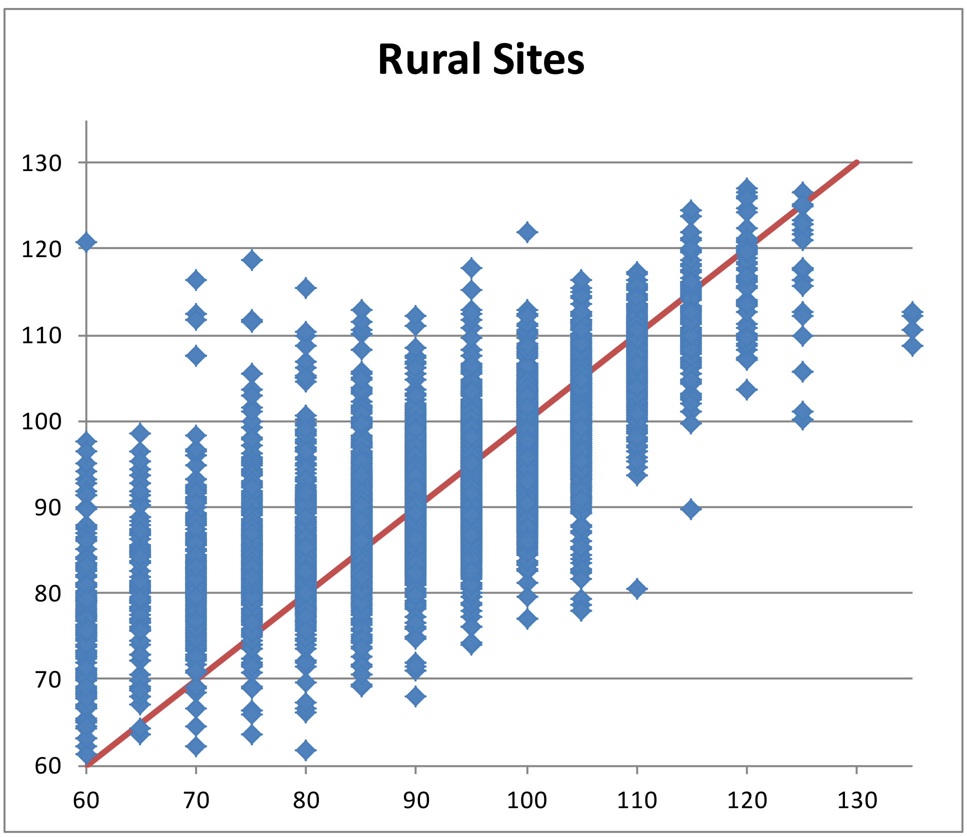


Figure 47: Rural Sites Modeled vs. Actual Median Speed

As expected, based on the low adjusted R^2 values, this figure demonstrates that there remains a systematic error in the predictive power of this model. While the model predicts speeds in the appropriate range, low speeds are consistently overestimated and high speeds consistently underestimated.

The same pattern is demonstrated in the figure below based on data from urban sites. Urban sites have a larger variation in travel speeds and, without a sophisticated density responsive component to the model, the predictive accuracy appears worse than that for rural sites.

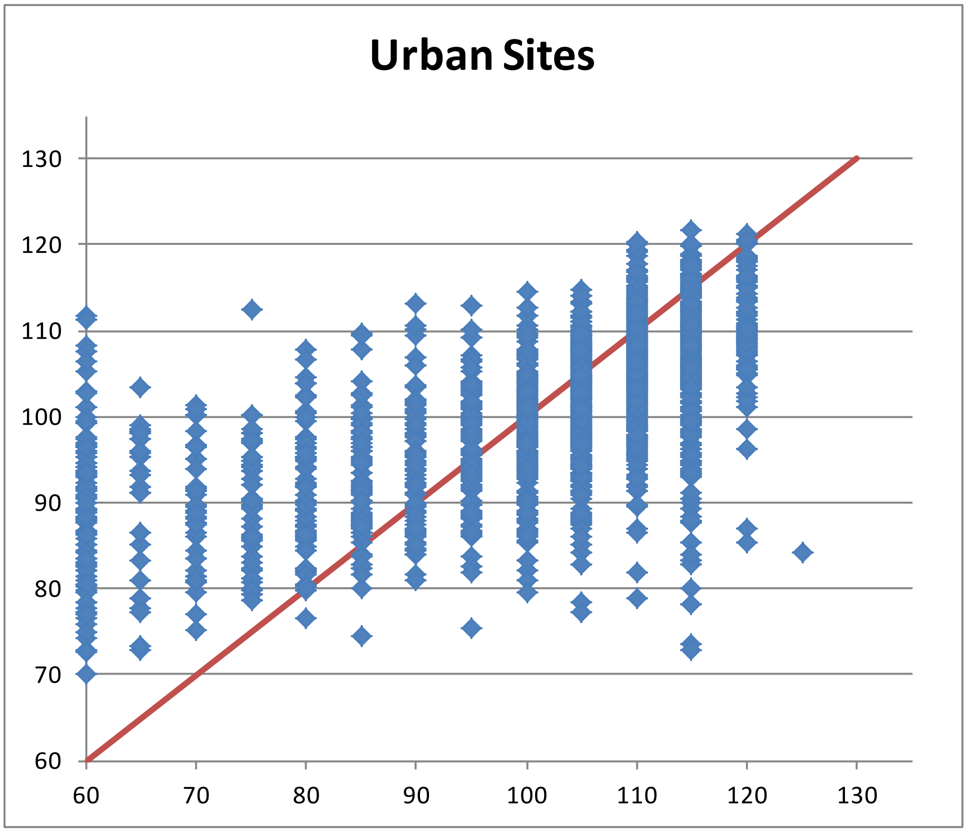


Figure 48: Urban Sites Modeled vs. Actual Median Speed

5.4.6 Interpretation of the Hourly Models

The relationship between the results of this analysis and real world phenomena are discussed below. Generally speaking, the results above agree with the findings of the literature as they relate to the atmospheric variables. Results in the literature showing a reduction in average speed on snow covered roads agree with the median speed reduction related to drops in RSI [7] [16].

Observations on each of the modeled variables reinforce several intuitive relationships. Results of the median speed analysis indicate effects on driving behaviour in adverse weather conditions.

5.4.6.1 Constant

The linear regression was performed on data records from snowstorms and the dependant variable was change in median speed from normal to snowstorm conditions. As such, the constant term represents the base speed reduction experienced during snowstorms. Other effects then modify this base reduction, up or down, depending on the specific conditions during a given hour on a given highway.

The constant term is the largest single factor in the fitted linear models. From it we can expect a base median speed reduction of 15.3km/h (rural) or 22.2km/h (urban) during snow storms. As shown below, RSI is the only other variable in this data set that approaches this magnitude of effect on speeds.

5.4.6.2 Temperature

The average temperature was not a strong variable affecting traffic speeds. For rural sites, it is an insignificant variable. The role of temperature was stronger for urban sites where a 10°C increase translates to a median speed increase of 4.2km/h. Considering the average temperature in the data set is close to freezing, this change in temperature may be confounded with other atmospheric effects. This, however, was not explored in the analysis.

5.4.6.3 Wind Speed

Wind speed was found to be significant; a 10km/h increase in wind speed is expected to result in 0.33 km/h (rural) or 0.48km/h (urban) drop in speed. The effect of wind speed on traffic speed is relatively small. This relatively small impact on speed is supportive of literature findings suggesting that wind speed was only a strong factor when very high wind speeds were reached [10] [16]. Despite the small coefficient, strong winds could still result in large median speed reductions.

5.4.6.4 Visibility

Visibility had a much stronger effect on median speed. Each 10km drop in visibility could lead to a 2.5km/h (rural) or 5.3km/h (urban) drop in median speed. This is an intuitive result and supports the literature findings related to fog [16].

5.4.6.5 Precipitation

Precipitation has the anticipated impact on median speed. Each additional centimetre of precipitation is expected to result in a 0.47km/h (rural) or 0.97km/h (urban) drop in median speed. Similar effects of precipitation are well documented in the literature [3] [7] [10] [11].

5.4.6.6 Volume

For urban sites the linear impact of volume to capacity ratio (v/c) on median speed was found to be moderate. An increase of 0.1 in v/c would lead to a .45km/h reduction in median speed.

However, for rural sites the opposite effect was evident in the data. An increase of 0.1 in v/c would lead to a 0.44km/h increase in speed. As road surface condition is only collected every few hours, it is possible that increased volume for rural sites improves RSI (by clearing wheel tracks) beyond that recorded by maintenance personnel.

5.4.6.7 Daylight

The presence of daylight was represented as a binary variable based on the simplification that daylight would be present between 08:00 and 18:00. Given the winter season and typical sunrise and sunset times for Ontario this approximation was appropriate. Daylight had about the same effect for both rural and urban sites where median speeds were about 2.4 to 2.9km/h faster during the day.

5.4.6.8 RSI

Road surface index was shown to be a significant factor in median speed models. Each drop of 0.1 in RSI is correlated with a 1.1km/h (rural) or 1.7km/h (urban) drop in median speed. A reduction value of approximately 4.4km/h to 6.8km/h in median speed was found for a 0.4 drop in RSI. This drop in RSI roughly corresponds to the difference between bare pavement and snowy roads (see Figure 2). Higher drops, such as 0.6 to 0.8 that might be typical of the difference between bare pavement and snow packed or ice covered roads, are associated with larger speed reductions: on the order of 6.6km/h to 13.6km/h.

6 Applications

6.1 Event Based Mobility Benefits of WRM – Case Study

This section shows an application of the developed mobility impact models for quantifying the mobility implications of alternative WRM policy and programs. As shown in the previous section, a small reduction in highway volume could represent a significant displacement of vehicles and a large impact on mobility of the surrounding community. For example, if work trips are postponed or cancelled, there is an obvious loss of productivity and loss of income. Discretionary trips are likely to be among the most commonly displaced. Loss of these trips represents a loss of the economic activity and social well-being commonly associated with these types of trips. A correlation between RSI and volume indicates that people will make cancellation or rescheduling decisions based on their knowledge of road conditions.

Likewise, a small reduction in speed can dramatically increase travel times. This supports the common knowledge that drivers will slow for poorer road conditions. On a typical 10km highway segment with a posted speed of 90 km/h, a drop to 70km/h translates to an additional 1.9 minutes of delay per vehicle.

A case study is developed to demonstrate these results using the three winter seasons of snow event data for the 21 sites. For the purposes of this case study the level of service (LOS) achieved through WRM activities is described by the average RSI during a snow event. For example, if the WRM goal is to achieve pavement minimum RSI of 0.6, then the average RSI of each highway over each event of a winter season must be greater than 0.6.

Benefits are calculated as increases in speed (travel time savings) and trips not displaced (trip making utility) by achieving a given RSI target as a result of WRM activities. For a given target RSI, all events are examined and their RSIs under the existing WRM program are estimated. If the average RSI during a snow event in the data set is higher than the target value then no benefit is calculated. For those events that have an RSI less than the target RSI, it is assumed that, under the new target LOS goal, additional WRM operations would be provided to improve their RSI to the target value. The improvement in RSI would lead to increase in traffic volume over these events, which can be predicted using Eq 5. The increase in traffic volume could then be translated benefit due to improved trip-making utility (i.e., these trips would otherwise be canceled or shifted to other periods). In addition, the increase in RSI would also improve the average traffic speed, as predicted by Eq 6. This will result in reduction in travel time, which can then be translated into dollar value based on value of time. In this exercise, we assumed a uniform $10 per trip not displaced (for trip making utility) and a value of time of $20 per hour (for travel time savings).

These benefits on a storm by storm basis for all the study sites are aggregated to the total of the three seasons in the data set and averaged to represent a single typical winter season. For the purposes of this case study, the results are scaled to the entire Ontario provincial highway network. This is achieved based on a simple ratio considering the study sites are made up of about 13% of the complete network (in terms of lane-km). It should be noted that the resulting amount represents the additional benefit that could be expected from implementing the new target LOS goal (minimum RSI to be maintained over each storm).

As shown in Figure 49, the mobility benefit of achieving the target RSI of 0.8 bare pavement conditions is on the order of 17 million dollars per winter season on the provincial highway network in Ontario. This figure represents the monetized value of WRM to maintain bare pavement. The WRM policy for the study sites expects bare pavement recovery within 8 hours of bare pavement loss.

There is significant benefit that occurs after an event has finished that is currently realized through ongoing WRM activities (but not included in this case study). In a study of highways in the state of Minnesota, Ye et al. estimated the benefits of the existing state WRM program to be $227 million per season with $11 million attributed to travel time savings alone [23]. The Oak Ridge National Laboratory estimated that total delay due to snow across the US was 43.8 million hours in 1999 [26]. Using a $20/h value for time as done in this case study, the US wide travel time impacts of delay due to snow were $876 million in 1999.

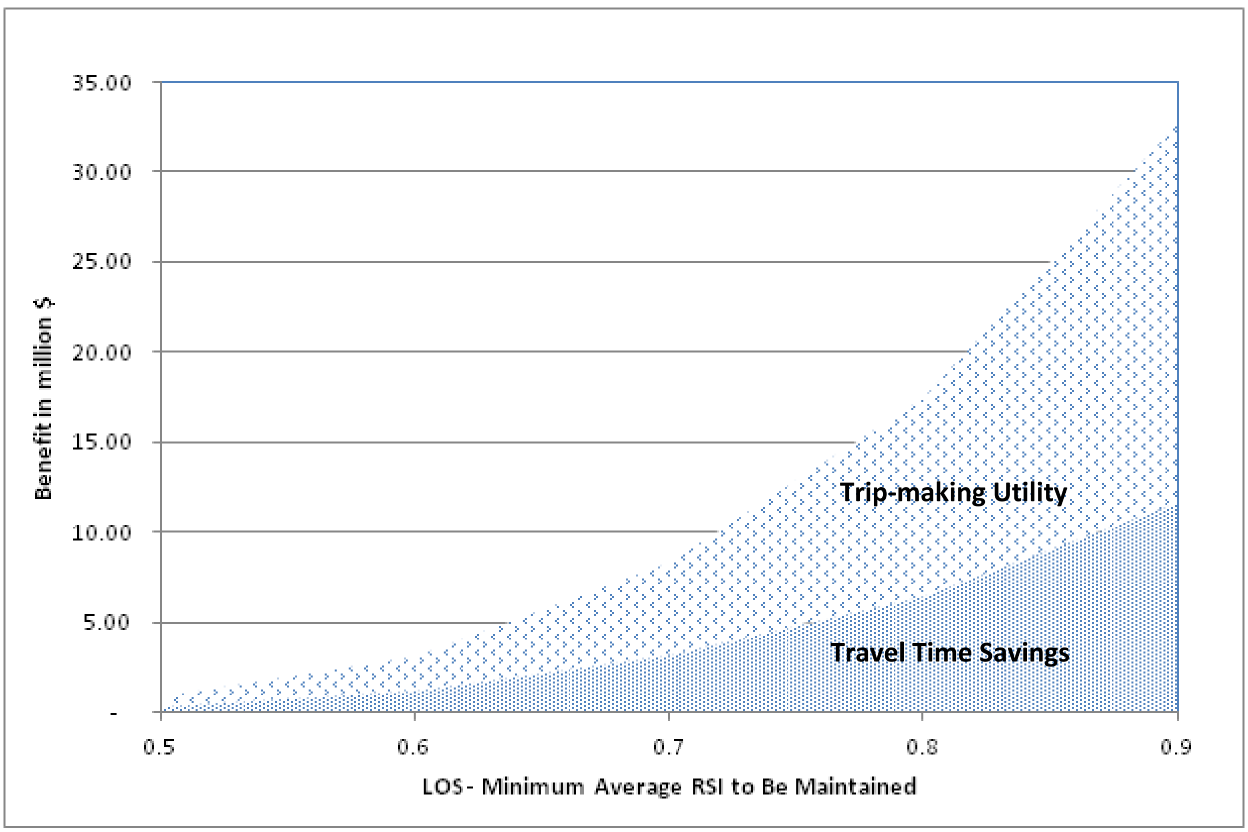


Figure 49: Mobility Benefit of WRM versus WRM LOS Standard (Ontario Provincial Network)

6.2 Mobility Effects of WRM at Hourly Resolution

The mobility impact of a winter snowstorm can be described as the period of time during which reduced speeds are warranted due to environmental conditions. As one of the largest determining factors, RSI and by extension, WRM, play a key role in mobility during winter months. Figure 50 shows the temporal profile for a sample snowstorm at a rural site. Shown are the speed (actual median speed), base speed (long term average for hour of day during winter) and modeled speed (speed predicted by regression model in Eq 7). In addition, RSI and V/C are plotted on the secondary axis.

This chart shows the similarity between speed and RSI profiles. As expected from the strong correlation between these variables they move, more or less, together.

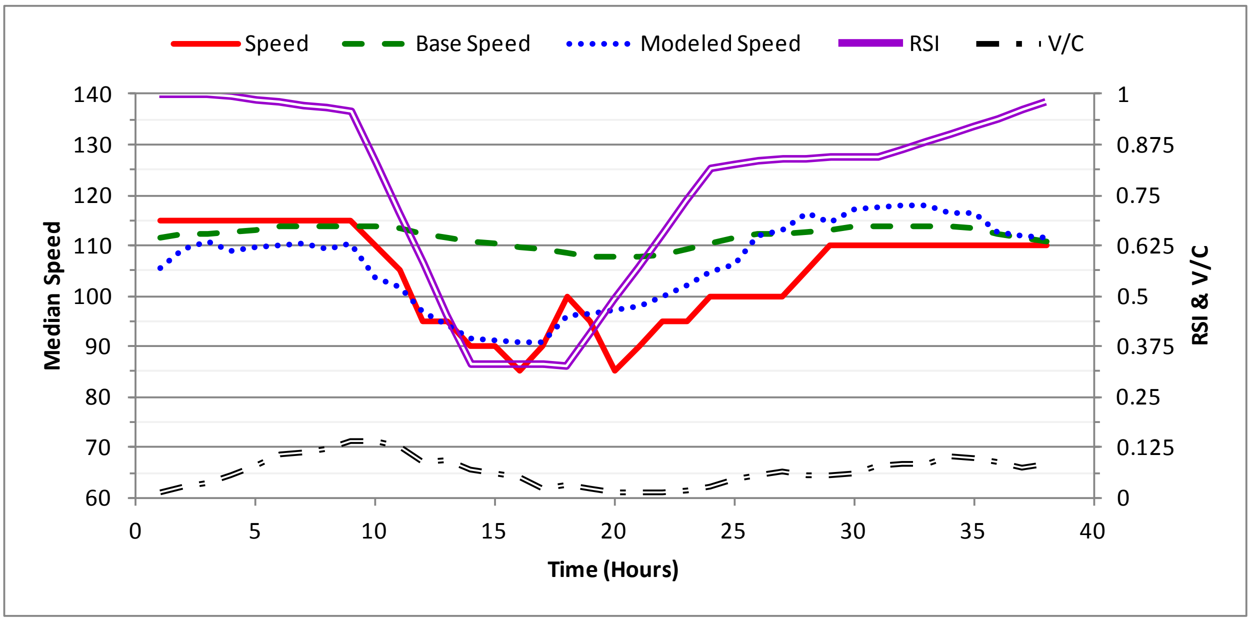


Figure 50: Sample Rural Event – Temporal Profile

In Figure 50, the area between the base speed and the actual speed is a measure of mobility impact. This can be expressed as cumulative delay over the duration of an event. By increasing WRM activities an authority might improve the RSI sooner and minimize this delay. The potential for this type of change is explored in the case study above.

Similarly, a road authority may evaluate WRM policy by comparing actual delays incurred to delays under a variety of bare pavement recovery policies. This delay might also be extended to an economic cost, as in the case study above, and used to evaluate the benefits of various levels of service policies.

In addition to use as a WRM policy assessment tool, this analysis may be used to remotely evaluate WRM performance based only on traffic sensors already deployed in the field. One of the largest factors in determining speed on a rural highway during a snowstorm in this model is RSI. By extending this relationship a model might be developed that could predict approximate

RSI based on traffic sensor data. This could in turn be used to verify maintenance performance and achievement of WRM policy targets for bare pavement recovery times. This is, however, left for future exploration.

The general pattern of relationships that these applications rely on holds true for urban highways. However, Figure 51 demonstrates that the complexities introduced by congestion effects may make application difficult. For example, in Figure 50 the drop in speed at about hour 10 is highly correlated with the drop in RSI at that time, the same cannot be said for the speed drop shown at about hour 20 in Figure 51.

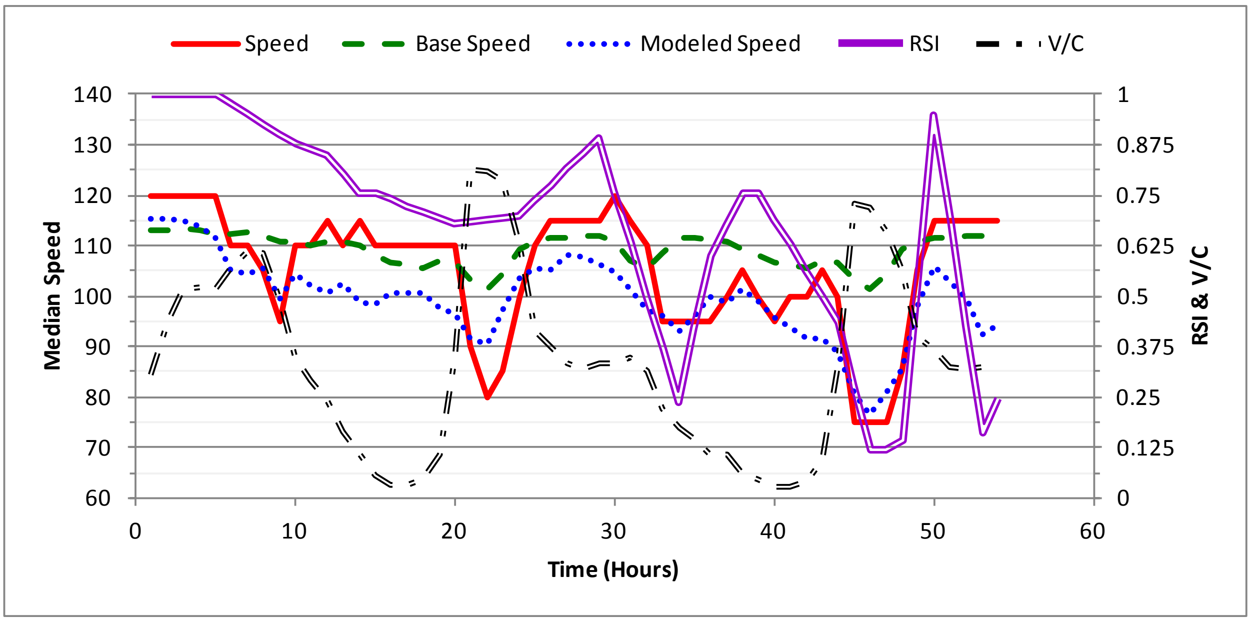


Figure 51: Sample Urban Event – Temporal Profile

7 Conclusions

Using data from 21 different highway locations through Ontario, Canada, this research investigated the relationship between winter road maintenance and mobility. This was achieved by using a measure of road surface condition as an indicator of what maintenance activities are achieving. Similarly the traffic volume and median speeds on these highways were used to estimate trip making utility and cost of delay, respectively.

Poisson and linear regression was carried out to model highway volume and speed as a function of environmental variables as well as road surface index. Both event based (event long average conditions) and hourly based (one hour average conditions) datasets were used in this analysis.

The literature identified that atmospheric variables contribute to both lower volume and lower travel speeds. These findings were supported by the analysis in this research. Most importantly, traffic volume and median speeds were shown to be related to RSI.

In the volume impact model it was found that a 10% drop in RSI was correlated with a 2% drop in volume. This is after controlling for the environmental factors identified in the literature (temperature, wind speed, visibility and precipitation).

When assessed on a per event basis the speed impact model found that a 0.1 drop in RSI was correlated with a 1.70 km/h drop in median speed. Similar results were found using the hourly data set. For rural highways the same 0.1 drop in RSI was correlated with a 1.09 km/h median speed reduction and for urban highways the same RSI drop was correlated with a 1.71 km/h drop in median speed.

These results indicate that drivers are not only sensitive to winter weather but that road conditions have an even greater effect on travelling speed than many other variables. In addition, people may tend to cancel or reschedule trips as a result of their knowledge of the expected road surface conditions and by extension the expected WRM level of service or service class of the highway. This has direct applications to WRM level of service policy setting and performance measurement.

The case study performed has shown that the mobility benefits of achieving higher service standards could amount to millions of dollars for the province of Ontario. A graphical analysis of hourly speed profiles shows that traffic speed may be a useful surrogate for measuring RSC in rural areas where congestion does not play a significant role in expected speeds.

Several extensions to this research are possible, which could lead to a better understanding of WRM policy impacts to driver mobility. In particular, the following possible extensions to this research would improve on the ability to practically apply these findings to WRM policy:

- This study only considered linear relationship between the dependent and independent variables. An obvious extension of this research would be to investigate the possible non-linear relationships between volume or speed and the other independent variables identified. For example, previous studies have suggested that a square of wind speed may have a stronger correlation to speed.

- In our analysis, we considered only first order effects. Interaction between variables, particularly those with intuitive relationships like visibility and precipitation, should be investigated to improve model performance and estimation power.
- Several previous studies have attempted to categorize variables (such as wind speed greater than 40km/h) to take into account possible correlation between some factors and travelers' complex decision-making behaviour. A study investigating different categorizations may improve the ability of these models to estimate impacts of snow events on speed and volume.
- In this research, we calibrated Poisson and linear regression models only; however, other model structures such as time series cross section models and multilevel models could also be calibrated for this data.

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Appendix A: Event Based Data Set Sample

In the data sample below each row is one hour of data for one direction of travel during a winter storm event. For the event based data, these values were aggregated to one row in each direction representing conditions during the entire event. For the volume analysis these two rows for each event were combined to perform the assessment on total bidirectional volume.

ID	UNIQ	SEQ_ID	SITE	HWY	HWY_NAME	REG	LANES
02.2004.10.31.11	1	4	6	11	Cochrane	NER	1
02.2004.10.31.11	0	4	6	11	Cochrane	NER	1
02.2004.10.31.12	1	4	6	11	Cochrane	NER	1
02.2004.10.31.12	0	4	6	11	Cochrane	NER	1
02.2004.10.31.13	1	4	6	11	Cochrane	NER	1
02.2004.10.31.13	0	4	6	11	Cochrane	NER	1
02.2004.10.31.14	1	4	6	11	Cochrane	NER	1
02.2004.10.31.14	0	4	6	11	Cochrane	NER	1
02.2004.10.31.15	1	4	6	11	Cochrane	NER	1

STORM_H	STORM_N	SEASON	MONTH	TimeStamp	TOD	DIR
9	352	5	1	2004.10.31 11:00	11	1
9	352	5	1	2004.10.31 11:00	11	2
10	352	5	1	2004.10.31 12:00	12	1
10	352	5	1	2004.10.31 12:00	12	2
11	352	5	1	2004.10.31 13:00	13	1
11	352	5	1	2004.10.31 13:00	13	2
12	352	5	1	2004.10.31 14:00	14	1
12	352	5	1	2004.10.31 14:00	14	2
13	352	5	1	2004.10.31 15:00	15	1

TEMP	WIND	VIS	H_PPT	RSI	VOL	VOL_T	MED
0	27	12.9	0.09	0.7772	70	105	100
0	27	12.9	0.09	0.7772	35	105	105
-0.85	30.5	12.9	0	0.7996	49	85	100
-0.85	30.5	12.9	0	0.7996	36	85	110
-0.8	19.5	4	0.09	0.822	60	104	100
-0.8	19.5	4	0.09	0.822	44	104	105
1	19	12.9	0.09	0.8444	59	95	100
1	19	12.9	0.09	0.8444	36	95	105
-0.65	23	6.4	0.09	0.8385	68	123	100

P_TimeStamp	P_TEMP	P_WIND	P_VIS	P_H_PPT	P_RSI	P_VOL	P_VOL_T	P_MED
2004.10.24 11:00	8	19	24.1	0	0.9986	86	121	100
2004.10.24 11:00	8	19	24.1	0	0.9986	35	121	105
2004.10.24 12:00	8.8	8	24.1	0	0.9805	97	142	100
2004.10.24 12:00	8.8	8	24.1	0	0.9805	45	142	105
2004.10.24 13:00	9.75	10	24.1	0	0.9624	78	127	100
2004.10.24 13:00	9.75	10	24.1	0	0.9624	49	127	105
2004.10.24 14:00	8	19	24.1	0	0.9443	101	163	100
2004.10.24 14:00	8	19	24.1	0	0.9443	62	163	105
2004.10.24 15:00	10.3	15	24.1	0	0.9444	107	163	100

Appendix B: Hourly Data Set Sample

In the dataset below each row represents one hour of combined traffic and environmental data. Both non-event and event data were used. The first to establish baseline speeds, the second to evaluate the impact of RSC and other variables.

TimeStamp	Date	Time	Site ID	Highway	Seasonal ID	Monthly ID	Storm Hour	Storm Number
2000.11.11 12	2000-11-11	12	32	400	1	2	0	0
2000.11.11 13	2000-11-11	13	32	400	1	2	0	0
2000.11.11 14	2000-11-11	14	32	400	1	2	0	0
2000.11.11 15	2000-11-11	15	32	400	1	2	0	0
2000.11.11 16	2000-11-11	16	32	400	1	2	0	0
2000.11.11 17	2000-11-11	17	32	400	1	2	0	0
2000.11.11 18	2000-11-11	18	32	400	1	2	0	0
2000.11.11 19	2000-11-11	19	32	400	1	2	0	0

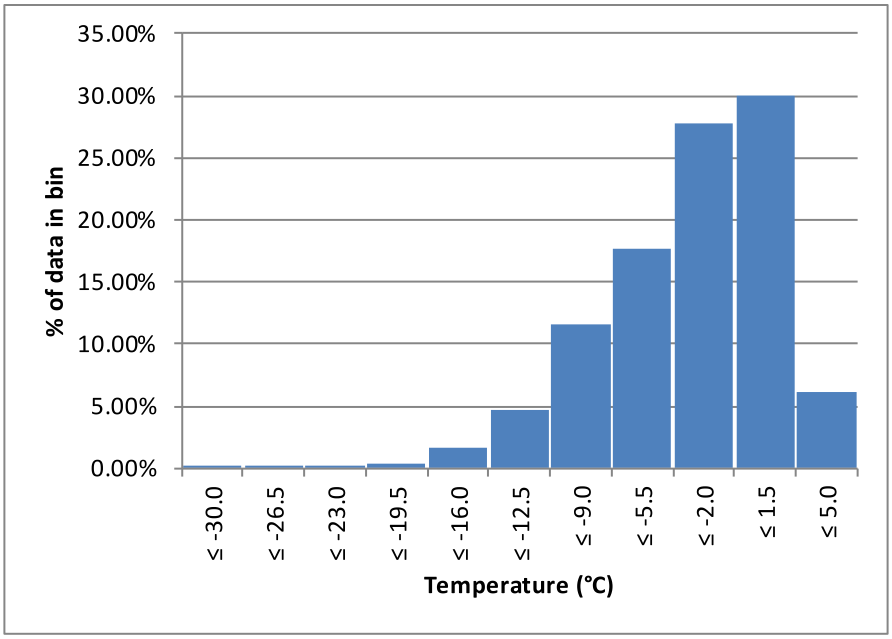
Temperature	Wind Speed	Visibility	Precipitation (cm)	RSI	Location	Lane Count	Direction
5.83	23	21.07		0.95	Maple______	3	SB
6.3	22.67	21.07		0.95	Maple______	3	SB
6.47	24.67	21.07		0.95	Maple______	3	SB
6	28	21.07		0.95	Maple______	3	SB
5.07	24.67	21.07		0.95	Maple______	3	SB
3.93	19.33	21.07		0.95	Maple______	3	SB
3.33	21.33	21.07		0.95	Maple______	3	SB
2.77	15.67	21.07		0.95	Maple______	3	SB

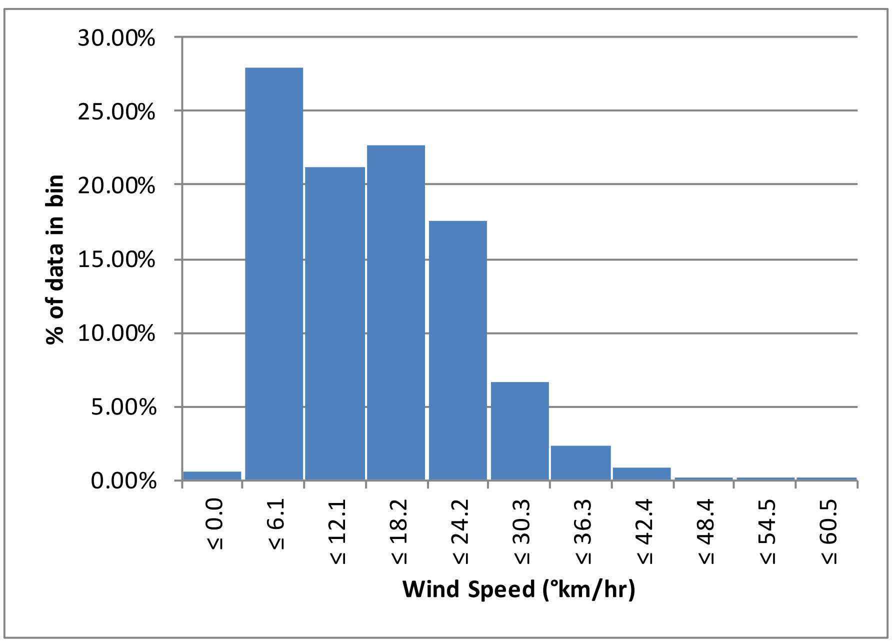
Speed Bin														
60	65	70	75	80	85	90	95	100	105	110	115	120	125	236
121	123	191	300	418	468	425	367	416	356	353	229	136	53	48
0	0	0	16	50	152	415	694	1006	965	709	518	329	201	123
0	0	1	15	53	207	535	1053	1460	1563	1605	1142	674	322	127
1	0	0	5	20	121	461	1095	1903	2456	2604	1629	560	162	75
10	32	44	119	198	276	606	983	1522	1740	1970	1683	798	314	104
0	0	3	9	25	83	227	485	911	1127	1423	1582	1265	613	251
0	0	0	1	8	34	91	204	367	549	856	1244	1141	548	314
0	0	0	0	3	9	51	147	300	448	663	971	889	493	381

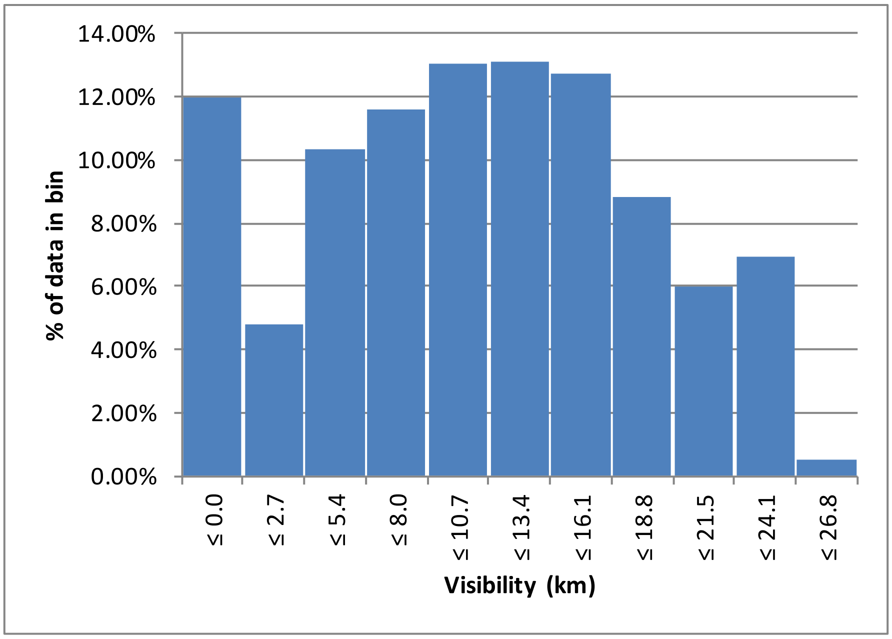
Count	Volume	Median	85th %ile	Route ID	WeekDay	WeekHour
4	4004	90	110	8	7	156
4	5178	105	115	8	7	157
4	8757	105	115	8	7	158
4	11092	105	115	8	7	159
4	10399	105	115	8	7	160
4	8004	110	120	8	7	161
4	5357	115	125	8	7	162
4	4355	115	125	8	7	163

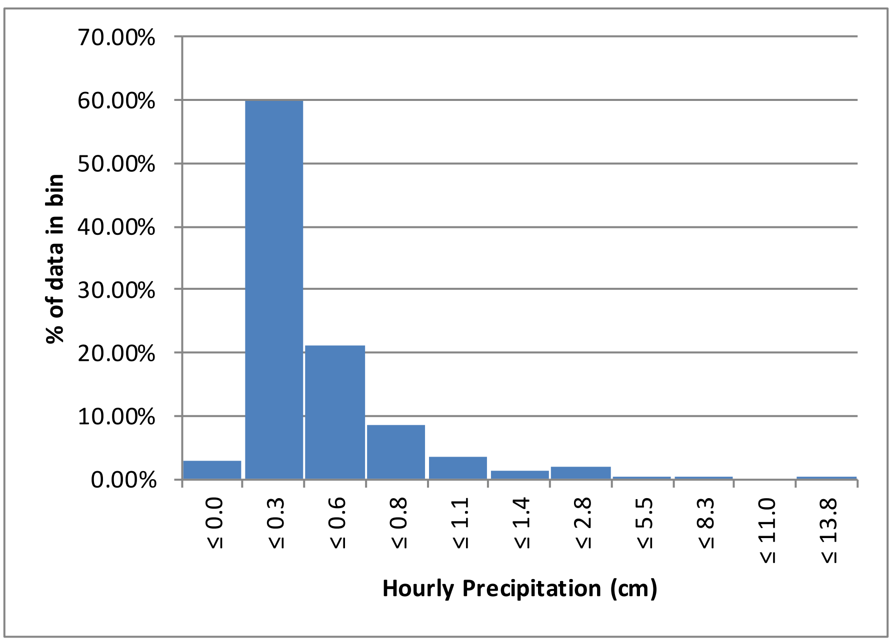
Appendix C: Variable Distributions

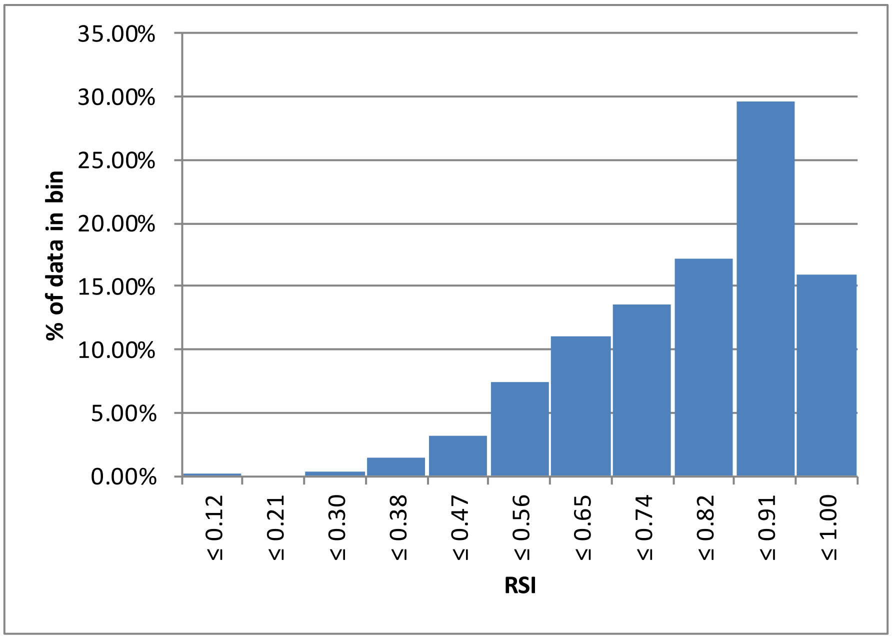
Event Based Data for Volume Analysis

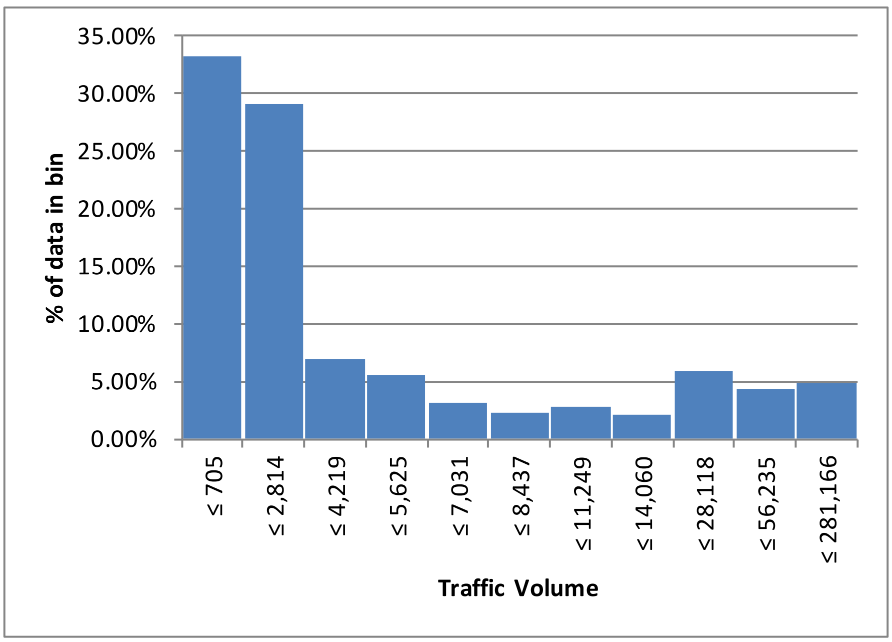




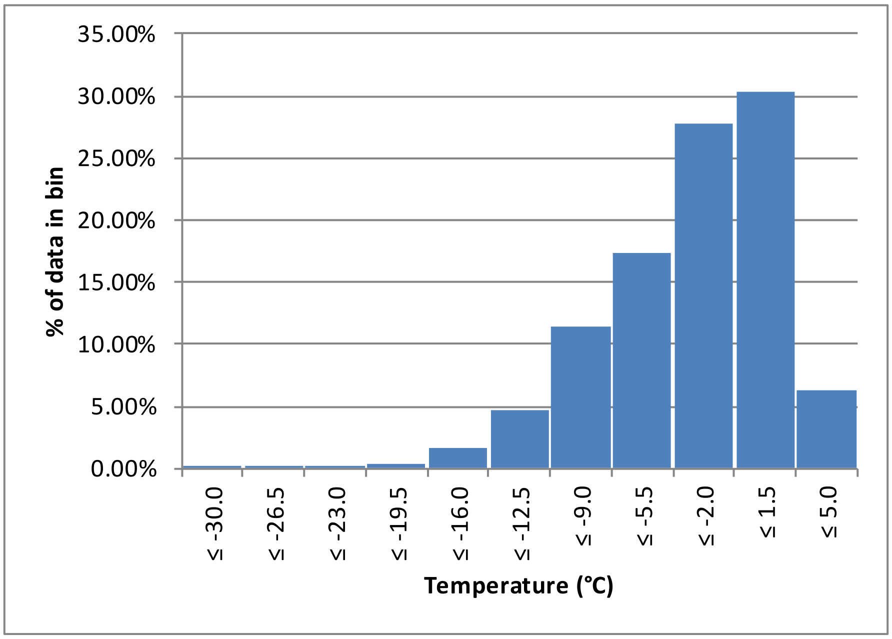

14.00%
12.00%
10.00%
8.00%
6.00%
4.00%
2.00%
0.00%
% of data in bin
≤ 0.0
≤ 2.7
≤ 5.4
≤ 8.0
≤ 10.7
≤ 13.4
≤ 16.1
≤ 18.8
≤ 21.5
≤ 24.1
≤ 26.8
Visibility (km)

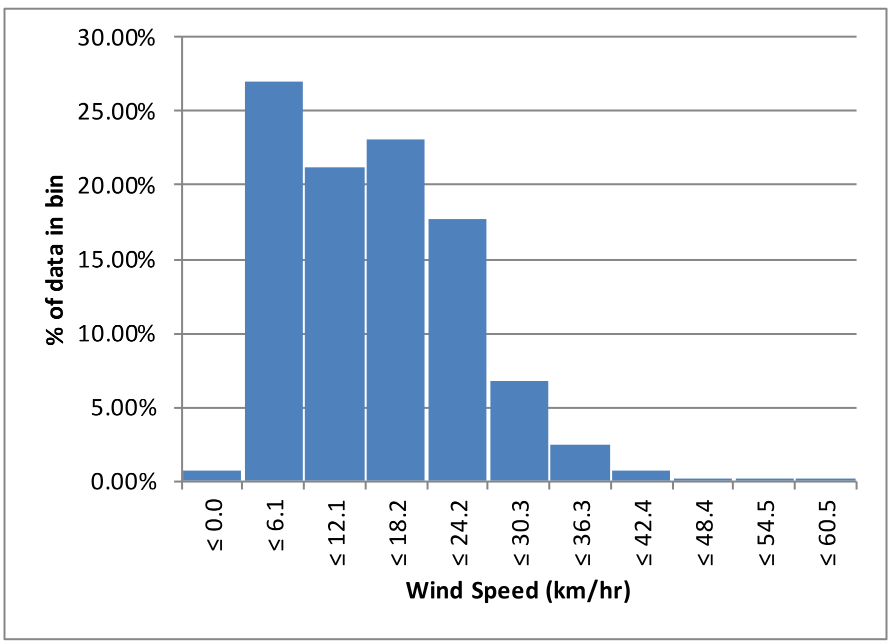

70.00%
60.00%
50.00%
40.00%
30.00%
20.00%
10.00%
0.00%
% of data in bin
≤ 0.0
≤ 0.3
≤ 0.6
≤ 0.8
≤ 1.1
≤ 1.4
≤ 2.8
≤ 5.5
≤ 8.3
≤ 11.0
≤ 13.8
Hourly Precipitation (cm)

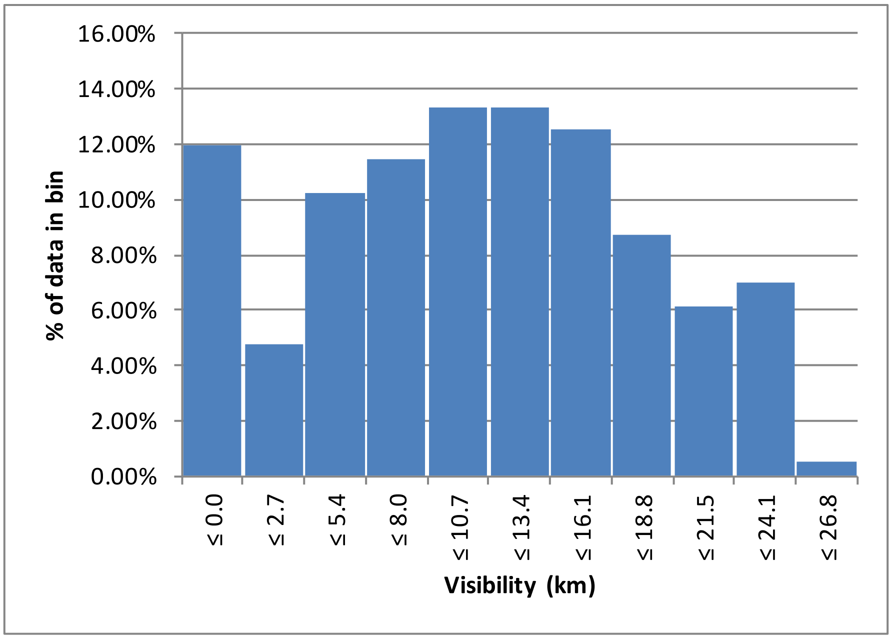

35.00%
30.00%
25.00%
20.00%
15.00%
10.00%
5.00%
0.00%
% of data in bin
≤ 0.12
≤ 0.21
≤ 0.30
≤ 0.38
≤ 0.47
≤ 0.56
≤ 0.65
≤ 0.74
≤ 0.82
≤ 0.91
≤ 1.00
RSI


35.00%
30.00%
25.00%
20.00%
15.00%
10.00%
5.00%
0.00%
% of data in bin
≤ 705
≤ 2,814
≤ 4,219
≤ 5,625
≤ 7,031
≤ 8,437
≤ 11,249
≤ 14,060
≤ 28,118
≤ 56,235
≤ 281,166
Traffic Volume

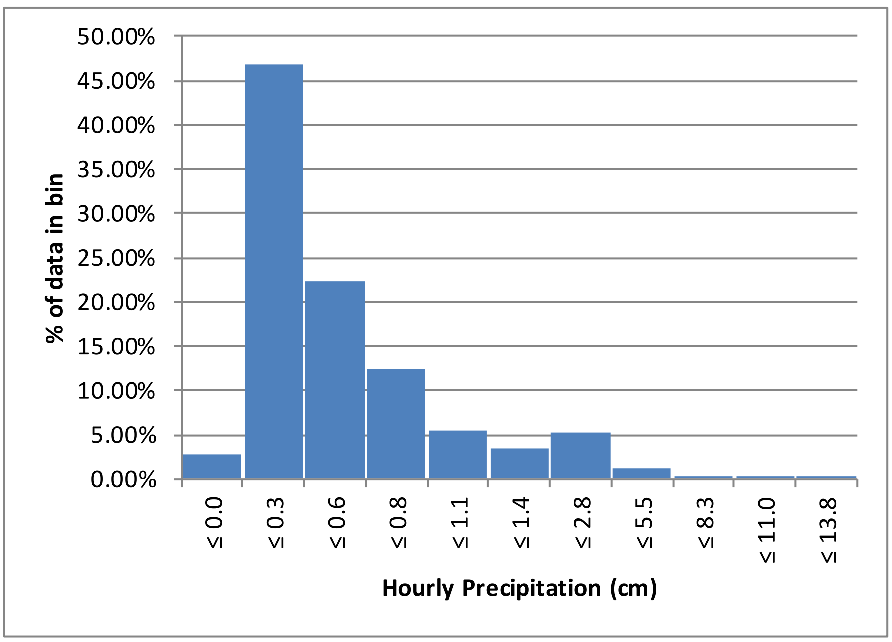
Event Based Data for Speed Analysis



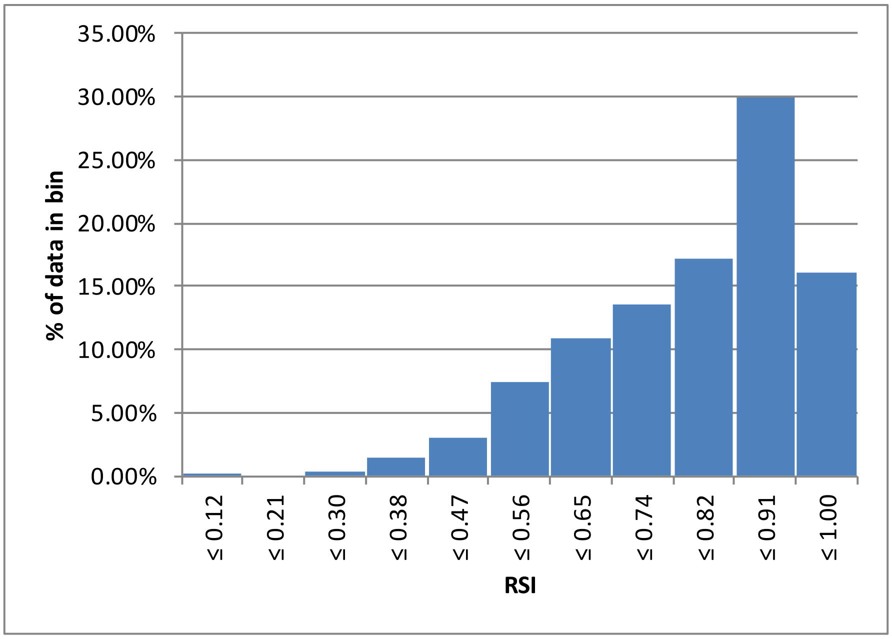


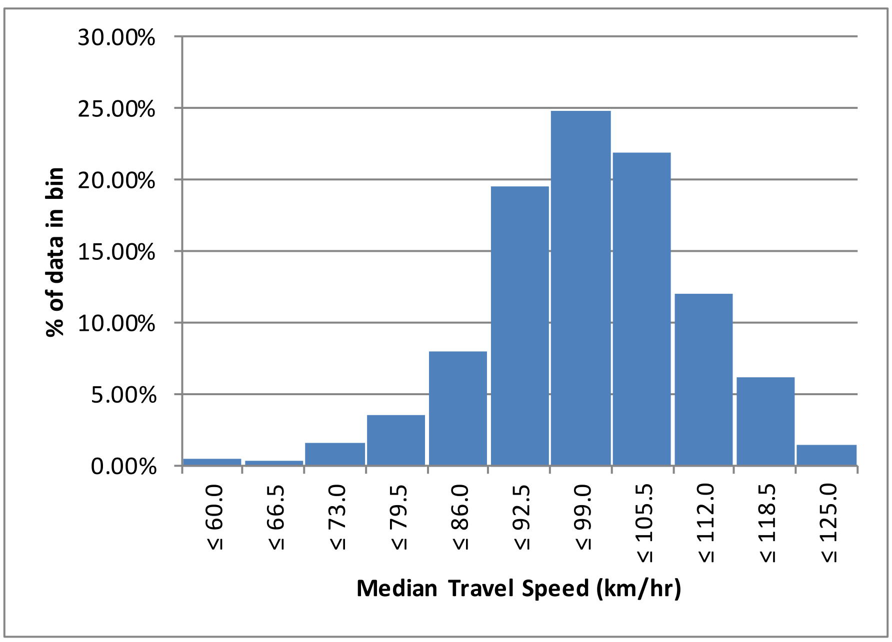


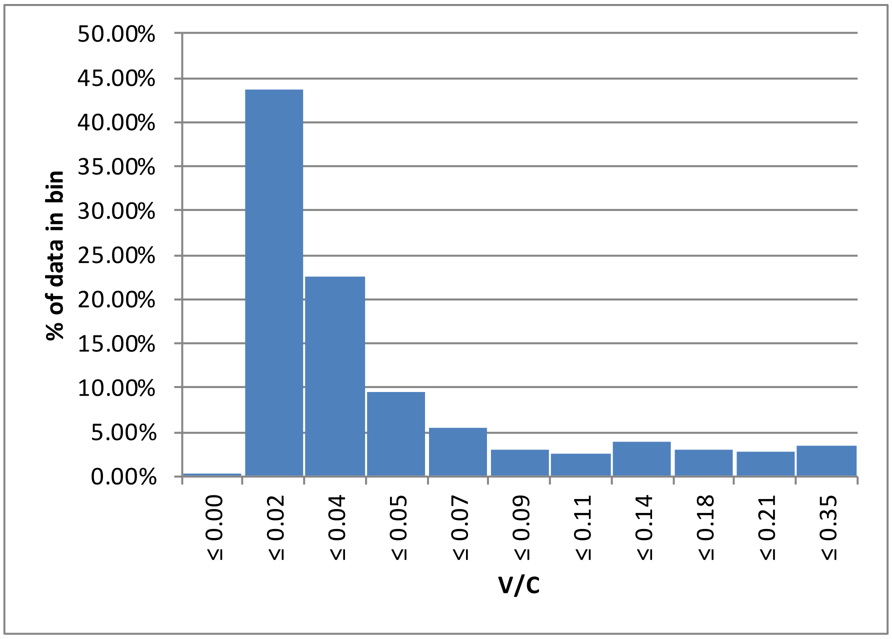
16.00%
14.00%
12.00%
10.00%
8.00%
6.00%
4.00%
2.00%
0.00%
% of data in bin
≤ 0.0
≤ 2.7
≤ 5.4
≤ 8.0
≤ 10.7
≤ 13.4
≤ 16.1
≤ 18.8
≤ 21.5
≤ 24.1
≤ 26.8
Visibility (km)



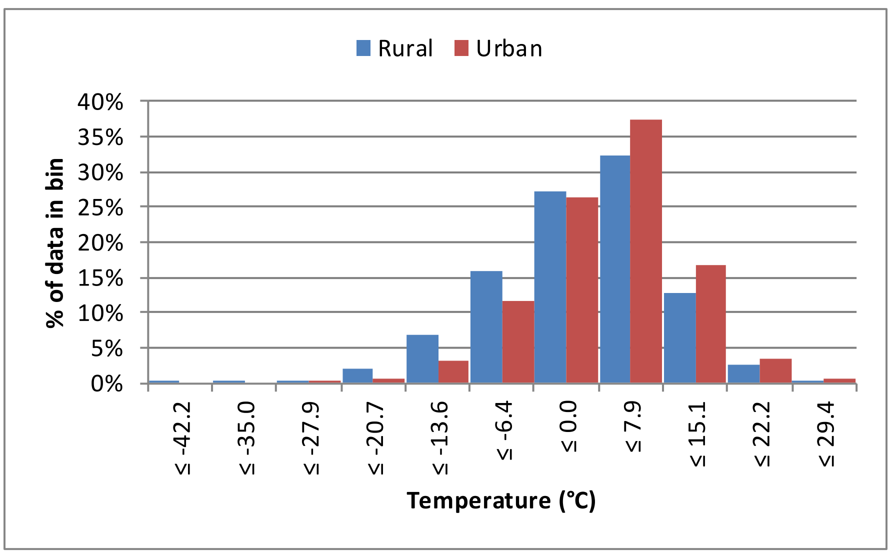
50.00%
45.00%
40.00%
35.00%
30.00%
25.00%
20.00%
15.00%
10.00%
5.00%
0.00%
% of data in bin
≤ 0.0
≤ 0.3
≤ 0.6
≤ 0.8
≤ 1.1
≤ 1.4
≤ 2.8
≤ 5.5
≤ 8.3
≤ 11.0
≤ 13.8
Hourly Precipitation (cm)

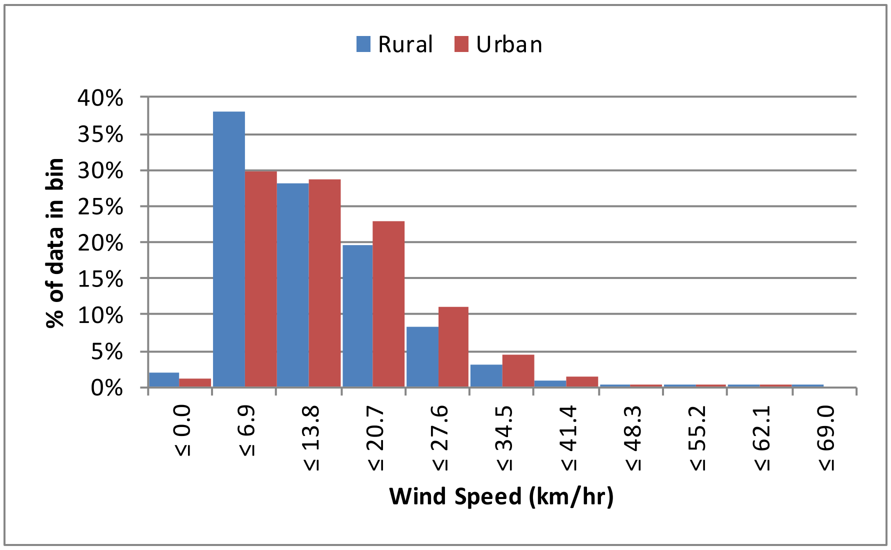

35.00%
30.00%
25.00%
20.00%
15.00%
10.00%
5.00%
0.00%
% of data in bin
≤ 0.12
≤ 0.21
≤ 0.30
≤ 0.38
≤ 0.47
≤ 0.56
≤ 0.65
≤ 0.74
≤ 0.82
≤ 0.91
≤ 1.00
RSI

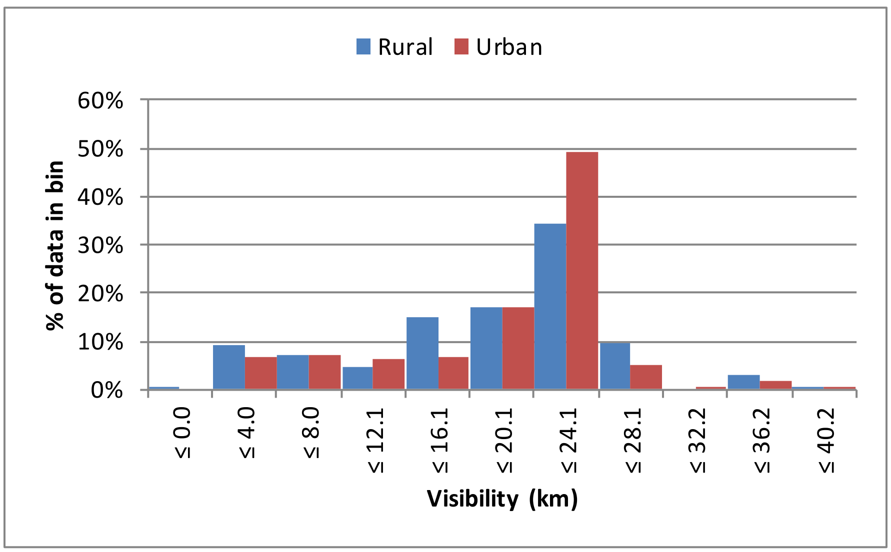

30.00%
25.00%
20.00%
15.00%
10.00%
5.00%
0.00%
% of data in bin
≤ 60.0
≤ 66.5
≤ 73.0
≤ 79.5
≤ 86.0
≤ 92.5
≤ 99.0
≤ 105.5
≤ 112.0
≤ 118.5
≤ 125.0
Median Travel Speed (km/hr)

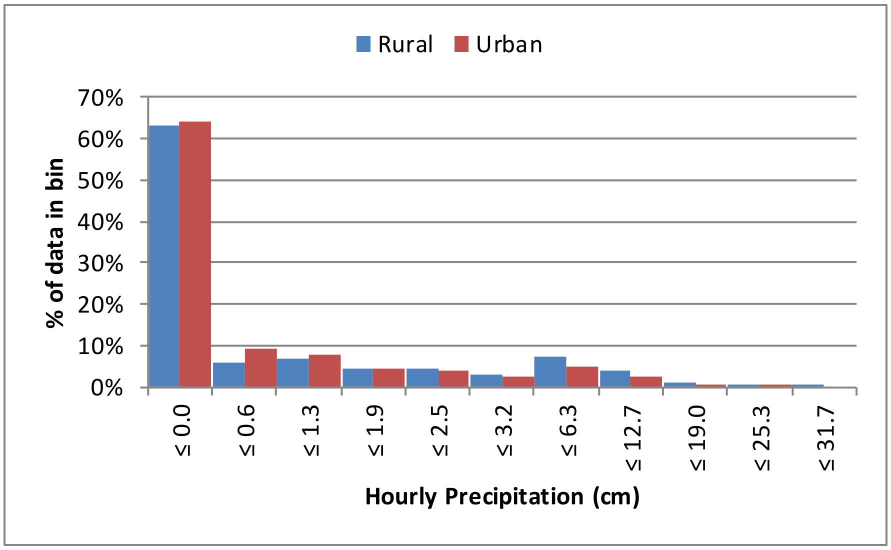


Hourly Data for Speed Analysis

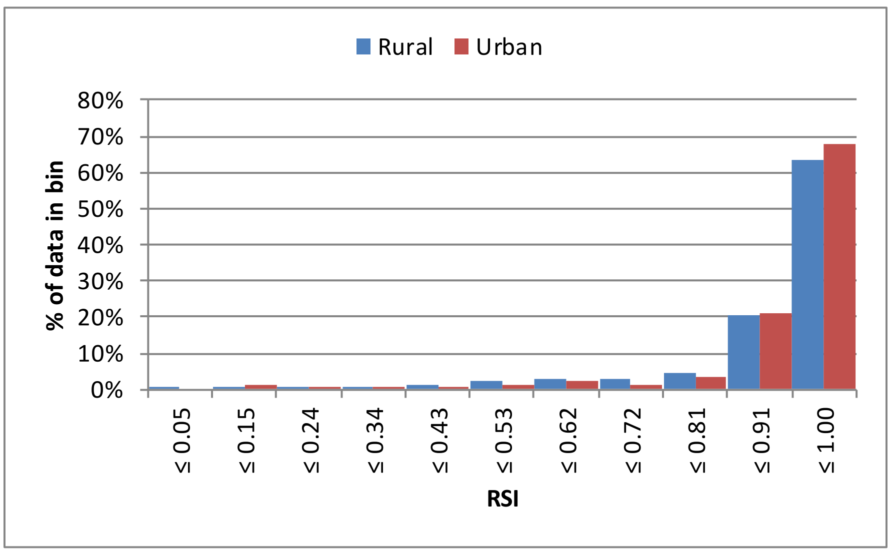



Rural
Urban
40%
35%
30%
25%
20%
15%
10%
5%
0%
% of data in bin
≤ 0.0
≤ 6.9
≤ 13.8
≤ 20.7
≤ 27.6
≤ 34.5
≤ 41.4
≤ 48.3
≤ 55.2
≤ 62.1
≤ 69.0
Wind Speed (km/hr)

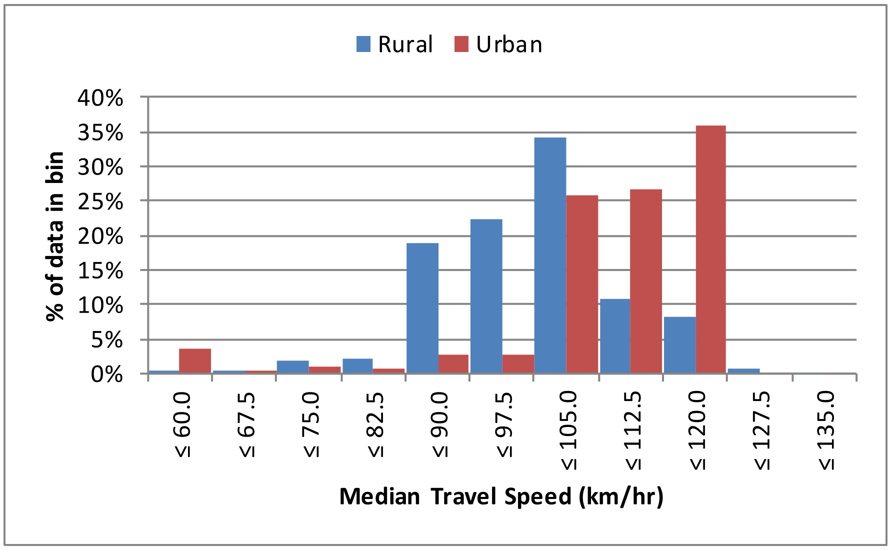

Rural
Urban
60%
50%
40%
30%
20%
10%
0%
% of data in bin
≤ 0.0
≤ 4.0
≤ 8.0
≤ 12.1
≤ 16.1
≤ 20.1
≤ 24.1
≤ 28.1
≤ 32.2
≤ 36.2
≤ 40.2
Visibility (km)

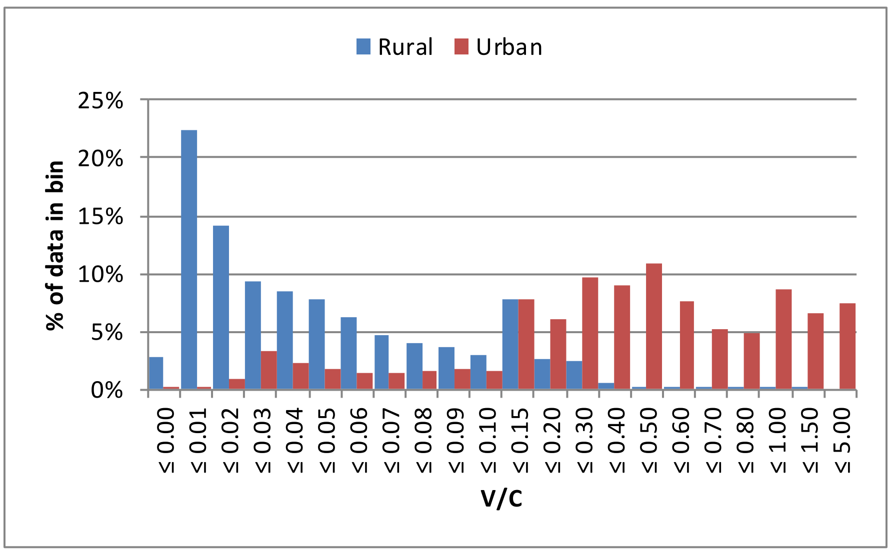


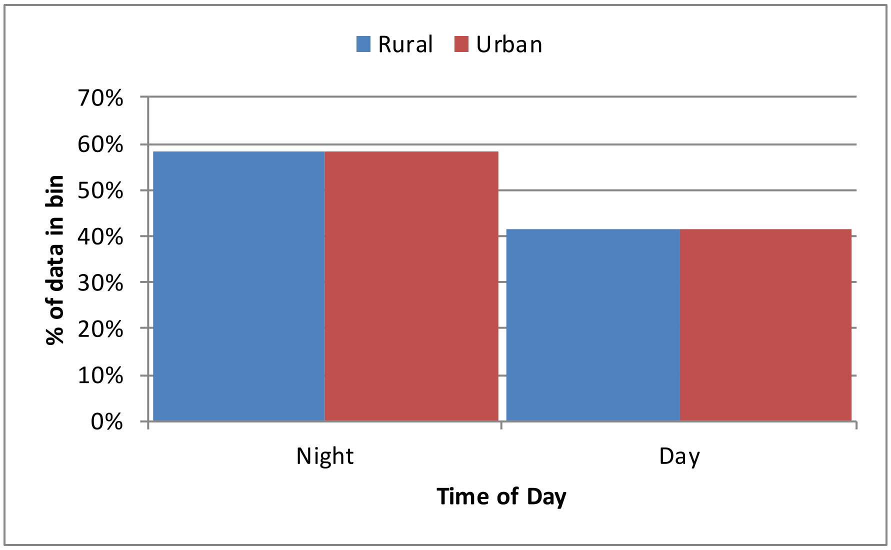
Rural Urban
70%
60%
50%
40%
30%
20%
10%
0%
% of data in bin
≤ 0.0
≤ 0.6
≤ 1.3
≤ 1.9
≤ 2.5
≤ 3.2
≤ 6.3
≤ 12.7
≤ 19.0
≤ 25.3
≤ 31.7
Hourly Precipitation (cm)



Rural Urban
80%
70%
60%
50%
40%
30%
20%
10%
0%
% of data in bin
≤ 0.05
≤ 0.15
≤ 0.24
≤ 0.34
≤ 0.43
≤ 0.53
≤ 0.62
≤ 0.72
≤ 0.81
≤ 0.91
≤ 1.00
RSI


Rural
Urban
40%
35%
30%
25%
20%
15%
10%
5%
0%
% of data in bin
≤ 60.0
≤ 67.5
≤ 75.0
≤ 82.5
≤ 90.0
≤ 97.5
≤ 105.0
≤ 112.5
≤ 120.0
≤ 127.5
≤ 135.0
Median Travel Speed (km/hr)


Rural
Urban
25%
20%
15%
10%
5%
0%
% of data in bin
≤ 0.00
≤ 0.01
≤ 0.02
≤ 0.03
≤ 0.04
≤ 0.05
≤ 0.06
≤ 0.07
≤ 0.08
≤ 0.09
≤ 0.10
≤ 0.15
≤ 0.20
≤ 0.30
≤ 0.40
≤ 0.50
≤ 0.60
≤ 0.70
≤ 0.80
≤ 1.00
≤ 1.50
≤ 5.00
V/C


Rural
Urban
70%
60%
50%
40%
30%
20%
10%
0%
% of data in bin
Night
Day
Time of Day

Appendix D: Data Processing Code

This research took advantage of a database of weather and volume data developed as part of previous research. In order to supplement this data the TOPS software package was used to extract raw Permanent Data Collection Station Data. This database contains binned records for traffic speed at the stations described above.

The raw export of this data required a significant amount of data cleaning and combination to develop a database suitable for the research being conducted. In addition to manual manipulation of the data tables several macro algorithms were developed in Microsoft Excel to parse and combine this data into a useable form. The algorithms are reproduced below.

Raw TOPS export file sample

After exporting the data for the study sites from TOPS there were 14,923 individual space delimited data files. One of the files containing only a few rows of speed bin data is shown below.

```
North_Bay___ nr_03_094___ 01 0200 010101 0230 010101 0015 05 2 100    10   501
0000 0000 0000 0000 0000 0000 0000 0000 0000 20XXXXXX '
'                    '                    '  NR - Hwy 11 - 17275 0.3
03 15        0060 0065 0070 0075 0080 0085 0090 0095 0100 0105 0110 0115 0120
0125 0236
01 02        0001 0002
00 00
01 01 2 0215 0000 0000 0000 0000 0000 0000 0001 0002 0001 0000 0000 0000 0000
0000 0000
01 02 0 0215 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0001 0000 0000
0000 0000
01 01 2 0230 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000
0000 0000
01 02 0 0230 0000 0000 0000 0000 0000 0000 0000 0000 0001 0000 0000 0000 0000
0000 0000
```

Combine raw TOPS export files into consistently formatted database

```
Option Explicit


Dim InputFile, OutputFile As Integer

Sub Initialize()
    InputFile = FreeFile
    OutputFile = InputFile + 1
    Call SelectFiles
End Sub
```

```
Sub SelectFiles()

     ' File names
    Dim SpeedSheets As Variant
    Dim SheetCount As Integer
    Dim Firstline As String
    Dim Location As String
    Dim ParsedSheet() As String
    Dim ExistingOutput As Boolean
    Dim InputLen As Long, OutputLen As Long
    Dim InputName As String, OutputName As String, OutputBins As String
    Dim i, j As Integer

    Application.ScreenUpdating = False

     'Set file names
    SpeedSheets = Application.GetOpenFilename("TOPS Export Files (*.PRN),*.PRN",
1, " Select the desired TOPS export file to read...", , True)

    On Error Resume Next
    SheetCount = UBound(SpeedSheets)
    If Err.Number <> 0 Then
        If SpeedSheets = False Then Goto CleanUp
    End If
    On Error Goto 0


    Load frmProgress

     'Open files for processing
    For i = 1 To SheetCount

        frmProgress.Show (vbModeless)
        InputLen = FileLen(SpeedSheets(i))

         'ParsedSheet(i - 1) = Left(SpeedSheets(i), Len(SpeedSheets(i)) - 4) & "
(Parsed).csv"

        Open SpeedSheets(i) For Input As #InputFile
         'Debug.Print Right(SpeedSheets(i), Len(SpeedSheets(i)) -
InStrRev(SpeedSheets(i), "\"))

        Input #InputFile, Firstline
        Seek InputFile, 1
        Location = Left(Firstline, InStr(1, Firstline, " "))

        Redim Preserve ParsedSheet(i)
        ParsedSheet(i) = Location & ".csv"

        For j = 1 To UBound(ParsedSheet)
            ExistingOutput = False
            If (ParsedSheet(i) = ParsedSheet(j)) And (i <> j) Then
```

```
                ExistingOutput = True
                Exit For
            End If
        Next j

        If ExistingOutput Then
             'previously opened
            Open ParsedSheet(i) For Input As #OutputFile
            Line Input #OutputFile, OutputBins
            Close #OutputFile
            Open ParsedSheet(i) For Append As #OutputFile
        Else
             'new file
            Open ParsedSheet(i) For Output As #OutputFile
             'Call AddHeader
        End If

        frmProgress.Caption = "Processing file " & i & " of " & SheetCount &
"..."
        Application.StatusBar = "Overall Progress: " & Round(i / SheetCount *
100, 1) & "%"

        InputName = Right(SpeedSheets(i), Len(SpeedSheets(i)) -
InStrRev(SpeedSheets(i), "\"))
        OutputName = Left(ParsedSheet(i), Len(ParsedSheet(i)) - 4)
        OutputLen = FileLen(ParsedSheet(i))

        Call ImportSpeeds(InputLen, OutputLen, InputName, OutputName, OutputBins)

        Close #InputFile
        Close #OutputFile

    Next i



CleanUp:
    Unload frmProgress
    Application.StatusBar = False
    Application.ScreenUpdating = True

End Sub


Sub ImportSpeeds(InputLen As Long, OutputLen As Long, InputName As String,
OutputName As String, OutputBins As String)

     'Data storage
    Dim ThisLine As String 'Raw line
    Dim LineText As Variant 'Line in array by word
    Dim LaneSet(14, 14) As Integer 'Data storage matrix
    Dim LaneTotal() As Integer 'Data summary array
    Redim LaneTotal(14) As Integer
```

```
    Dim Lane, Heading2 As Integer
    Dim StartDate, Location, Direction, SpeedHeadings As String
    Dim ThisDate As Long
    Dim ThisTime, LastTime, Heading3 As String
    Dim NextFree As Integer
    Dim EXP_Heading2Bins As Integer
    Dim OutputString As String


     ' Loop control
    Dim i As Integer
    Dim j As Integer
    Dim Heading2Lanes As Boolean


     'Positioning
    Dim LineNumber As Long
    Dim SpeedBins, ClassBins, DataBins, Heading2Bins, HeaderLines, DateBin,
LocationBin As Integer
    Dim LaneBin, Heading2Bin, DirectionBin, TimeBin, DataStart As Integer

    HeaderLines = 6
    DateBin = 5 - 1
    LocationBin = 1 - 1


    LaneBin = 1 - 1
    Heading2Bin = 2 - 1
    DirectionBin = 3 - 1
    TimeBin = 4 - 1
    DataStart = 5 - 1


     'Error info
    Dim JustCountDataLines As Boolean



     'Initial conditions
    LineNumber = 0
    ThisTime = "0000"


     'Read input file
    Do While Not (EOF(InputFile))


        Line Input #InputFile, ThisLine 'Read one line for each loop into
"ThisLine"
        LineNumber = LineNumber + 1 'Capture line number for positioning


        If JustCountDataLines Then Goto JustCount


        LineText = Split(ThisLine) 'Split current line into words (space
delimited) and store in "LineText" array


        If LineNumber <= 6 Then
            For i = UBound(LineText) To 0 Step -1
                If LineText(i) = "" Then
                    Redim Preserve LineText(i - 1)
```

```
                Else
                    Exit For
                End If
            Next i
        End If


        Select Case LineNumber
        Case 1
             'Store first line data
            StartDate = DateSerial(2000 + Int(Right(LineText(DateBin), 2)),
Int(Left(LineText(DateBin), 2)), Int(Mid(LineText(DateBin), 3, 2)))
            ThisDate = StartDate
             'NextFree = Workbooks("Processing Step
1.xls").Worksheets("Temp").Range("A65536").End(xlUp).Row + 1
             'Workbooks("Processing Step 1.xls").Worksheets("Temp").Range("A" &
NextFree) = Format(ThisDate, "MMDD-YYYY")
            Location = LineText(LocationBin)
        Case 2, 3, 6
             'Do Nothing
        Case 4
            If Int(LineText(0)) = 3 Then
                Heading3 = "Speed"
                SpeedBins = UBound(LineText) - 9
                SpeedHeadings = GetSpeedBins(LineText)
                If OutputLen <> 0 Then
                    If Not (CheckSpeedBins(LineText, OutputBins)) Then
                        JustCountDataLines = True
                        Goto JustCount
                    End If
                End If
            ElseIf Int(LineText(0)) = 2 Then
                Heading3 = "Class"
                ClassBins = UBound(LineText) - 9
            Else
                Debug.Assert False
            End If
        Case 5
            If Int(LineText(0)) = 3 Then
                SpeedBins = UBound(LineText) - 9
                EXP_Heading2Bins = 14
                SpeedHeadings = GetSpeedBins(LineText)
                If OutputLen <> 0 Then
                    If Not (CheckSpeedBins(LineText, OutputBins)) Then
                        JustCountDataLines = True
                        Goto JustCount
                    End If
                End If
            ElseIf Int(LineText(0)) = 2 Then
                ClassBins = UBound(LineText) - 9
                EXP_Heading2Bins = 14
            ElseIf Int(LineText(0)) = 6 Then
                ClassBins = UBound(LineText) - 9
                EXP_Heading2Bins = 3
            ElseIf Int(LineText(0)) = 1 Then
                 'Heading2 is Lanes
                Heading2Lanes = True
                LaneBin = Heading2Bin
            Else
                Debug.Assert False
            End If
        Case Else
             'Populate bin storage matrix
```

```
    If Heading2Lanes Then
        Heading2 = 1
    Else
        Heading2 = Int(LineText(Heading2Bin))
    End If
    For i = 0 To DataBins
        LaneSet(i, Heading2 - 1) = Int(LineText(i + DataStart))
         'Heading2 is stored in j (vertical)
         'Heading3 is stored in i (horizontal)
    Next i
End Select


If LineNumber = 6 Then
    If Heading3 = "Speed" Then
        DataBins = SpeedBins
        If Not (Heading2Lanes) Then
            Heading2Bins = ClassBins
            Debug.Assert Heading2Bins = EXP_Heading2Bins
        Else
            Heading2Bins = 0
        End If
    ElseIf Heading3 = "Class" Then
        DataBins = ClassBins
        If Not (Heading2Lanes) Then
            Heading2Bins = SpeedBins
            Debug.Assert Heading2Bins = EXP_Heading2Bins
        Else
            Heading2Bins = 0
        End If
    End If
    Debug.Assert DataBins = 14
    If OutputLen = 0 Then
        Call AddHeader(SpeedHeadings)
    End If
End If


 'Print data on final class
If Heading2 = Heading2Bins + 1 Then
    Redim LaneTotal(DataBins) As Integer 'Clear totals array
    LastTime = ThisTime 'Store previous timestamp to track date turnover
    ThisTime = LineText(TimeBin) 'Store current timestamp
    Lane = LineText(LaneBin) 'Store current lane
    Direction = LineText(DirectionBin) 'Store current direction

    Select Case Direction
    Case "0"
        Direction = "NB"
    Case "1"
        Direction = "EB"
    Case "2"
        Direction = "SB"
    Case "3"
        Direction = "WB"
    Case "X"
         'Do nothing
    End Select


    If Int(ThisTime) < Int(LastTime) Then
        ThisDate = ThisDate + 1 'Move date forward at time turnover
```

```
                'NextFree = Workbooks("Processing Step
1.xls").Worksheets("Temp").Range("A65536").End(xlUp).Row + 1
                'Workbooks("Processing Step 1").Worksheets("Temp").Range("A" &
NextFree) = Format(ThisDate, "MMDD-YYYY")
            End If


            'Sum bin storage matrix into array
            If Heading3 = "Speed" Then
                For i = 0 To SpeedBins
                    For j = 0 To ClassBins
                        LaneTotal(i) = LaneTotal(i) + LaneSet(i, j)
                         'Sums vertical into horizontal
                    Next j
                Next i
            Else
                For j = 0 To SpeedBins
                    For i = 0 To ClassBins
                        LaneTotal(j) = LaneTotal(j) + LaneSet(i, j)
                         'Sums horizontal into vertical
                    Next i
                Next j
            End If


            'Build Output String
            OutputString = Location & "," & Lane & "," & Direction & "," &
ThisDate + Int(Left(ThisTime, 2)) / 24 + Int(Right(ThisTime, 2)) / 24 / 60 & ","
            For i = 0 To UBound(LaneTotal)
                OutputString = OutputString & LaneTotal(i)
                If i <> UBound(LaneTotal) Then
                    OutputString = OutputString & ","
                End If
            Next i


            'Print record
            Print #OutputFile, OutputString
            'Location & "," & Lane & "," & Direction & "," & ThisDate +
Int(Left(ThisTime, 2)) / 24 + Int(Right(ThisTime, 2)) / 24 / 60 & "," & _
            LaneTotal (0) & "," & LaneTotal(1) & "," & LaneTotal(2) & "," &
LaneTotal(3) & "," & LaneTotal(4) & "," & LaneTotal(5) & "," & LaneTotal(6) & ","
& LaneTotal(7) & "," & LaneTotal(8) & "," & LaneTotal(9) & "," & LaneTotal(10) &
"," & LaneTotal(11) & "," & LaneTotal(12) & "," & LaneTotal(13) & "," &
LaneTotal(14)


            'Update progress
            If Not (EOF(InputFile)) Then frmProgress.ProgressBar.Value =
Seek(InputFile) / InputLen
            DoEvents


        End If


JustCount:


    Loop


    If JustCountDataLines Then Goto SpeedBinsBad
```

```
    Exit Sub

SpeedBinsBad:
     'If this happens it means that the current exported .prn file does not have
the standard 15 speed bins
    Open "1 - Errors.txt" For Append As #(OutputFile + 1)
    Print #(OutputFile + 1), InputName & " | " & OutputName & " | " & LineNumber
- 6
    Close #(OutputFile + 1)

End Sub


Function GetSpeedBins(LineText As Variant)

    Dim SpeedHeadings As String
    Dim i As Integer

    For i = 9 To UBound(LineText)
        SpeedHeadings = SpeedHeadings & "," & LineText(i)
    Next i

    GetSpeedBins = SpeedHeadings

End Function


Sub AddHeader(SpeedHeadings As String)

    Print #OutputFile, "Location,Lane,Direction,TimeStamp" & SpeedHeadings
'60,65,70,75,80,85,90,95,100,105,110,115,120,125,236"

End Sub


Function CheckSpeedBins(LineText As Variant, OutputBins As String) As Boolean

    Dim SpeedText As Variant
    Dim i As Integer
    Dim ChecksOut  As Boolean

    ChecksOut = True

    SpeedText = Split(OutputBins, ",")

    For i = 0 To 14
        If Int(SpeedText(i + 4)) <> Int(LineText(i + 9)) Then
            ChecksOut = False
```

```
            Exit For
        End If
    Next i

    CheckSpeedBins = ChecksOut

End Function
```

Combine data from adjacent lanes

```
Option Explicit

Dim InputFile, OutputFile As Integer

Sub Initialize()
    InputFile = FreeFile
    OutputFile = InputFile + 1
    Call SelectFiles
End Sub



Sub SelectFiles()

     ' File names
    Dim SpeedSheets As Variant
    Dim BPFile As String
    Dim BPBook As String
    Dim SheetCount As Integer
    Dim ParsedSheet As String
    Dim InputLen As Long
    Dim i As Integer

     'application.ScreenUpdating = False

     'Set file names
    SpeedSheets = Application.GetOpenFilename("Step 1 Processed Files
(*.csv),*.csv", 1, " Select the desired processed files to read...", , True)

    SheetCount = UBound(SpeedSheets)

     'Open files for processing
    For i = 1 To SheetCount

        Load frmProgress
        frmProgress.Show (vbModeless)
        InputLen = FileLen(SpeedSheets(i))
```

```
        Open SpeedSheets(i) For Input As #InputFile

        ParsedSheet = Left(SpeedSheets(i), Len(SpeedSheets(i)) - 4) & " (Lanes
Combined).csv"

        Open ParsedSheet For Output As #OutputFile

        frmProgress.Caption = "Processing file " & i & " of " & SheetCount &
"..."

        Call ImportSpeeds(InputLen)

        Close #InputFile
        Close #OutputFile

    Next i

    Unload frmProgress
    Application.ScreenUpdating = True

End Sub

Sub ImportSpeeds(InputLen As Long)

     'Data storage
    Dim ThisLine, LastLine, NextLine As String 'Raw line
    Dim LineText As Variant 'Line in array by word
    Dim ThisDateTime As Double
    Dim ThisLaneDir As String
    Dim TimeDir() As String

     ' Loop control
    Dim i As Integer
    Dim OneLastTime As Boolean

     'Positioning
    Dim LineNumber As Long
    Dim DateTimeBin, LaneDirBin As Integer
    Dim ThisSpeedBins() As String
    Dim TempSpeeds() As Integer
    Dim SpeedBinsStart As Integer
    Dim TempString As String
    Dim PrintThis As Boolean
    Dim LaneCount, TotalLanes As Integer

    DateTimeBin = 4 - 1
    LaneDirBin = 3 - 1
    SpeedBinsStart = 5 - 1
```

```
    LineNumber = 0

     'Read input file
    Do While Not (EOF(InputFile))

        LineNumber = LineNumber + 1 'Capture line number for positioning

        Select Case LineNumber
        Case 1
            Line Input #InputFile, ThisLine 'Read one line for each loop into
"ThisLine"
            Line Input #InputFile, NextLine
        Case Is > 1
            LastLine = ThisLine
            ThisLine = NextLine
            Line Input #InputFile, NextLine
        End Select

        Redim Preserve TimeDir(LineNumber + 1)
        LineText = Split(NextLine, ",") 'Split next line into words (comma
delimited) and store in "LineText" array
        TimeDir(LineNumber + 1) = Val(LineText(DateTimeBin)) &
LineText(LaneDirBin)

ProcessThisLine:

        LineText = Split(ThisLine, ",")
        ThisDateTime = Val(LineText(DateTimeBin))
        ThisLaneDir = LineText(LaneDirBin)

        If LineNumber = 1 Then
            Redim ThisSpeedBins(UBound(LineText) - SpeedBinsStart) 'Make sure
speed bins array is big enough
            Redim TempSpeeds(UBound(LineText) - SpeedBinsStart) 'Make sure temp
bins array is big enough
             'Header row setup
            TempString = LineText(0) & "," & "Lane Count"
            For i = 2 To UBound(LineText)
                TempString = TempString & "," & LineText(i)
            Next i
            PrintThis = True 'Make sure header is printed
        End If

         'Popolate speed bins
        For i = SpeedBinsStart To UBound(LineText)
            ThisSpeedBins(i - SpeedBinsStart) = LineText(i)
        Next i

        If LineNumber > 1 Then

            LaneCount = LaneCount + 1
```

```
            For i = 0 To UBound(TempSpeeds)
                TempSpeeds(i) = TempSpeeds(i) + Int(ThisSpeedBins(i))
            Next i

            On Error Resume Next
            If (TimeDir(LineNumber) <> TimeDir(LineNumber + 1)) Then
                If OneLastTime Then
                     'error is ok
                ElseIf Err.Number <> 0 Then
                    Debug.Assert False
                End If
                On Error Goto 0
                TotalLanes = LaneCount
                PrintThis = True
                LaneCount = 0
                TimeDir(LineNumber) = TimeDir(LineNumber) & "-P"
            End If

        End If

         'Build Temp String
        If PrintThis Then
            If LineNumber <> 1 Then
                TempString = vbNullString
                TempString = LineText(0) & "," & TotalLanes & "," & ThisLaneDir &
"," & ThisDateTime
                For i = 0 To UBound(TempSpeeds)
                    TempString = TempString & "," & TempSpeeds(i)
                    TempSpeeds(i) = 0
                Next i
            End If
            Print #OutputFile, TempString
            PrintThis = False
        End If

         'Update progress
        If Not (EOF(InputFile)) Then frmProgress.ProgressBar.Value =
Seek(InputFile) / InputLen
        DoEvents

        If OneLastTime Then Exit Sub

    Loop

    ThisLine = NextLine
    LineNumber = LineNumber + 1
    OneLastTime = True
    Goto ProcessThisLine

End Sub
```

Match speed data with weather data

```
Option Explicit

Dim InputFile, OutputFile As Integer

Sub Initialize()
    InputFile = FreeFile
    OutputFile = InputFile + 1
    Call SelectFiles
End Sub



Sub SelectFiles()

     ' File names
    Dim SpeedSheets As String
    Dim DataFile As String
    Dim DataName As String
    Dim InputLen As Long

     'Set file names
    DataFile = Application.GetOpenFilename("Processed Data,*.xlsm", 1, " Select
Processed Data File...", , False)
    DataName = Mid(DataFile, InStrRev(DataFile, "\") + 1, Len(DataFile) -
InStrRev(DataFile, "\"))
    SpeedSheets = Application.GetOpenFilename("Step 2 Processed File
(*.csv),*.csv", 1, " Select corresponding traffic file for " & DataName, , False)

    InputLen = FileLen(SpeedSheets)

    Open SpeedSheets For Input As #InputFile

    Workbooks.Open DataFile

    Application.ScreenUpdating = False

    Call ImportSpeeds(InputLen, DataName)

    Close #InputFile
    Workbooks(DataName).Close SaveChanges:=True

    Application.ScreenUpdating = True
```

```
End Sub

Sub ImportSpeeds(InputLen As Long, DataBook As String)

     'Data storage
    Dim ThisLine As String 'Raw line
    Dim LineText As Variant 'Line in array by word
    Dim ThisDateTime As Double
    Dim MatchValue As String
    Dim MatchTime As Double
    Dim DataDateTime() As String
    Dim LastRow As Long
    Dim TargetRow As Double
    Dim OutputSheet As Worksheet
    Dim OutputColumn As Integer
    Dim StartTime As Double

     ' Loop control
    Dim i As Integer
    Dim Bins As Integer
    Dim DateTimeBin As Integer
    Dim Dir As String
    Dim DirBin As Integer
    Dim DirOffset As Integer
    Dim DirOffsetDefault As Integer
    Dim LineNumber As Long

    DateTimeBin = 4 - 1
    DirBin = 3 - 1
    OutputColumn = 79
    DirOffsetDefault = 20
    StartTime = Time

     'Prep OutputFile
    Set OutputSheet = Workbooks(DataBook).Worksheets("Hourly Data")
    LastRow = Workbooks(DataBook).Worksheets("Hourly Data").Cells.Find(What:="*",
After:=[A1], SearchOrder:=xlByRows, SearchDirection:=xlPrevious).Row
    Redim DataDateTime(LastRow)
    For i = 2 To LastRow
        DataDateTime(i) = Format(Int(Workbooks(DataBook).Worksheets("Hourly
Data").Range("A" & i)) + Int(Workbooks(DataBook).Worksheets("Hourly
Data").Range("B" & i)) / 24, "YYYY.MM.DD.HH")
    Next i

     'Read input file
    Do While Not (EOF(InputFile))
        LineNumber = LineNumber + 1 'Capture line number for positioning
        Line Input #InputFile, ThisLine
        LineText = Split(ThisLine, ",") 'Split next line into words (comma
delimited) and store in "LineText" array
        Bins = UBound(LineText)

        If LineNumber = 1 Then
            For i = 0 To Bins
```

```
                OutputSheet.Cells(1, OutputColumn + i) = LineText(i)
                OutputSheet.Cells(1, OutputColumn + i + DirOffsetDefault) =
LineText(i)
            Next i
            OutputSheet.Cells(1, OutputColumn + Bins + 1) = "Count"
            OutputSheet.Cells(1, OutputColumn + Bins + 1 + DirOffsetDefault) =
"Count"
        Else
            If LineNumber = 2 Then Dir = LineText(DirBin)
            ThisDateTime = Val(LineText(DateTimeBin))
            MatchTime = Int(ThisDateTime) + Int((ThisDateTime -
Int(ThisDateTime)) * 24 - 0.01) / 24
            MatchValue = Format(MatchTime, "YYYY.MM.DD.HH")


             '***** Find row as quickly as possible
            If MatchValue = DataDateTime(TargetRow) Then 'is it this row again
                 'Do Nothing we're on the right target row
            ElseIf UBound(DataDateTime) >= TargetRow + 1 Then
                If MatchValue = DataDateTime(TargetRow + 1) Then 'is it the next
row
                    TargetRow = TargetRow + 1 'Increment by 1, data is sequential
                Else 'neither do search
                    On Error Resume Next
                    TargetRow = Application.WorksheetFunction.Match(MatchValue,
DataDateTime, 0) - 1 'Match Row as last resort
                    If Err.Number <> 0 Then TargetRow = 0 'not found, Reset
target row
                    On Error Goto 0
                End If
            Else 'neither do search
                On Error Resume Next
                TargetRow = Application.WorksheetFunction.Match(MatchValue,
DataDateTime, 0) - 1 'Match Row as last resort
                If Err.Number <> 0 Then TargetRow = 0 'not found, Reset target
row
                On Error Goto 0
            End If


            If TargetRow > 0 Then


                Debug.Assert UBound(Filter(DataDateTime, MatchValue)) = 0 'Double
check for multiple matches
                DirOffset = 0 'Reset to first direction
                If LineText(DirBin) <> Dir Then DirOffset = DirOffsetDefault 'Set
direction


                 '***** Populate first 3 values
                For i = 0 To DateTimeBin - 1
                    If OutputSheet.Cells(TargetRow, OutputColumn + i + DirOffset)
<> "" And i <> 1 Then
                        Debug.Assert
Application.WorksheetFunction.Text(OutputSheet.Cells(TargetRow, OutputColumn + i
+ DirOffset), "General") = LineText(i)
                    End If
                    OutputSheet.Cells(TargetRow, OutputColumn + i + DirOffset) =
LineText(i)
                Next i
```

```
                '***** Populate date/time
                If OutputSheet.Cells(TargetRow, OutputColumn + DateTimeBin +
DirOffset) <> "" Then
                    Debug.Assert OutputSheet.Cells(TargetRow, OutputColumn +
DateTimeBin + DirOffset) = MatchTime
                End If
                With OutputSheet.Cells(TargetRow, OutputColumn + DateTimeBin +
DirOffset)
                    .Value = MatchTime
                    .NumberFormat = "YYYY.MM.DD  HH"
                End With

                '***** Populate speed bins
                For i = DateTimeBin + 1 To Bins
                    OutputSheet.Cells(TargetRow, OutputColumn + i + DirOffset) =
OutputSheet.Cells(TargetRow, OutputColumn + i + DirOffset) + LineText(i)
                Next i

                OutputSheet.Cells(TargetRow, OutputColumn + Bins + 1 + DirOffset)
= OutputSheet.Cells(TargetRow, OutputColumn + Bins + 1 + DirOffset) + 1

            End If

        End If

         'Update progress
        If LineNumber Mod 10 = 0 Then Application.StatusBar = Format(Time -
StartTime, "HH:MM:SS") & "    Progress = " & Round(Seek(InputFile) / InputLen, 5)
* 100 & "%"

    Loop

    Application.StatusBar = False

    Call MsgBox("Complete." & vbNewLine & "Elapsed Time = " & Format(Time -
StartTime, "HH:MM:SS"), vbOKOnly + vbInformation, "Processing Complete!")

End Sub
```

Match data with paired hour

```
Sub FileList()



    Dim ThisList() As String
    Dim i As Integer
```

```
    Redim ThisList(24)


    ThisList(0) = "00 - 404 Hwy events.xlsm"
    ThisList(1) = "00 - 410 Hwy events.xlsm"
    ThisList(2) = "00 - Carleton events.xlsm"
    ThisList(3) = "08 - Maple events.xlsm"
    ThisList(4) = "09 - Massey events.xlsm"
    ThisList(5) = "10 - Morrisburg events.xlsm"
    ThisList(6) = "11 - North Bay events.xlsm"
    ThisList(7) = "13 - Kanata events.xlsm"
    ThisList(8) = "14 - Port Hope events.xlsm"
    ThisList(9) = "15 - Port Severn events.xlsm"
    ThisList(10) = "16 - Snelgrove events.xlsm"
    ThisList(11) = "17 - Grand Bend events.xlsm"
    ThisList(12) = "18 - Kenora events.xlsm"
    ThisList(13) = "20 - Nipigon events.xlsm"
    ThisList(14) = "21 - Shelburne events.xlsm"
    ThisList(15) = "22 - Simcoe events.xlsm"
    ThisList(16) = "23 - Sioux Narrows events.xlsm"
    ThisList(17) = "24 - Shabaqua events.xlsm"
    ThisList(18) = "25 - wood stock events.xlsm"
    ThisList(19) = "26 - QEW1 events.xlsm"
    ThisList(20) = "27 - QEW2 events.xlsm"
    ThisList(21) = "30 - Patrol 1 events.xlsm"
    ThisList(22) = "31 - Patrol 2 events.xlsm"
    ThisList(23) = "33 - Patrol 4 events.xlsm"
    ThisList(24) = "34 - Patrol 5 events.xlsm"


    For i = 3 To 24
        Workbooks.Open Filename:="C:\Users\Garrett\Desktop\3 - Paired\" &
ThisList(i)
        Workbooks(ThisList(i)).Activate
        Call PairingFormulas
        Workbooks(ThisList(i)).Close True
    Next i


End Sub







Sub PairingFormulas()
     '
     ' Keyboard Shortcut: Ctrl+Shift+P
     '


    Dim RedWS, HrlyWS, Sample, ThisWB As String
    Dim RedRows, HrlyRows As Long
    Dim NextFormula As String
    Dim WSCell As Range
    Dim CountCells, Count As Long


    Application.ScreenUpdating = False
```

```
    If Worksheets.Count <> 2 Then
        Application.DisplayAlerts = False
        Worksheets("Full Hrly event").Delete
        Worksheets("Avg Event Data").Delete
        Application.DisplayAlerts = True
    End If


    Sample = "Macro - 3.xlsm"
    ThisWB = ActiveWorkbook.Name
    RedWS = "Red Hry event" 'ActiveSheet.Name
    HrlyWS = "Hourly Data"


    Application.StatusBar = "Inserting Hourly Data Formulas..."
    Sheets(HrlyWS).Select
    Workbooks(Sample).Worksheets(HrlyWS).Range("DP1:DV2").Copy
Destination:=Workbooks(ThisWB).Worksheets(HrlyWS).Range("DP1:DV2")

    Application.StatusBar = "Inserting Hourly Array Formulas..."
    HrlyRows = Cells.Find(What:="*", After:=[A1],
SearchDirection:=xlPrevious).Row
    Range("DW1").FormulaArray = "=INDEX(RC[-46]:R[" & HrlyRows & "]C[-
46],MATCH(MAX(COUNTIF(RC[-46]:R[" & HrlyRows & "]C[-46],RC[-46]:R[" & HrlyRows &
"]C[-46])),COUNTIF(RC[-46]:R[" & HrlyRows & "]C[-46],RC[-46]:R[" & HrlyRows &
"]C[-46]),0))"
    Range("DX1").FormulaArray = "=INDEX(RC[-27]:R[" & HrlyRows & "]C[-
27],MATCH(MAX(COUNTIF(RC[-27]:R[" & HrlyRows & "]C[-27],RC[-27]:R[" & HrlyRows &
"]C[-27])),COUNTIF(RC[-27]:R[" & HrlyRows & "]C[-27],RC[-27]:R[" & HrlyRows &
"]C[-27]),0))"

    Application.StatusBar = "Filling Hourly Data Formulas..."
    Range("DP2:DU2").Copy Destination:=Range("DP3:DU" & HrlyRows)

    CountCells = (HrlyRows - 1) * 6 'Range("DP2:DU2").Columns


    Application.StatusBar = "Converting Hourly Data Formulas to Text..."
    Application.Calculation = xlCalculationManual
    For Each WSCell In Range("DP3:DU" & HrlyRows)
        Count = Count + 1
        WSCell.Value = WSCell.Value
        Application.StatusBar = "Converting Hourly Data Formulas to Text... " &
Round(Count / CountCells * 100, 3) & "%"
    Next WSCell
    Application.Calculation = xlCalculationAutomatic
     'Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone,
SkipBlanks:=False, Transpose:=False


    Count = 0


    Application.StatusBar = "Inserting Reduced Data Formulas..."
    Sheets(RedWS).Select
    RedRows = Cells.Find(What:="*", After:=[A1], SearchDirection:=xlPrevious).Row
    Range("CG1").FormulaR1C1 = "DateTime"
    Range("CG2").FormulaR1C1 = "=RC[-84]+INT(RC[-83])/24"
    Range("CH1").FormulaR1C1 = "='Hourly Data'!RC[35]"
    Range("CH2").FormulaR1C1 = "=IFERROR(VLOOKUP(RC85,OFFSET('Hourly
Data'!R2C102,0,0,COUNTA('Hourly
Data'!R2C102:R250000C102),25),COLUMNS(R1C86:R1C)+18,0),0)"
```

```
    Range("CH1:CH2").AutoFill Destination:=Range("CH1:CM2"), Type:=xlFillDefault
    Range("CN1").FormulaR1C1 = "Previous Week"
    Range("CN2").FormulaR1C1 = "=IFERROR(MATCH(RC85-7,OFFSET('Hourly
Data'!R2C102,0,0,COUNTA('Hourly Data'!R2C102:R250000C102),1),0),0)"
    Range("CO1").FormulaR1C1 = "Following Week"
    Range("CO2").FormulaR1C1 = "=IFERROR(MATCH(RC85+7,OFFSET('Hourly
Data'!R2C102,0,0,COUNTA('Hourly Data'!R2C102:R250000C102),1),0),0)"
    Range("CP1").FormulaR1C1 = "Choice"
    Range("CP2").FormulaR1C1 = "=IF(RC[-2]<>0,2,IF(RC[-1]<>0,3,1))"
    Range("CQ1").FormulaR1C1 = "=""P_""&RC[-10]"
    Range("CQ2").FormulaR1C1 = "=CHOOSE(RC[-1],"""",RC[-10]-7,RC[-10]+7)"
    Range("CG2:CQ2").Select


    Application.StatusBar = "Filling Reduced Data Formulas..."
    Range("CG2:CQ2").Copy Destination:=Range("CG3:CQ" & RedRows)


    CountCells = (RedRows - 1) * 11 'Range("CG2:CQ2").Columns


    Application.StatusBar = "Converting Reduced Data Formulas to Text..."
    Application.Calculation = xlCalculationManual
    For Each WSCell In Range("CG3:CQ" & RedRows)
        Count = Count + 1
        WSCell.Value = WSCell.Value
         'Debug.Print WSCell.Address
        Application.StatusBar = "Converting Reduced Data Formulas to Text... " &
Round(Count / CountCells * 100, 3) & "%"
    Next WSCell
    Application.Calculation = xlCalculationAutomatic


    Application.StatusBar = False
    Application.ScreenUpdating = True
End Sub
```

Set up combination of separate sites into master database

```
Option Explicit


Sub SelectFiles()


     ' File names
    Dim TargetSheets As Variant
    Dim SheetCount As Integer
    Dim ThisSheet As String
    Dim i As Integer


    Application.ScreenUpdating = False
    Application.Calculation = xlCalculationManual


     'Set file names
    TargetSheets = Application.GetOpenFilename("Processed Data,*.xlsm", 1, "
Select the desired files to read...", , True)
```

```
    On Error Resume Next
    SheetCount = UBound(TargetSheets)
    If Err.Number <> 0 Then
        If TargetSheets = False Then Goto CleanUp
    End If
    On Error Goto 0


    Load frmProgress


     'Open files for processing
    For i = 1 To SheetCount


        frmProgress.Show (vbModeless)


        ThisSheet = Mid(TargetSheets(i), InStrRev(TargetSheets(i), "\") + 1,
Len(TargetSheets(i)))


        Workbooks.Open Filename:=TargetSheets(i), ReadOnly:=True


        frmProgress.Caption = "Processing file " & i & " of " & SheetCount &
"..."
        Application.StatusBar = "Overall Progress: " & Round((i - 1) / SheetCount
* 100, 1) & "%"


        Call Combine(ThisSheet)


        Workbooks(ThisSheet).Close False


    Next i




CleanUp:
    Workbooks("Combined Data.xlsx").Close True
    Unload frmProgress
    Application.StatusBar = False
    Application.ScreenUpdating = True
    Application.Calculation = xlCalculationAutomatic


End Sub


Private Sub Combine(InputFile As String)


     'Data storage
    Dim H_Col, R_Col As Integer
    Dim OutputString As String
    Dim FinalSheet, H_Sheet, R_Sheet, O_Sheet, P_Sheet As String
```

```
    Dim AddHeader As Boolean

     ' Loop control
    Dim H_Rows, H_Row As Long
    Dim H_Cell, R_Cell As Range
    Dim R_Rows, R_Row As Long
    Dim O_Rows, O_Row As Long
    Dim P_Rows, P_Row As Long
    Dim ThisTime As Double
    Dim i As Long
    Dim j As Long
    Dim k As Integer

    FinalSheet = "Combined Data.xlsx"
    O_Sheet = "Original"
    P_Sheet = "Pairs"
    H_Sheet = "Hourly Data"
    R_Sheet = "Red Hry event"

    H_Rows = Workbooks(InputFile).Worksheets(H_Sheet).Cells.Find(What:="*",
After:=[A1], SearchDirection:=xlPrevious).Row
    R_Rows = Workbooks(InputFile).Worksheets(R_Sheet).Cells.Find(What:="*",
After:=[A1], SearchDirection:=xlPrevious).Row
    O_Rows = Workbooks(FinalSheet).Worksheets(O_Sheet).Cells.Find(What:="*",
After:=[A1], SearchDirection:=xlPrevious).Row
    P_Rows = Workbooks(FinalSheet).Worksheets(P_Sheet).Cells.Find(What:="*",
After:=[A1], SearchDirection:=xlPrevious).Row
    H_Col = 86
    R_Col = 96
    H_Row = 1
    R_Row = 1
    O_Row = O_Rows + 1
    P_Row = P_Rows + 1

     'compare header

    Workbooks(InputFile).Worksheets(H_Sheet).Range("A:A").NumberFormat =
"0.0000000000"
    For Each H_Cell In Workbooks(InputFile).Worksheets(H_Sheet).Range("A2:A" &
H_Rows)
        H_Cell.Value = H_Cell.Value
    Next H_Cell
    Set H_Cell = Nothing



    For i = 1 To R_Rows

        If i = 1 Then
             '            k = 1
             '            For j = 1 To 126
             '                Select Case j
             '                    Case 1
             '
Workbooks(FinalSheet).Worksheets(O_Sheet).Cells(i, k) = "ID"
             '
Workbooks(FinalSheet).Worksheets(P_Sheet).Cells(i, k) = "ID"
```

```
'                        k = k + 1
'
Workbooks(FinalSheet).Worksheets(O_Sheet).Cells(i, k) = "DIR"
'
Workbooks(FinalSheet).Worksheets(P_Sheet).Cells(i, k) = "DIR"
'                        k = k + 1
'
Workbooks(FinalSheet).Worksheets(O_Sheet).Cells(i, k) = "TimeStamp"
'
Workbooks(FinalSheet).Worksheets(P_Sheet).Cells(i, k) = "TimeStamp"
'                        k = k + 1
'                    Case 4, 5, 6, 7, 8, 9, 10, 15, 16, 17, 29, 35,
37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 121, 122, 123
'                        If
Workbooks(FinalSheet).Worksheets(O_Sheet).Cells(i, k) = "" Then
'
Workbooks(FinalSheet).Worksheets(O_Sheet).Cells(i, k) =
Workbooks(InputFile).Worksheets(H_Sheet).Cells(i, j).Value
'                        ElseIf
Workbooks(FinalSheet).Worksheets(O_Sheet).Cells(i, k) =
Workbooks(InputFile).Worksheets(H_Sheet).Cells(i, j).Value Then
'                            'ok ignore
'                        Else
'                            Debug.Assert False
'                        End If
'                        If
Workbooks(FinalSheet).Worksheets(P_Sheet).Cells(i, k) = "" Then
'
Workbooks(FinalSheet).Worksheets(P_Sheet).Cells(i, k) =
Workbooks(InputFile).Worksheets(H_Sheet).Cells(i, j).Value
'                        ElseIf
Workbooks(FinalSheet).Worksheets(P_Sheet).Cells(i, k) =
Workbooks(InputFile).Worksheets(H_Sheet).Cells(i, j).Value Then
'                            'ok ignore
'                        Else
'                            Debug.Assert False
'                        End If
'                        k = k + 1
'                    Case Else
'                        'Ignore
'                End Select
'            Next j
            Goto ContinueSearch
        End If


        Set H_Cell = Nothing
        ThisTime = Workbooks(InputFile).Worksheets(R_Sheet).Cells(i, H_Col).Value
         'On Error Resume Next
        Set H_Cell =
Workbooks(InputFile).Worksheets(H_Sheet).Range("A:A").Find(What:=ThisTime,
After:=Cells(H_Row, 1), LookIn:=xlValues, SearchOrder:=xlByColumns,
SearchDirection:=xlNext)
         'On Error GoTo 0
        If H_Cell Is Nothing Then
            'not found
            H_Row = 1
            Goto ContinueSearch
        Else
            'Debug.Assert False
        End If
        H_Row = H_Cell.Row
```

```
        If Workbooks(InputFile).Worksheets(R_Sheet).Cells(i, R_Col) <> "" Then

            Set R_Cell = Nothing
            ThisTime = Workbooks(InputFile).Worksheets(R_Sheet).Cells(i,
R_Col).Value
            On Error Resume Next
            Set R_Cell =
Workbooks(InputFile).Worksheets(H_Sheet).Range("A:A").Find(What:=ThisTime,
After:=Cells(R_Row, 1), LookIn:=xlValues, SearchOrder:=xlByColumns,
SearchDirection:=xlNext)
            On Error Goto 0
            If R_Cell Is Nothing Then
                 'not found
                Debug.Assert False
                R_Row = 1
                Goto ContinueSearch
            End If
            R_Row = R_Cell.Row


            If Workbooks(InputFile).Worksheets(R_Sheet).Cells(i, H_Col + 1) <> 0
Then 'First Direction

                k = 1
                For j = 1 To 126
                    Select Case j
                    Case 1
                        Workbooks(FinalSheet).Worksheets(O_Sheet).Cells(O_Row, k)
= Left(InputFile, 2) & "." &
Format(Workbooks(InputFile).Worksheets(H_Sheet).Cells(H_Row, j).Value,
"YYYY.MM.DD.HH")
                        Workbooks(FinalSheet).Worksheets(P_Sheet).Cells(P_Row, k)
= Left(InputFile, 2) & "." &
Format(Workbooks(InputFile).Worksheets(H_Sheet).Cells(H_Row, j).Value,
"YYYY.MM.DD.HH")
                        k = k + 1
                        Workbooks(FinalSheet).Worksheets(O_Sheet).Cells(O_Row, k)
= 1
                        Workbooks(FinalSheet).Worksheets(P_Sheet).Cells(P_Row, k)
= 1
                        k = k + 1
                        Workbooks(FinalSheet).Worksheets(O_Sheet).Cells(O_Row, k)
= Workbooks(InputFile).Worksheets(H_Sheet).Cells(H_Row, j).Value
                        Workbooks(FinalSheet).Worksheets(P_Sheet).Cells(P_Row, k)
= Workbooks(InputFile).Worksheets(H_Sheet).Cells(R_Row, j).Value
                        k = k + 1
                    Case 4, 5, 6, 7, 8, 9, 10, 15, 16, 17, 29, 35, 37, 38, 39,
40, 41, 42, 43, 44, 45, 46, 47, 48, 121, 122, 123
                        Workbooks(FinalSheet).Worksheets(O_Sheet).Cells(O_Row, k)
= Workbooks(InputFile).Worksheets(H_Sheet).Cells(H_Row, j).Value
                        Workbooks(FinalSheet).Worksheets(P_Sheet).Cells(P_Row, k)
= Workbooks(InputFile).Worksheets(H_Sheet).Cells(R_Row, j).Value
                        k = k + 1
                    Case Else
                         'Ignore
                    End Select
                Next j
                O_Row = O_Row + 1
                P_Row = P_Row + 1
            End If
```

```
            If Workbooks(InputFile).Worksheets(R_Sheet).Cells(i, H_Col + 4) <> 0
Then 'Second Direction
                k = 1
                For j = 1 To 126
                    Select Case j
                    Case 1
                        Workbooks(FinalSheet).Worksheets(O_Sheet).Cells(O_Row, k)
= Left(InputFile, 2) & "." &
Format(Workbooks(InputFile).Worksheets(H_Sheet).Cells(H_Row, j).Value,
"YYYY.MM.DD.HH")
                        Workbooks(FinalSheet).Worksheets(P_Sheet).Cells(P_Row, k)
= Left(InputFile, 2) & "." &
Format(Workbooks(InputFile).Worksheets(H_Sheet).Cells(H_Row, j).Value,
"YYYY.MM.DD.HH")
                        k = k + 1
                        Workbooks(FinalSheet).Worksheets(O_Sheet).Cells(O_Row, k)
= 2
                        Workbooks(FinalSheet).Worksheets(P_Sheet).Cells(P_Row, k)
= 2
                        k = k + 1
                        Workbooks(FinalSheet).Worksheets(O_Sheet).Cells(O_Row, k)
= Workbooks(InputFile).Worksheets(H_Sheet).Cells(H_Row, j).Value
                        Workbooks(FinalSheet).Worksheets(P_Sheet).Cells(P_Row, k)
= Workbooks(InputFile).Worksheets(H_Sheet).Cells(R_Row, j).Value
                        k = k + 1
                    Case 4, 5, 6, 7, 8, 9, 10, 15, 16, 17, 29, 35, 37, 38, 39,
40, 41, 42, 43, 44, 45, 46, 47, 48, 124, 125, 126
                        Workbooks(FinalSheet).Worksheets(O_Sheet).Cells(O_Row, k)
= Workbooks(InputFile).Worksheets(H_Sheet).Cells(H_Row, j).Value
                        Workbooks(FinalSheet).Worksheets(P_Sheet).Cells(P_Row, k)
= Workbooks(InputFile).Worksheets(H_Sheet).Cells(R_Row, j).Value
                        k = k + 1
                    Case Else
                         'Ignore
                    End Select
                Next j
                O_Row = O_Row + 1
                P_Row = P_Row + 1
            End If
        End If


ContinueSearch:
        frmProgress.ProgressBar = i / R_Rows
    Next i


End Sub
```