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The effect of weather on speed reduction on a freeway and air pollutant dispersion pattern near the freeway

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by

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ABSTRACT

This paper examines the variations in traffic speed and the dispersion pattern of NO_x produced from traffic in clear, rainy and snowy weather conditions. The data used for the analysis include weekday hourly traffic count of 193 days in 1998 on Gardiner Expressway, Toronto, Ontario, and the coincide 193 meteorology days. The ordered logistic regression model was used to identify the relationships between speed reduction and various factors. The EPA emission factor model and AERMOD were used to predict NO_x concentrations using traffic volumes and meteorology data.

Analysis of speed reduction shows precipitation, hour of day, snowy condition and seasons reduce speed. The predicted dispersion show NO_x concentration was high in clear weather condition compared to adverse weather condition due to higher traffic volumes and higher emissions. However, in snowy weather condition, wind speed had more influence on NO_x concentration than emission rate.

DEDICATION

To my beloved grandparents for their faith and unconditional love in me.

To my parents, Hung and Thu Nguyen, for their hard work keeping me in school.

To my sister, Janet: my first teacher.

Lastly to Trinh, my guidance and supporter through this journey.

I love you all.

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CHAPTER I

INTRODUCTION

1.1 OVERVIEW

Transportation contributes to high levels of air pollution. The emission from transportation makes up 27% of Canada's total greenhouse gas emissions Environment Canada (2007). Statistic Canada's (2005) survey shows on average commuters spent 60 minutes per day in vehicles. The adverse health effect of air pollution is well known including cardio-pulmonary disease (Environment Canada, 2010). With a significant number of populations resided within 300 to 500 m of major roads in big cities, Environmental Canada concluded that there is sufficient evidence for health and environmental concern from traffic pollutant and deserves public attention (Environment Canada, 2010).

The primary pollutants from transportation sources include carbon monoxide (CO), nitric oxide (NO), Particulate Matter, sulphur oxide (SO_2) and other chemicals (Onursal, 1997). Once released, NO oxidizes to form nitrogen dioxide (NO_2). NO and NO_2 are collectively called oxides of nitrogen or NO_x. Environment Canada estimates that transportation sources account for 53% of Canada's total NO_x emissions (Environment Canada, 2007). Therefore NO_x is a significant problem in high-traffic areas.

The vehicular emissions and fuel consumption are in direct association to congestion in transportation. Congestion is defined as the increases traffic density or the frequent accelerations and stop-and-go transients. One of the major causes in congestion is adverse weather. The weather conditions have impact on traffic operation, and flow and safety of travel for commuters, especially in geographic area with predominant seasonal changes like Canada. A study by Audrey et al. (2003) shows collision risks has 50-100% increase during precipitation events, i.e. snowfall and rainfall. Another study by Eisenberg et al. (2005) show injuries and vehicular damages occurs more on snow fall days than dry days.

The impact of weather has been analyzed by many researchers as a cause of traffic congestion and accidents. In the environmental and social aspect, weather is known to influenced driver behaviour and the dispersion of emission. In the past, researchers have often analyzed the impact of traffic operation on weather condition and traffic on air quality. However, there is a lack of study on the comprehensive analysis to determine the relationship of weather on traffic and air quality.

1.2 RESEACH OBJECTIVES

The overall objective of this study is to examine the effect of weather conditions on speed variation and compare the dispersion of air pollutants in different condition from traffic sources over the Gardiner Expressway in Toronto, Ontario. The first part investigates the effect of weather conditions such as precipitation rate and visibility on speed variation. The second part estimates the vehicular emissions of NO_x and models the dispersion patterns to examine how traffic pollutant scatters near the freeway on clear and adverse weather conditions.

The specific objectives are:

- To examine the impact of weather on traffic without influence from incidents and recurrent congestions.
- To examine the effect of weather on traffic volume in calculation of NO_x emission.
- To examine the dispersion patterns of NO_x from traffic under different weather conditions.

1.3 ORGANIZATION OF THESIS

This thesis is organized in eight chapters. Chapter 1 introduces the topic and the objective of the study. Chapter 2 presents the literature review of traffic study and on how weather affects the traffic flow, emission and dispersion patterns. Chapter 3 explains the data used in this study, including the data sources, as well as the processing methods. Chapter 4 explains the methodology in analyze the relationship between speed variation and weather condition. Chapters 5 present the results of traffic analysis. Chapter 6 explains the methodology to obtain vehicular emission rate of NO_x on the Gardiner

Expressway, and the use of AERMOD model for dispersion simulations. Chapter 7 presents the results of dispersion patterns. Lastly, Chapter 8 includes the conclusions and recommendations.

CHAPTER II

REVIEW OF LITERATURES

2.1 WEATHER CONDITIONS, VEHICULAR SPEED AND VOLUME

2.1.1 EFFECT OF WEATHER ON SPEED

The weather conditions' impact on speed was confirmed by the Federal Highway Administration in the 70's (FHWA, 1977). Since then, many studies have assessed the impact of weather on traffic flow (Faouzi, 2010). In fact, the weather impact on speeds documented in the Highway Capacity Manual (2010) was based on Ibrahim and Hall's (1994) study.

Severe weather conditions including tornados, floods, and hurricanes are beyond the scope of this study. However, other weather conditions such as rain and snow cause reduction in vehicle speed. The reductions in vehicle speed are in direct relation to reduction in visibility and pavement friction. Previous research efforts show bad weather reduces speed about 9-11 km per hour (Andre and Hammarstrom, 2000). Smith et al. (2003) showed a reduction of 3% - 5% in operating speed under rainfall conditions compared to no rain. This study also concluded that operating speed reductions were not as dramatic as the capacity reductions during adverse weather. Ibrahim and Hall (1994) investigate the relationship between speed reduction in light and heavy weather condition as summarized in Table 2-1.

Table 2- 1. Speed reduction during rain and snow condition. (Source: Ibrahim and Hall, 1994)

	Light	Heavy
Rain	1.9-12.9 km/hr	0.97 km/hr
Snow	4.8-16.1 km/h	37-41.8 km/hr

It is difficult to quantify weather conditions because some are not measurable parameters. Thus, Martin et al. (2000) suggested that for the purpose of analyzing the impact of weather conditions on traffic operation, four factors should be considered:

Severity of the weather condition

- The duration of the weather condition
- Traffic flow or the demand served by the network
- The geographic area

Weather condition can differ in intensity. The weather conditions can be classified into one of three types: “clear” "rain", and "snow". Each weather conditions ranges from light to heavy conditions and can last for hours. Depending on the duration of weather condition, it can have high or low impact on traffic operation. Result indicates the longer (Sabir, 2010) and heavier (Alhassan, 2011) the adverse weather condition the more speed reduction.

Speed variation in weather conditions is affected by both visibility and road surface friction. Visibility is defined as the farthest distance an unlighted object can be identified by visual estimate during the day or prominent lighted objects at night. Visibility is expressed in distance. Visibility reduces in foggy condition, heavy rain or heavy snow (Weather Office, 2011). Reduced visibilities leads to lower speed due to the reduction of distance drivers see while driving. The maximum visibility is greater than 10 kilometres on a clear day where a flat ground horizon can still be observed (Weather Network, 2011). In order to record visibility beyond this distance, weather station use visibility markers such as mountains/hills, towers and tree lines to estimate how far away these objects can be identified without obstruction. A study by Kyte et al. (2001) defined 300 m is a critical visibility distance that affect the response time in drivers. Below this critical value, drivers reduced their speed 770 m/hr for every 10 m change in visibility. However, in a laboratory simulation, Snowden et al. (1998) found that drivers would underestimate their speeds under less visibility conditions in familiar surroundings.

Vehicles response such as accelerating, decelerating, or steering is affected by the traction between the tires and the road surface (Zeitlin, 1995). Due to high precipitation rate and ice formation in winter, it is expected that the speed reduction is higher in snow condition as compared to dry or rain. Martin et al. (2000) reported a 10 percent speed reduction in wet conditions as compared to a 25 percent reduction in slushy and wet conditions. These results were also confirmed by Rakha et al. (2006) using detailed traffic and weather data from 2002 to 2004. The FHWA (2010) classify weather conditions into seven categories of road surfaces. Each road surface is designated with a severity IDs, and was related to speed reductions. The FHWA categories were summarized in Table 2-2.

Table 2- 2. Speed reduction based on road surfaces. (Source: FHWA, 1977)

Condition	Severity ID	Percent Speed Reduction
Dry	1	0%
Wet	2	0%
Wet and snowing	3	13%
Wet and slushy	4	22%
Slushy in wheel paths	5	30%
Snowy and sticking	6	35%
Snowing and packed	7	42%

Due to the limitation of data and the interference of high rate of accidents occurred during adverse weather conditions few studies were able to quantify the weather impact on the traffic speed variation. Nevertheless, Stern et al. (2003) used a two-step linear regression analysis to study weather condition such as precipitation types, wind, visibility and pavement conditions on travel time. Result indicates an average of 14% increase in travel time under adverse weather condition. Smith et al., (2004) provided two evident explanations for this result are the surface friction and the presence of precipitation.

2.1.2 EFFECT OF WEATHER ON TRAFFIC VOLUME

Hanbali et al (1992) studied the reduction in traffic volumes during snowstorms in rural areas of Illinois, Minnesota, New York, and Wisconsin. The result is summarized in Table 2-3. The study suggested that there is a reduction in hourly traffic volume during snowstorm compared to the “normal” hourly traffic. However, this reduction is less predominant during peak-hours and during weekdays. The reason for this was due to nondiscretionary type of trips such as home to work and work to home. This study was confirmed by Knapp (2000) indicating traffic volume reduces 16-47% in winter storm events. Knapp included in his study factors such as: precipitation, air temperature below freezing, wet pavement surface, wind speed and pavement temperature below freezing. The data analyzed more than 4 hours in adverse weather and snowfall exceeds 5.1 mm/hr. From the regression analysis, the study concluded that the percent volume reduction had a significant relationship with total snowfall and wind speed. Capacity studies by Ries (2004) on highway I-35W in Minneapolis and its suburbs indicates trace of rain reduces volume of vehicles by 8%, each additional 0.01 inch of rain decreased capacity by 0.6%. Similarly, the study by Hall and Barrow (1988) on the Queen Elizabeth Way in Hamilton, Ontario concluded capacity is reduced because during rainstorms, traffic flow changes from uncongested to congest at lower occupancy rates.

Table 2- 3. Volume reduction due to snowstorm. (Source: Hanbali and Kuemmel, 1992)

Precipitation Rate	Weekdays	Weekends
< 25 mm	7-17%	19-31%
25-75 mm	11-25%	30-41%
75-150 mm	18-34%	39-47%

2.1.3 EFFECT OF WEATHER ON EMISSIONS FROM TRAFFIC

In general the emission from traffic is affected by traffic speed and volume. The emissions of vehicles on the road is related to the fuel usage based on the speed travelled (FHWA, 2001). Research indicates the fuel usage is maximized at speeds between 50 and 90 km/h (Transportation Alberta (TA), 2000). At higher speeds the increased in aerodynamic forces reduce fuel usage causing less air emissions. For highways, it is often observed that the average speeds are often above the posted speed limit (TA, 2000). However at congestion periods and bad weather conditions the reduction in speed can be tremendous. At low speeds additional fuel is required to keep the engine running for the same distance of travel, thus higher emissions is emitted (TA, 2000). In addition, trucks fuelled by diesel have higher emission than cars fuelled by gasoline. The more heavy-duty vehicle on the road the greater the impact on air quality (Keuken et al. 2009). Figure 2-1 shows the speed in relation to emission of NO_x and CO.

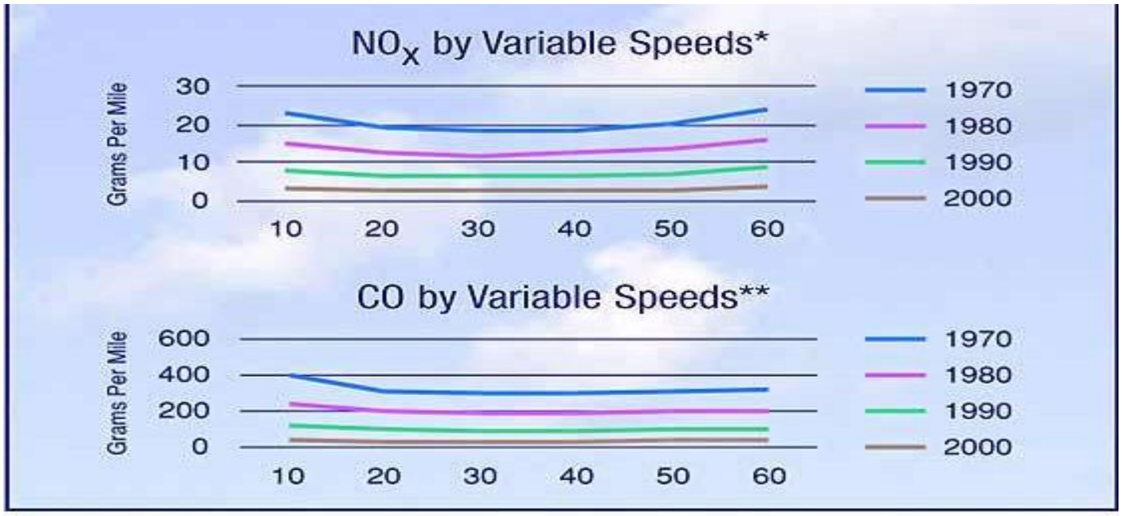


Figure 2- 1. NO_x and CO emission produced from traffic in different speed. (Source: FHWA, 2011)

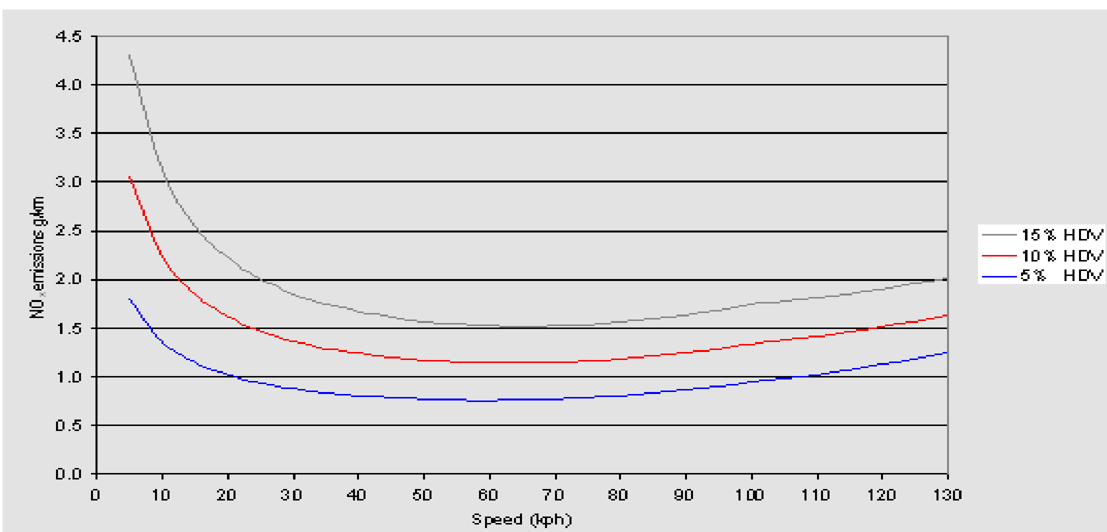


Figure 2- 2. NO_x emission from traffic in different speed and vehicle composition (Source: The Department of Transport, England, U.K, 2005)

Roadway traffic is composed of car and truck volumes. Adverse weather can reduce the demand on the road because drivers cancel or postponed their activities. For vehicles driven in adverse weather, a reduction in speed and volume was observed (Alhassan, 2011, Maze, 2005). This affect is due to driver's natural caution response during bad weather (Lockwood, 2006). The changes in vehicular count and speed reduction on roadway affect the total emission release into the environment. Logically, reduction in traffic volume due to weather would decreases total emission. However, increase in idleness would cause higher fuel consumption thus increase the emission. Figure 2-3 shows the difference in emissions with higher NO_x and CO concentrations emits from cars than trucks.

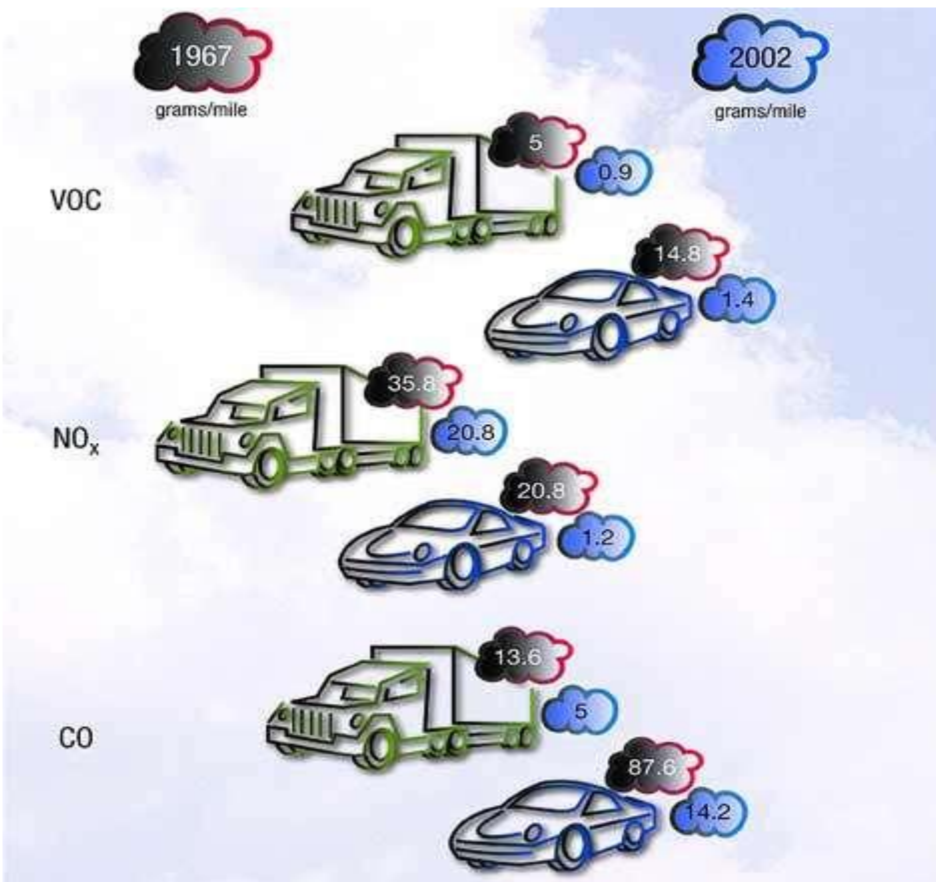


Figure 2- 3. VOC, NO_x and CO emission for car and trucks. (Source: FHWA, 2011)

From Figure 2-3, it can be seen that over the years, the total emission emits reduces significantly due to high government restriction. Based on the review of traffic speed and volume with emission, it can be concluded that vehicular emission has great impact toward pollutants in the environment.

2.2 DISPERSION OF AIR POLLUTANTS FROM TRAFFIC

Dispersion of air pollutants is effected by meteorological conditions including wind speed and wind directions. Due to the requirement of quantitating air pollution for highway planning and roadway projects in early 1960 (Beychok, 2005), the atmospheric dispersion models were developed. These models vary in methodologies including: Gaussian plume models, puff models, box models, statistical modeling, and computational fluid dynamics (CFD), geographical information systems (GIS), and wind tunnel simulations. An extensive review of 30 dispersion models can be found in Holmes and Morawska (2006). The most preferred types of dispersion model are those based on proven Gaussian dispersion methodology for simulating air pollutant emissions from industrial sources (IDNR, 2004). One applicable research for this methodology is by Keuken et al (2009). In this study, HEAVEN software was used to modeled NO_x and PM10. This software is an approved line-source model in the Netherlands for assessing air quality impacts of motorways under the environmental legislation (RIVM, 2008). Keuken et al (2009) indicates speed reduction on the motorway reduces NO_x by 5-30% and PM_{10} by 2-25%. Eneroth et al (2008) uses Airviro which is an approved program in Sweden. In North America, a Gaussian-based highway models known as CALINE4 dispersion modeling in an urban environment was assessed by Kenty et al (2006). This study also modeled the pollutant of NO_2 and NO_x near Gandy Boulevard in Tampa, FL. Result indicates CALINE4 under-estimate the chemical reaction NO_x when ambient O_3 concentrations is less than 40 ppb. Another complex model known as TAPM accommodates both complex meteorology, topography and includes atmospheric chemistry reaction. While this model provides high advantage, it also requires high computer resources and long computation time (Wallace, 2008).

Statistical modeling of air pollution can be assessed by developing a relationship between parameters such as meteorological and pollutant concentration estimates. Techniques include regression, time series analysis Markov chain-Monte Carlo methods, and extreme value theory. Gokhale and Khare (2004) use this approach to predict the CO from vehicle release.

There are two types of CFD techniques: the diagnostic and prognostic. The diagnostic interpolation methods are based on measurements that are subject to physical constraints (Li et al., 2006). The prognostic uses three approaches the Reynolds-averaged Navier-Stokes theory, the direct numerical simulation, and the large eddy simulation. This type of dispersion model allows more detailed examination of vehicle-induced turbulence in areas with complex street canyon geometries (Pierce, 2004), (Huber, 2006) uses CFD to study human exposure factors and human exposure profiles dominated by local source emissions.

Another method of modeling dispersion pattern resulting from vehicular emissions is to use a GIS to map traffic related pollution. This method requires integration from other models to calculate the impacts resulting from vehicular emissions. For example, Jin and Fu (2004) study the application of GIS on modification of emission dispersion. This study compared the observed hourly concentration and the simulated concentration. The simulation concentration was derived from GIS and input into the Gaussian model which provides adequate results. Table 2-4 summarized the dispersion models reviewed by Peirce et al, 2004)

Table 2- 4. Summary of Dispersion Models (Source: Table from Peirce et al, 2004)

Model Name	Developer
U.S. EPA Regulatory Models	
AMS/EPA Regulatory Model (AERMOD)	U.S. EPA, AMS http://www.epa.gov/scram001/dispersion_prefrec.htm
CALINE4	California Department of Transportation http://www.dot.ca.gov/hq/env/air/index.htm
CAL3QHC/ CAL3QHCR	U.S. EPA http://www.epa.gov/scram001/dispersion_prefrec.htm #cal3qhc
California Puff Model (CALPUFF)	Sigma Research Corporation/ TRC Environmental Corporation
Miscellaneous Publicly Available Models	
Canyon Plume Box Model, version 3.6a (CPB3)	Federal Highway Administration
Contaminants in the Air from a Road-Finnish Meteorological Institute (CAR-FMI)	Finnish Meteorological Institute
Emissions and Dispersion Modeling System (EDMS)	Federal Aviation Administration
Hybrid Roadway Model (HYROAD)	SAI/ICF Consulting, Inc.
Point, Area, Line (PAL)	U.S. EPA
Quick Urban & Industrial Complex (QUIC)	Los Alamos National Laboratory in collaboration with the University of Utah and the University of Oklahoma
Atmospheric Dispersion Modeling System (ADMS)-ROADS	Cambridge Environmental Research Consultants (CERC)
Operational Street Pollution Model (OSPM)	National Environmental Research Institute of Denmark
PROKAS	Lohmeyer Consulting Engineers, Inc. (German firm)
Miscellaneous Research-Grade Models	
Micro-Calgrid Model (MCG)	R. Stern and R. Yamartino
ROADWAY-2	NOAA Air Resources Laboratory
PUFFER	University of Nottingham (UK)
TRAQSIM	University of Central Florida
UCD 2001	University of California, Davis

Among these models, the highly recommended model (EPA, 2005), for near-roadway analysis is the American Meteorological Regulatory Model (AERMOD) model

(EPA, 2005). This model was used by Zou et. al. (2010) to study one, three and eight hours period with daily, monthly, and annual SO_2 concentrations. Zou et al (2010) found that AERMOD performs better in simulating SO_2 concentrations when combined both point and mobile emission sources were inputs into the model rather than using point or mobile emission sources alone. In addition, Kesarkar et. al. (2006) uses AERMOD to study the impact of PM_{10} over Pune, India. This study suggested that AERMOD tends to underestimates the pollutant concentrations especially over the city compared to rural. It is believe to be attributed to the lack of background concentration in the model or the under-representation of source profiles in the emission. A conference paper published by Kuwait University (Saquer, 2007) examined SO_2, non-methane hydrocarbon and NO_x using AERMOD. This study concluded there is a high degree of agreement 86%-98% between predicted and measured concentration at different receptor locations.

2.3 SUMMARY

Based on this literature review, there are some limitations of previous studies. Many studies have observed that adverse weather conditions such as poor lighting condition, poor visibility and wet road condition reduce traffic speed and volume. However, the reduced speed and volume are not only caused by adverse weather but also by incidents or recurrent congestion. Thus, to analyze the effect of weather on traffic, the relationship between weather on reduced speed and traffic volume should be identified. Also, there is a lack of studies on the traffic emissions caused by adverse weather condition. Thus, modelling the dispersion pattern of a NO_x from traffic and examine the concentration scatters over a distance in different weather condition should be addressed. These two limitations will be addressed in this study.

CHAPTER III

DESCRIPTION OF DATA AND STUDY SITE

3.1 STUDY SITE AND DATASETS

This thesis was focused on a section of the Gardiner Expressway in Toronto, Ontario, Canada. The Gardiner Expressway is an urban freeway, frequently used by local commuters going to and from downtown Toronto. The highway is presented in Figure 3-1,the Gardiner Expressway stretches 21.6 km long starting at Highway 427 at point A extending to Don Valley Parkway at point B. The freeway generally spans 10 m wide in each direction with the posted speed limit of 90 km/hr. The Gardiner Expressway resides next to Lake Ontario (point E in Figure 3-1). At Highway 427 (point A), it is 2.9 km away from the nearest point on the lake, where as at point B, it is 200 m away from the nearest point on the lake.

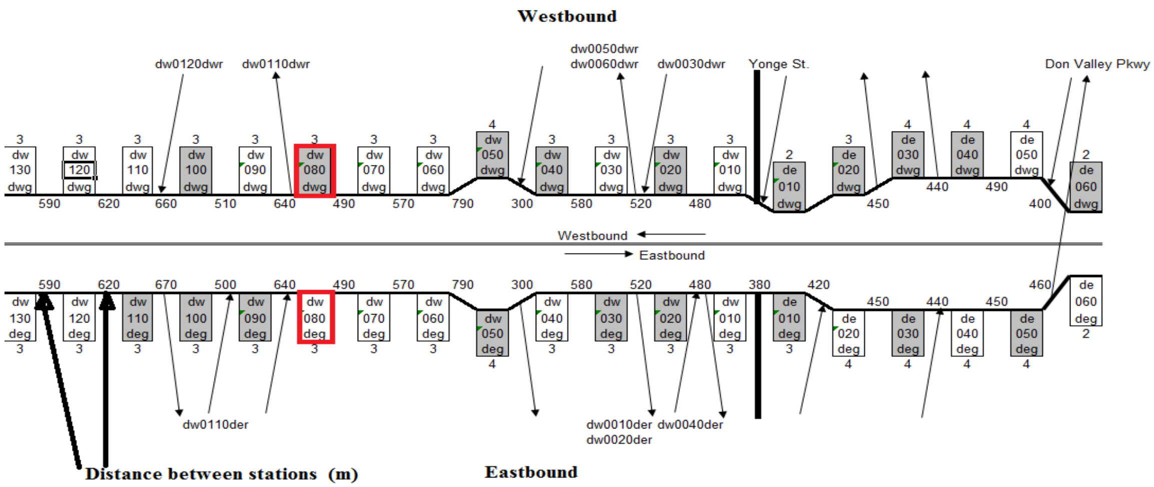
Figure 3- 1. Map of Gardiner Expressway, Toronto, ON. (Source: Base map by Google, 2011)

There are two sets of data collected for this study. One set of data was for traffic analysis and the other is for dispersion modeling. The first dataset for traffic analysis was obtained from the City of Toronto Traffic Operation Center (CTOOC) containing 4 files including: the detector location map, the percentage of vehicles on the highway, the weekday hourly traffic record, and the incident logs. The second dataset are the weather related data which were obtained from the Ministry of Environment Weather Office (MOE – WO) database website (2010). This dataset contains 3 files namely: the meteorology data, the hourly weather observations and the hourly weather conditions.

3.2 TRAFFIC DATA

The traffic data collected were for the Gardiner Expressway in Toronto. This freeway is a six lane highway with three lanes in each direction ran from east to west. At any given time in the weekday, this highway contains approximately 2500 to 3000 cars per hour, which equates to 67, 000 cars in the 24 hours period (CoT, 2010). Thus, making this is one of the busiest highways in Toronto.

Along the Gardiner Expressway there are many detectors. The map file obtained from the CTOOC shows 19 stations in each direction. The schematic drawing of this section of freeway is shown in Figure 3-2. The traffic data was collected at station #80 highlighted in Figure 3-2, which is located near Kipling Ave on the both side of the highway.



Arrow pointing outward = off-ramps, arrows pointing inward = on-ramps; letters inside squares = detector station IDs; number above or below station IDs = number of lanes; numbers between two successive detectors = distance (m); shaded detector stations = where traffic influenced by merging or diverging vehicles; bold number above or below distance numbers = total number of crashes in 13 months.

Figure 3- 2. Traffic stations along Gardiner Expressway. (Source: Lee et al., 2002)

3.2.1 WEEKDAY TRAFFIC

The Weekday Traffic files contain the occupancy, hourly speed and volume on the road. The speed reading and the volume of vehicles on the Gardiner Expressway pertains to the 24-hour period from zero to 23 hour. There are 193 days of records data for eastbound and westbound direction. A sample of the raw data obtained at the loop detector station 80 (highlighted in Figure 3-2) for the westbound direction is shown in Table 3.1 in local time.

Table 3- 1. Raw data of speed and traffic volume on January 2nd, 1998. (Source: Toronto Traffic Operation Office Center, 2010)

Time	Speed (km/hr)	Volume (veh/hr)	Occupancy (%)
10:01:23	87	2340	1
11:01:23	91	1800	3
12:01:23	94	1980	4
13:01:23	97	2160	1
14:01:23	99	2160	2
15:01.23	86	2340	2
16:01:23	79	1980	3
17:01:23	89	1980	4
18:01:23	93	1980	1

In addition, the percentage of car and truck was provided by the City of Toronto for the year 2001, 2004 and 2006. The averages of these three years indicated 90% of passenger cars and 10% of trucks on this highway for both eastbound and westbound. These percentages were used in the calculation of NO_x emission in the later chapter.

3.2.2 INCIDENT LOGS

Detail record of incidents that occurred in 1998 was obtained from the incident logs. Each incident was detected and verified by an operation at the control center and the following information is recorded: a unique ID, date (year, month, and day), day of week, station (closest upstream station to the incident site), the reported time, the type of incidents (e.g. crash, construction), the weather condition and whether the incident was confirmed or a false alarm. An example of the file is shown in Figure 3-3.

DAILY UNSCHEDULED TRAFFIC EVENT REPORT
For 02-DEC-1998 00:00 To 03-DEC-1998 00:00
INCIDENT EVENTS Report Date: 1998 12 3 01:15:37
Page: 1

Event ID : 9244 Event Type : INCIDENT
Detected : 2-DEC-1998 07:13:02 Confirmed : 1-JAN-1900 00:00:00 Owner : NOT_OWNED
Event Source : APID
Event Cause : TRAFFIC EVENT
Event State : UNCONFIRMED
Severity : not severe
Station ID : dw0060deg
Location : 2m downstream of STRACHAN, 790m upstream of BATHURST on the Eastbound_Gardiner
Blocked Lanes : OOO
Left Shoulder :
Right Shoulder:
2nd Incident : not specified
Precipitation : not specified
Road Condition: not specified
Description :
Updated: 2-DEC-1998 07:13:02

EVENT UPDATES:

Updated: 2-DEC-1998 07:13:15 Owner : MFREDERICKS
Updated: 2-DEC-1998 07:24:03 Event State : UNCONFIRMED(SYSTEM CLEAR)
Updated: 2-DEC-1998 07:24:13 Event State : FREE

Figure 3- 3. Sample of incident log for December 2, 1998. (Source: Toronto Traffic Operation Office Center10)

3.3 WEATHER DATA

The weather data were obtained at the Center Island location (point C in Figure 3-1) which is 675 meter away from detector location station #40 (Figure 3-2). These data were recorded according to the Eastern Standard Time (EST) in Toronto, Ontario. To adjust for the daylight saving time (DST) months, a shift of one hour was added to all time recorded.

3.3.1 HOURLY WEATHER CONDITIONS FOR TRAFFIC ANALYSIS

Weather data for the freeway were also obtained from the Weather Office. There are two set of weather data, one is hourly weather-observations and the other is the hourly weather classification. The hourly weather observation was monitored for the total of 193 weekdays. Analysis shows in the 12-month period, 72.5 % of the 193 days was considered to be adverse weather condition (of more than one hour of rain or snow). In the hourly weather-observations, the conditions were labelled as either snow, rain, light rain or drizzle. Forty-three hours are light rain, seven hours are drizzles, 278 are rainy, and 71 hours are snowy condition. The remaining hours are clear weather condition. Due to the small number of light rain and drizzles, these were considered as rain and were combined with other rainy condition. Table 3-2 shows the example of the data for January 8 - January 10.

Table 3- 2. Example of weather condition. (Source: Toronto Traffic Operation Office Center , 2010)

R- rain S: Snow L: light rain

Date	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
8-Jan						R	R	R		R	R	R		R		L			L			L		
9-Jan					S	R	R									S		S						
10-Jan						S	S	S	S	S		S	S	S				S						

The original hourly weather categorization, also taken from the Weather Office has two files in excel format. One file listed the hourly records of temperature, dew point, relative humidity, wind direction, wind speed, visibility and standard pressure. In this study, visibility was extracted to use for analysis. The second file listed the daily precipitation intensity among other variables which were extracted to calculate the hourly precipitation concentration to use for analysis.

3.3.2 METEOROLOGICAL DATA USED FOR DISPERSION MODELING

The meteorological data were obtained from the MOE consists of two files: surface scalar parameters, and the vertical profiles. Since no upper air surfaces data were collected from Toronto, Ontario, this study uses the data collected from Buffalo, New York (42.93 ^{o}

N, 78.73 ^{o} W), the nearest upper air station. The meteorology data was collected twice daily at 7 a.m. and 7 p.m., Eastern Standard Time. The condition is assumed to be consistent within a 500 km^2 area zone (NOAA, 2010). Surface data were obtained at Toronto City Airport (43.67^{o}N, 79.60 ^{o}W) shown at point D in Figure 3-1. Interpolation of the upper air condition in between the times collected was done using the meteorology pre-processor, taking into consideration the local land use around Toronto. This process was completed by the MOE and the data were downloaded from the website (MOE, 2010). The example of pre-processed upper air data and surface is shown in Table 3-3 and Table 3-4, respectively. The listed of all the data collected and the number of records in each are outlined in Table 3-5. The processing and use of these data will be presented in later chapters.

Table 3- 3. Sample pre-processed upper air file. (Source: MoE, 2010)

Year	Month	Day	Julian Da	Hour	Sensitive Heat Flux (W/m2)	Surface friction velocity (m/s)	Convection velocity scal (m/s) *	Year
98	1	1	1	1	-4.2	0.087	-999	98
98	1	1	1	2	-9.3	0.13	-999	98
98	1	1	1	3	-22.3	0.309	-999	98

Vert potential temp gradient above PBL*	Height of convectively-generated boundary layer *	Height of mechanically-generated boundary layer	Morning Obukhov length (m)	Surface roughness length (m)	Bowen ratio	Albedo	Wind speed (m/s)
-999	-999	59	14.2	1	1.5	1	1
-999	-999	108	21.4	1	1.5	1	1.5
-999	-999	394	119.3	1	1.5	1	2.1

Wind direction (degrees)	Ref height for W_s & W_d (m)	Temp (K)	Ref height for temp (m)	Precipitation code	Precipitation (mm) *	Humidity **	Pressure (Pa)
201	10	259.9	2	0	-999	9999	1013
258	10	262	2	0	-999	9999	1013
224	10	263.1	2	0	-999	9999	1013

* −999 for missing data.

** 9999 for invalid data.

Table 3- 4. Sample pre-processed surface file. (Source: EC, 2010)

Year	Month	Day	Hour	Measurement height (m)	Top flag	Wind direction (degree)	Wind speed (m/s)	Temp (Kelvin)	Standard dev of wind direction - F2 (degree)**	Standard dev of vertical wind speed -Fw (m/s)**
98	1	1	1	10	1	201	1	-13.3	9999	9999
98	1	1	2	10	1	258	1.5	-11.1	9999	9999
98	1	1	3	10	1	224	2.1	-10	9999	9999

** 9999 for invalid data.

Table 3- 5. Summary of data obtained from all sources

	File	Data Year	# of Entries	Source
1	Detector Location Map			CTTOC
2	Percentage of cars and rucks	2001, 2004, 2006	14 records each year each direction	CTTOC
3	Hourly Traffic on Weekdays	1998	5304 records for 193 days	CTTOC
4	Crash/ Accidents	1998	234 records for the same 193 days as in Hourly traffic on Weekdays was listed	CTTOC
5	Daily Incident logs	1998	Records varies day to day Listed 365 days but only 193 days were used.	CTTOC
6	Meteorological Conditions	1998	Hourly record - 365 days	MOE-WO
7	Hourly Weather Observation	1998	5304 records - 193 days	MOE-WO
8	Hourly Weather Classification	1998	Listed 365 days but only 193 days was used	MOE-WO

CHAPTER IV

METHODOLOGY - TRAFFIC ANALYSIS

In this study, the speed variation is defined as the difference in speed between normal weather condition and adverse weather condition. It is expected that the speed will be changed due to adverse weather. However, speed will also be affected by traffic events such as recurrent congestion and non-recurrent incidents. To isolate the effect of weather on speed, the reduction in speed during recurrent congestion should be considered, and the speed data collected when non-recurrent incidents occurred should be excluded. This chapter outlines the deduction process and general overview of the data analysis.

4.1 NORMAL SPEED PROFILES

The normal speed profile (NSP) is defined as the average hourly speed when the speed was unaffected by weather events and non-recurrent incidents. In other words, the NSP represent the traffic flow on this freeway free from all incidents and weather conditions and by no means indicate the traffic condition under uncongested or free-flow traffic conditions. The incidents were obtained through incident logs at the City of Toronto's traffic management center. Since the Normal Speed Profile includes average hourly speed for each hour, each incident was assumed to effect speed for a maximum of one hour period. If an incident occurred before 45^{th} minute of the given hourly period, the incident affects the speed in that given hourly period. If an incident occurred after 45^{th} minute of the given hourly period, the incident affects the speed in the next hourly period. For example, if the incident occurred at 5:15 p.m., then it affects the speed from 5 -6 p.m. However, if the incident occurred at 5:47 p.m., then it affects the speed from 6 – 7 p.m. If these two incidents occurred then the duration is 2 hours in total.

The processes to generate the Normal Speed Profile are as follow. First, false alarm incidents were filtered from the data. Speed data affected by the real incidents were removed. The remaining speed data are the speed affected by weather only. Consequentially, speed affected by weather was removed leaving the hours without incidents and weather. The overall outline of these steps is shown in Figure 4-1. The

Visual Basic coding for these elimination processes are in Appendix A. The 193 days in Hourly Traffic data yields 5204 hours for analysis. All missing speeds or volume were replaced with a star, during analysis.

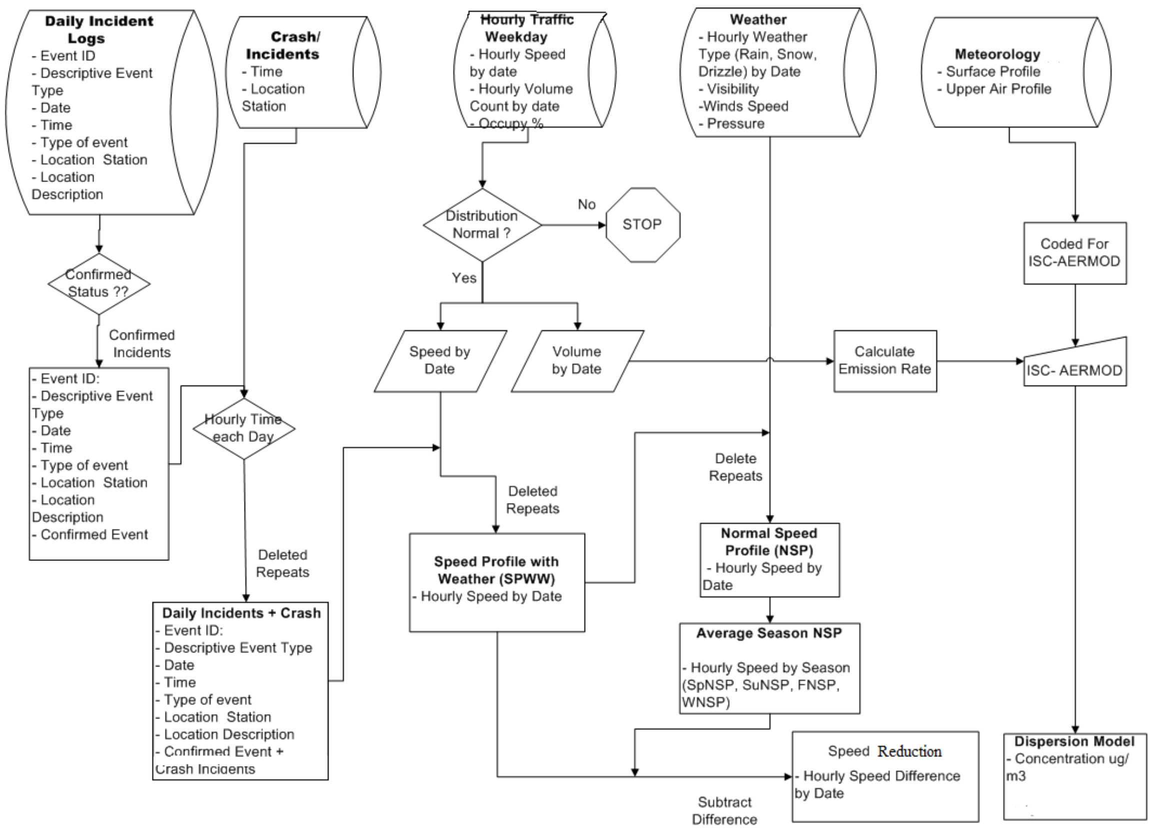


Figure 4- 1. Process flowchart of all data

4.2 PRECIPITATION AND VISIBILITY

The weather data collected from the Weather Office contained one daily total precipitation intensity (mm) file and one hourly visibility and weather classification file. Visibility was measured in the unit of distance and the value ranges from 0 to 15 km. High visibility indicates good weather conditions. In a clear day the visibility ranges from 10-15 km (Weather Network, 2011).

Since only daily precipitation intensity was provided, this was used to estimate the hourly precipitation rate. The main assumption for calculating hourly precipitation was each weather classification lasted for one hour. For example, if the weather is classified as rainy condition at 5 p.m., then it was assumed that it rained from 5 -6 p.m. The hourly precipitation rate is the total daily precipitation divided by the number of hours with rain, snow or drizzle weather condition on that day. For example, with the weather conditions record for January 9th in Table 3-2, there were five hours and daily precipitation of 4.5 mm, the hourly precipitation is 0.9 mm/hr. This hourly precipitation rate is consistent for the 3 hours of snow and 2 hours of rain in January 9th, 1998.

4.3 DAYLIGHT CONDITION

Since there was a difference in time stamp between Daylight Saving Time and Eastern Standard Time in the Northern Hemisphere, the lighting conditions were categorized separately for these time periods. Eastern Standard Time starts from the first week of November and ends in mid-March. In these months, the daytime is from 8:00 a.m to 6:59 p.m and the nighttime is 7:00 p.m to 7:59 a.m. The Daylight Saving Time starts from mid-March and ends in the first week of November. During these months, the daytime is from 7:00 a.m to 7:59 p.m and the nighttime is 8:00 p.m to 6:59 a.m.

4.4 SPEED REDUCTION

To better understand how weather condition reduces speed without being affected reduction from recurrent congestion, speed reduction was used for analysis. Speed reduction is defined as Normal Speed Profile minus actual hourly speed excluding non-recurrent events such as accidents and incidents. The positive values indicate speed reduction, whereas negative values indicate higher speed than speed under the normal condition. Speed reduction was categorized into 4 subsections for analysis: no speed reduction, >5 km/hr, 5-10 km/hr and > 10 km/hr. The difference between Normal Speed profile and the observed speed without non-recurrent incidents would exempt any effect due to recurrent congestion such as rush hour. An example of speed variation for April 30th is shown in Figure 4-2. The difference in speed reduction due to non-recurrent incidents is noticeable at the 8:00 and 12:00 hour. This study only considered the speed reduction and not the impact of weather on incidents and speed reduction caused by incidents.

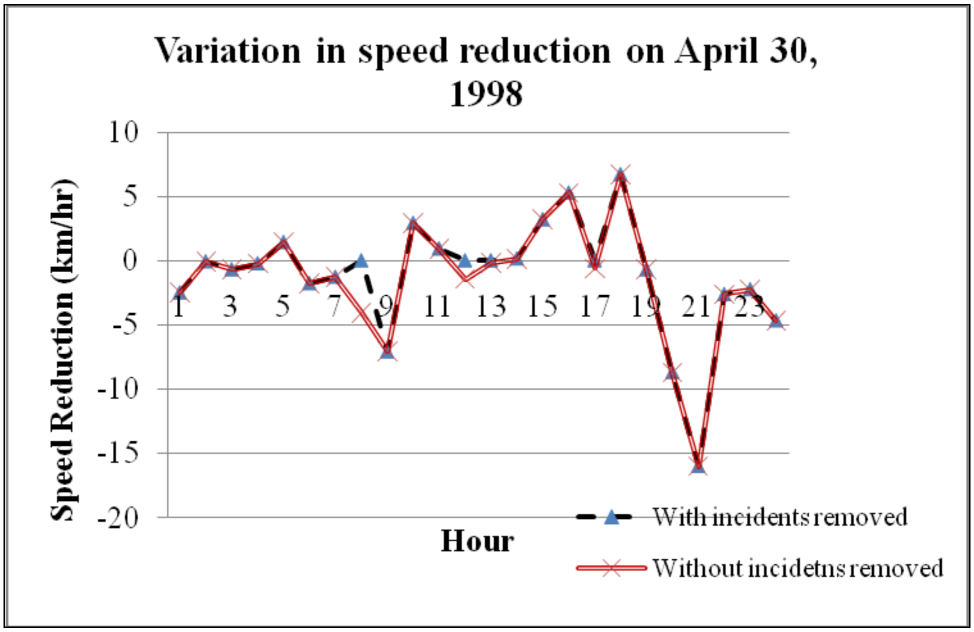


Figure 4- 2. Hourly variation in speed reduction on April 30, 1998

Due to the nature of the data the speed reduction was used as a categorical variable because there as insufficient data to use as a continuous variable. If continuous variable was used there will be very small number of samples for a specific speed reduction and it limits the advantage of observing the general relationships between speed reduction and weather related factors.

4.5 STATISTICAL METHODS

The Statistical Analysis System (SAS) (2008) format is used for statistical testing. SAS is an integrated system of software products provided by SAS Institute Inc, which enables users to perform computational statistical analysis. A SAS program has three major parts: the data, categorization steps procedure (if required), and the macro programming language that direct the software to conduct the analysis. At runtime, the data are compiled and the software run the sequence procedures based on the interpreted macro coding as they appear in the SAS program.

For this study, two statistical models were from the SAS 9.2 (2008) program to investigate the effect of weather on speed reduction. They are the Chi-square test and the Logistic Model known as Ordered Logistic Regression.

4.5.1 CHI-SQUARE TEST

Chi-square is a statistical test commonly used to compare observed data with the expected data obtained in reference to the null hypothesis. The null hypothesis states that there is no significant difference between the expected and observed result. In other words, the null hypothesis is that there is no relationship between the two factors being considered. The alternative hypothesis is that there is a relationship between the two factors being considered. The null hypothesis will be rejected when the test statistic has a p-value ≤ 0.05. The Chi-square is the sum of the squared difference between observed (O) and the expected (E) value (or the deviation, *d*), divided by the expected data in all possible categories. This can be express as:

$$X^2 = \frac{\sum (O-E)^2}{E} \qquad (1)$$

where: O = observed data

E = expected value

X^2 = chi square value

The higher the Chi-square values the stronger the relationship between the variables. The probability value is calculated alongside with the Chi-square test. In addition there is another “parameters estimate” can express the likelihood relationship of the data sample such as the p-value. The probability value or p-value is such a parameter. If the p-value is less than 10%, this means the relationship between the variables has a 90% confidence. From this statistical test, the Chi-square value and the p-value will indicate how strong the weather variables in relation to the speed observed.

4.5.2 LOGISTIC REGRESSION: ORDERED REGRESSION MODEL

The logistic regression describes the effects of independent variables on dependent variable. The model is described as following (Kachigan, 1986):

$$Ln[\frac{P(Y=i)}{1-P(Y=i)}] = a + b_1x_1 + b_2x_2 + ...b_kx_k \qquad (2)$$

where,

P(Y = i) = the probability that Y belongs to category i;

a = a constant;

b_k = a coefficient for the k^{th} explanatory variable;

X_k = explanatory variable.

Logistic regression does not assume a linear relationship between the dependent and independent variable. The relationship between the dependent and independent variable may be linear or nonlinear. Also it does not require the sample to be normally distributed. In fact the sample can be normal, Poisson or Negative Binominal. In addition, this model does not assume that there is an equal variance among all independent variables.

There are some limitations of this model as follows. The dependent variable in the data sample should be dichotomous in nature. The error term is assumed to be independent for each variable. Although logistic regression does not assume a linear relationship, the relationship between the odds ratio and the independent variable is linear. However, since the weather data are categorical in nature, this model is more suitable for investigating the effect of weather on speed reduction.

The logistic regression does not account for the ordinal nature of the categorical variables. Subsequentially, a subset of this model known as the Ordered Logistic Model was considered. This model was chosen because the categories of speed reduction within our data are ordinal in nature. In other words, a model was selected to compare the difference between higher level and low level magnitude of effects. In ordered regression, the dependent variable is ranked (Logistic regression, 2010). The first category is usually considered as the lowest category (first ordered) and the last category is considered as the highest category (last ordered) (Gelman, 2007) or vice versa. In other words, the higher level represents higher magnitude of effects than lower levels. The ordered model is described as follows (Kleinbaum, et al., 2008).

$$Y_i^* = b_1x_1 + b_2x_2 + ...+ b_kx_k + \xi_i \qquad (3)$$

where

Y_i^* = the independent variable which is an indicator of category of speed reduction

b = coefficient

x_k is the independent variable including visibility, precipitation, season, weather condition, lighting condition

ξ_i is the random error term

The category of the dependent variable (speed reduction) is predicted based on Y_i^* based on the following criteria:

$Y_i = 1$ if $Y_i^* <= \mu_1$

$Y_i = 2$ if $\mu_1 < Y_i^* <= \mu_2$

: : :

$Y_i = m$ if $Y_i^* > \mu_{m-1}$

where m = number of categories for that dependent variable

$\mu_{1,}\ \mu_{2....}\ \mu_m$ = the threshold values of each category in Table 4-1.

4.6 VARIABLE CLASSIFICATIONS

Before examining the relationship between speed and speed reduction with weather variables, the variables must be categorized. The classifications of each parameter are shown in Table 4-1.

Table 4- 1. Classifications of Variable for analysis

Variables	# cat	Classifications			
Speed (km/hr)	5	Congested : Free flow :	<60, 80-90	60 -80 90-100	 >100
Speed reduction (km/hr)	4	No reduction; > 10	> 0 and ≤ 5	> 5 and ≤ 10	
Precipitation (mm/hr)	3	0	0.05-5	>5	
Visibility (km)	3	0-5 (low)	5-10 (med)	10-15 (high)	
Season	4	Spring	Summer	Fall	Winter
Weather	3	Clear	Rain	Snow	
Lighting	2	Day	Night		

CHAPTER V

RESULTS OF TRAFFIC ANALYSIS

5.1 SPEED DISTRIBUTION

To better understand the trend of the data collected, the distribution of all hourly speeds was graphed. Figure 5-1 and 5-2 shows the histogram of speed distribution for the 193 days for westbound and eastbound direction.

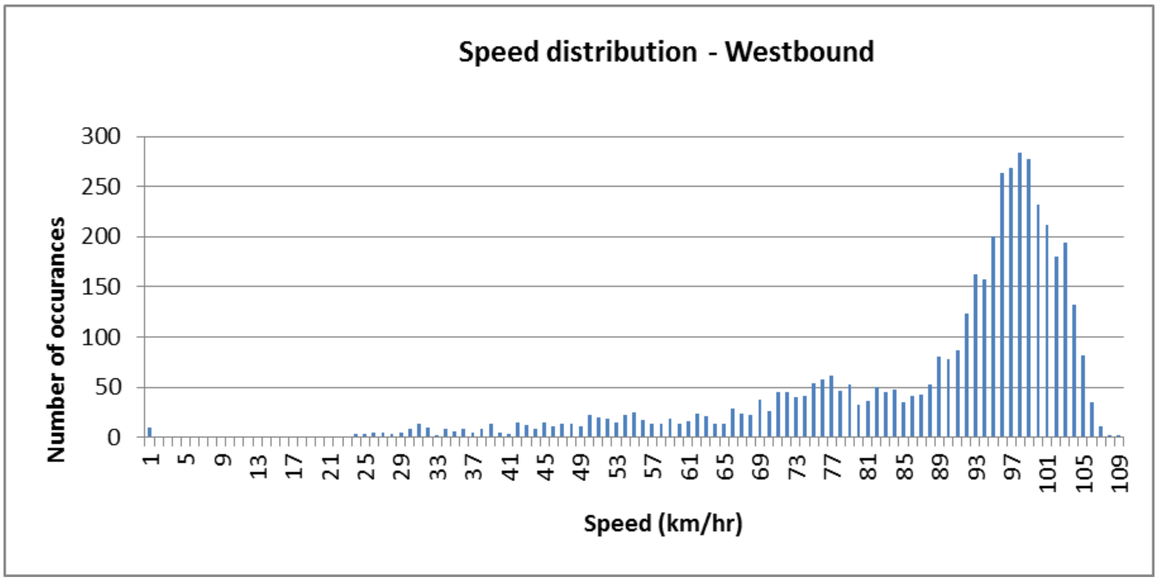


Figure 5- 1. Westbound speed distribution for 1998

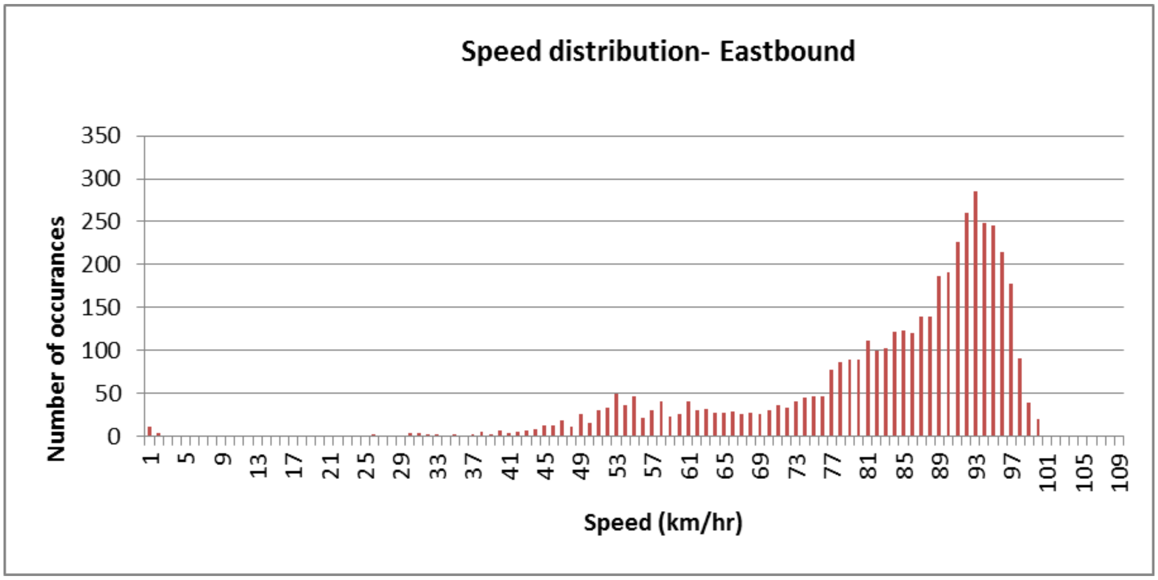


Figure 5- 2. Eastbound speed distribution for 1998

The westbound speed ranges from 0 – 108 km/hr, whereas it is 0- 99km/hr for eastbound. The average lies at 86.7 km/hr for westbound and 81.6 km.hr for eastbound. Speed over 80 km/hr was considered as the speed free of congestion. For further analysis of weather on speed, the free-flow speed was categorized into 3 subsections: 80 – 90 km/hr, 90-100 km/hr and above 100 km/hr. The congested speed was categorized into 2 subsections: 0-60 km/hr and 60-80 km/hr. These categorizations were based on the different emission trend for each speed in Figure 2-2.

5.2 VOLUME DISTRIBUTION

The volume distribution for Gardiner Expressway in 5304 hours is shown in Figures 5-3 and 5-4. In westbound lane the volume ranges from 0 – 2164 veh/hr with the average of 1221 ve/hr. In eastbound lane the volume ranges from 0- 2151 veh/hr with the average of 1158 veh/hr.

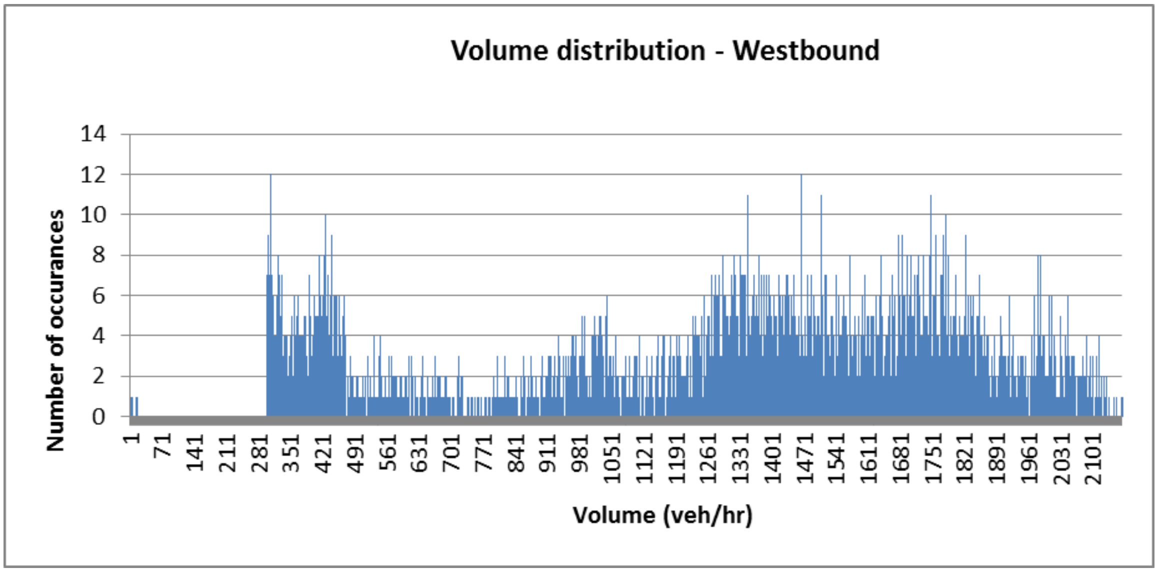


Figure 5- 3. Westbound volume distribution for 1998

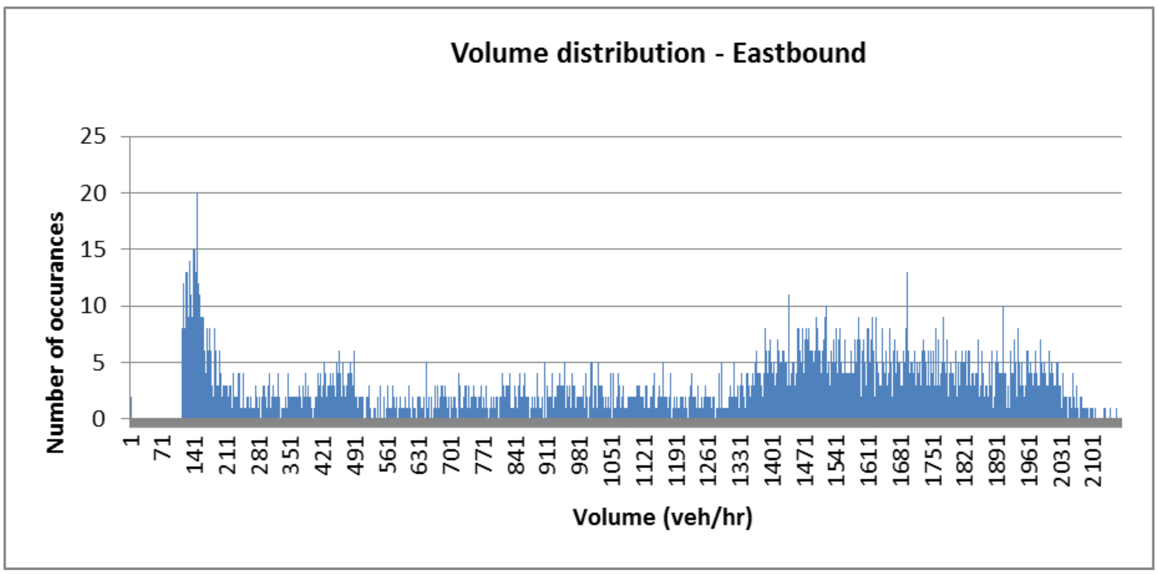


Figure 5- 4. Eastbound volume distribution for 1998

To calculate the emission of NO_x, a closer look at between the clear weather condition and adverse weather condition was examined. The volume distribution between 399 hours of adverse weather and 399 hours of clear condition is shown in Figures 5- 5 – 5-8. The clear hours are selected based on the hour subsequent ot the day that either rain or snow with visibility of 15 km (maximum visibility). If the next adverse weather condition of same hour did not meet the visibility condition then the following day was condisered. All volume were above zero vehicle per hours. The minimal traffic volume use for eastbound is 71 veh/hr for clear and 86 veh/hr for adverse weather condition. In westbound direction the minimum traffic volume used is 226 veh/hr for clear and 246 veh/hr for adverse weather condition.

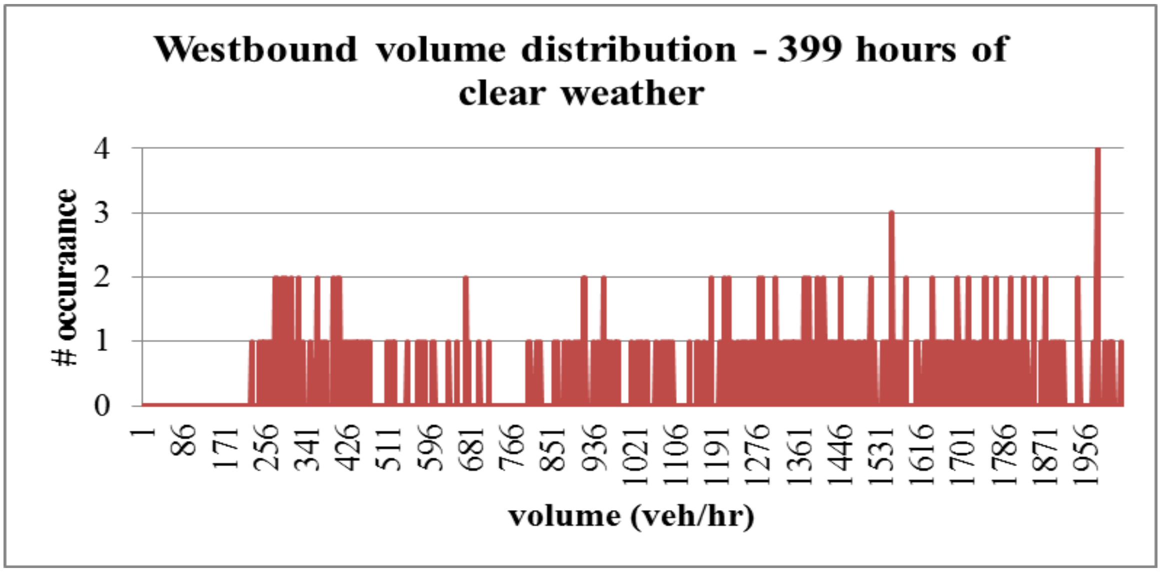


Figure 5- 5. Westbound volume distribution for 399 hours of clear weather condition

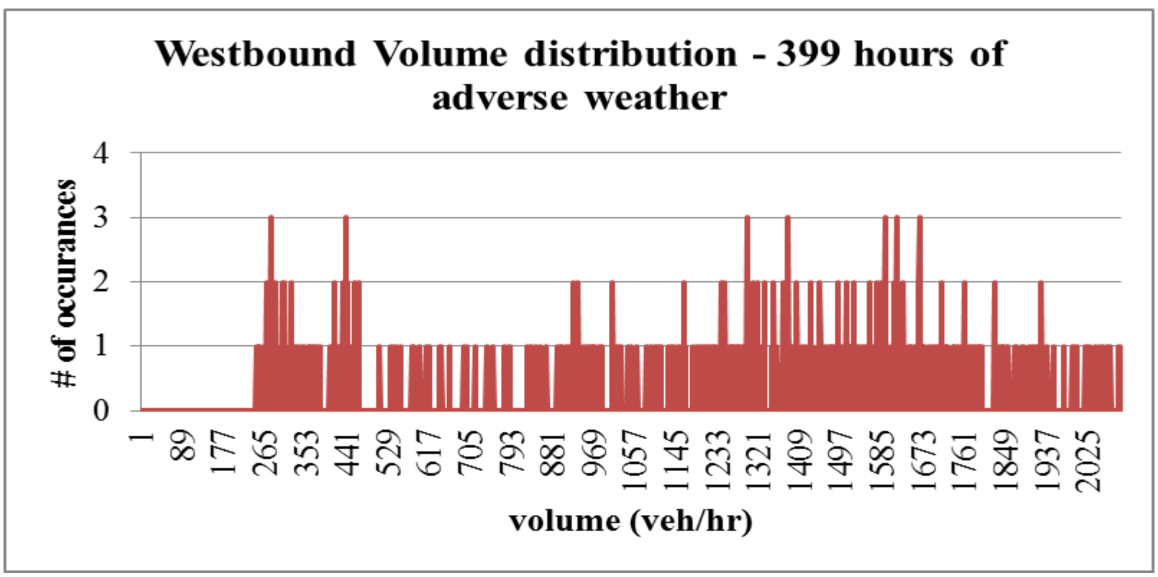


Figure 5- 6. Westbound volume distribution for 399 hours of adverse weather condition

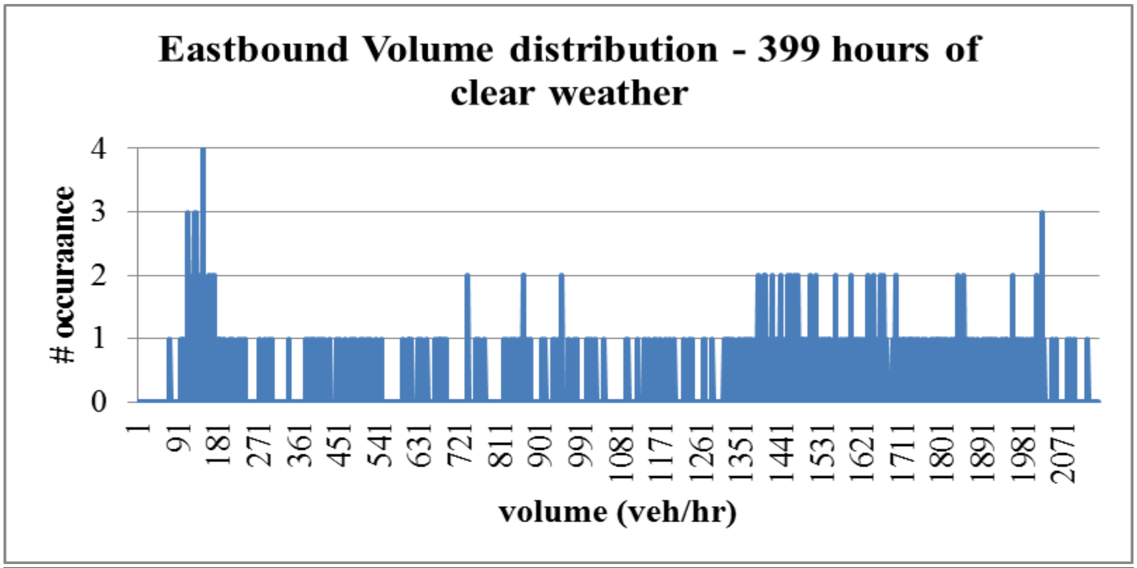


Figure 5- 7. Eastbound volume distribution for 399 hours of clear weather condition

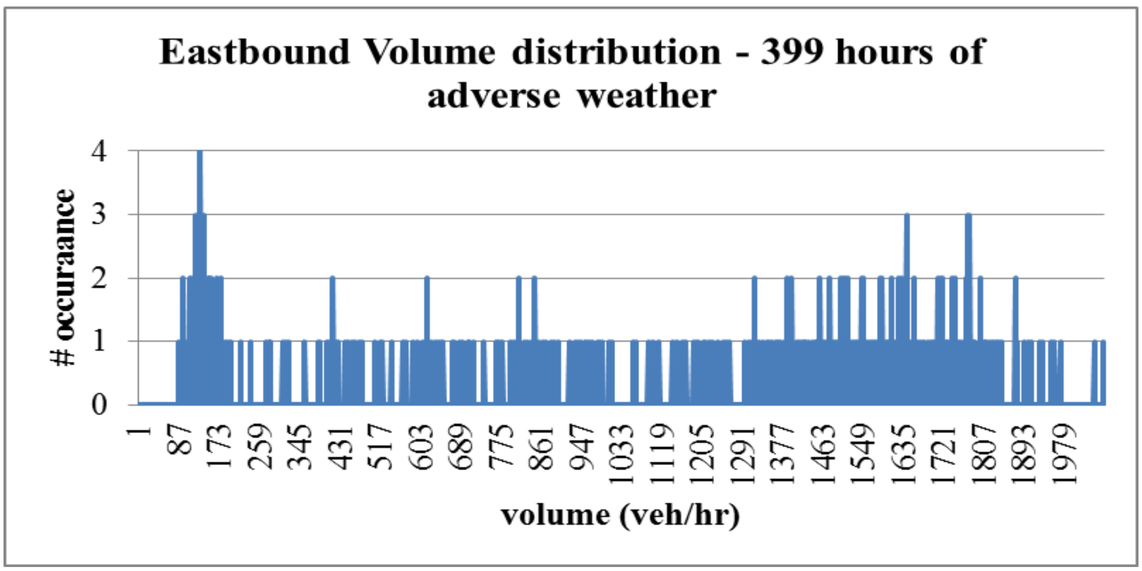


Figure 5- 8. Eastbound volume distribution for 399 hours of clear weather condition

5.3 MONTHLY NORMAL SPEED PROFILES

To compare the difference in the Normal Speed Profile among four seasons, the monthly and seasonal patterns of Normal Speed Profile for east and westbound were calculated. The hourly averages were calculated based on the same hours within the month. The total number of incidents for both directions is shown in Table 5-1. The westbound lane monthly Normal Speed Profiles are shown in Figure 5-9 - 5-12 based on the seasons. For the corresponding months on each season please refer to Table 4-1. Noted that December of 1998 occurred at the end of the year was combined with January and February at the beginning of the year to mark the winter season. Monthly NSP was used for to minimize the deviation of the speed profile in each season.

In traffic research, it is common that traffic flow conditions are different based on the hour of the day. The trends for this highway can be observed in Figures 5-9 – 5-12. In the westbound lane, speed slows during morning peak of 7 a.m. to 10 a.m., two off peak periods are 11 am to 3 pm and 9 pm to 7 a.m., and an afternoon peak period at 3 pm to 9 pm. In the afternoon peak periods, speed significantly dropped more than the morning peak period. The afternoon peak went well below the free-flow speed of 100 km/hr. The speed variation shown in Figure 5-13 indication most speed varies within 25 km/hr range of the average speed.

Table 5- 1. Number of total non-recurrent incidents by season

	Westbound	Eastbound
Spring	379	130
Summer	711	223
Fall	487	111
Winter	430	112

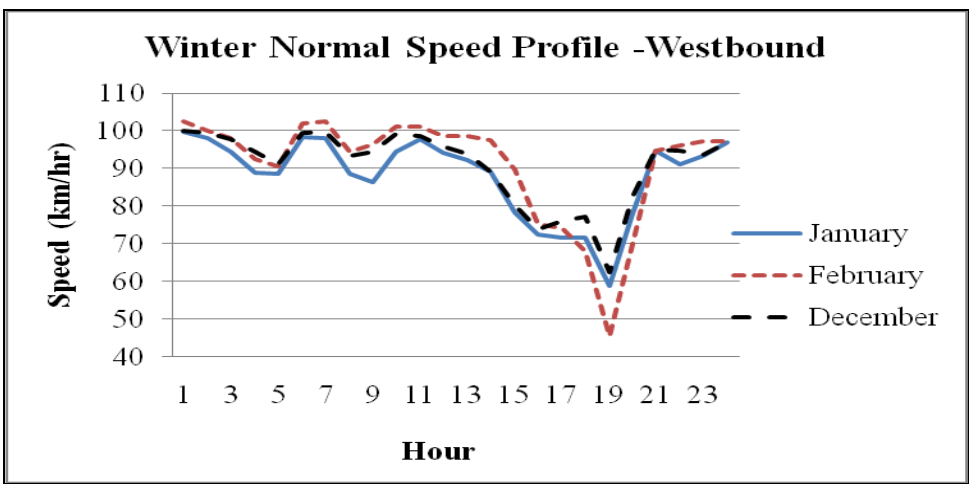


Figure 5- 9. Winter Normal Speed Profile in westbound direction.

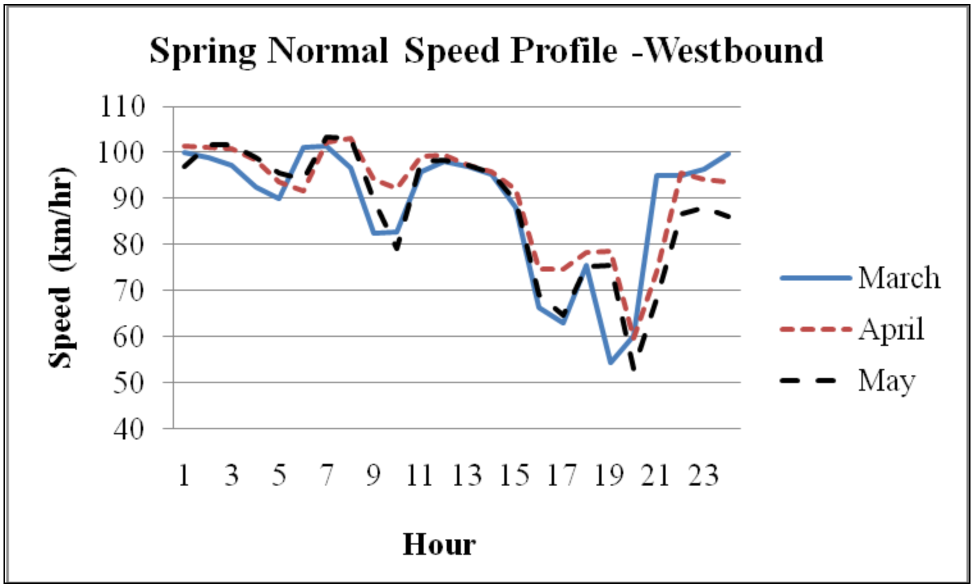


Figure 5- 10. Spring Normal Speed Profile in westbound direction.

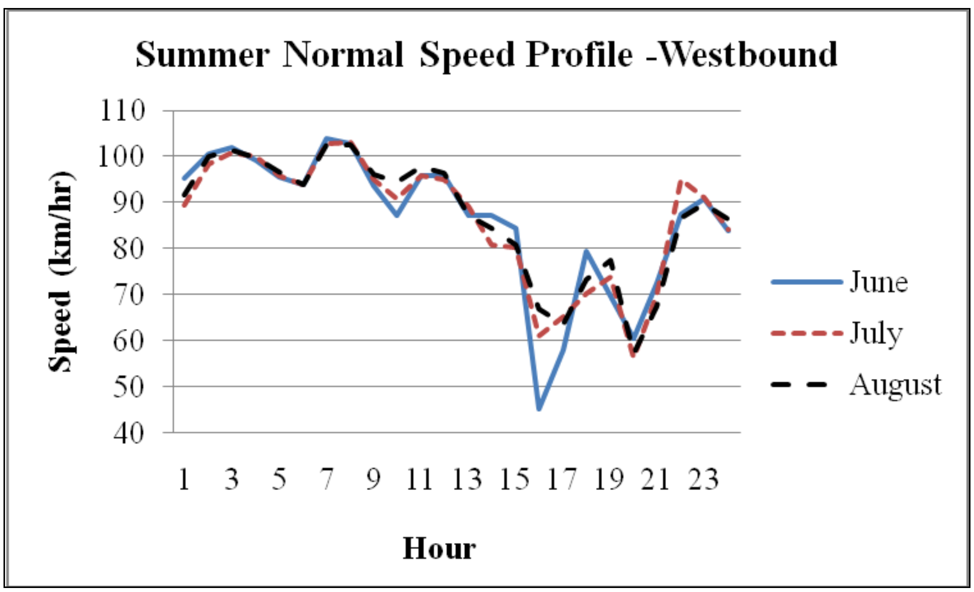


Figure 5- 11. Summer Normal Speed Profile in westbound direction.

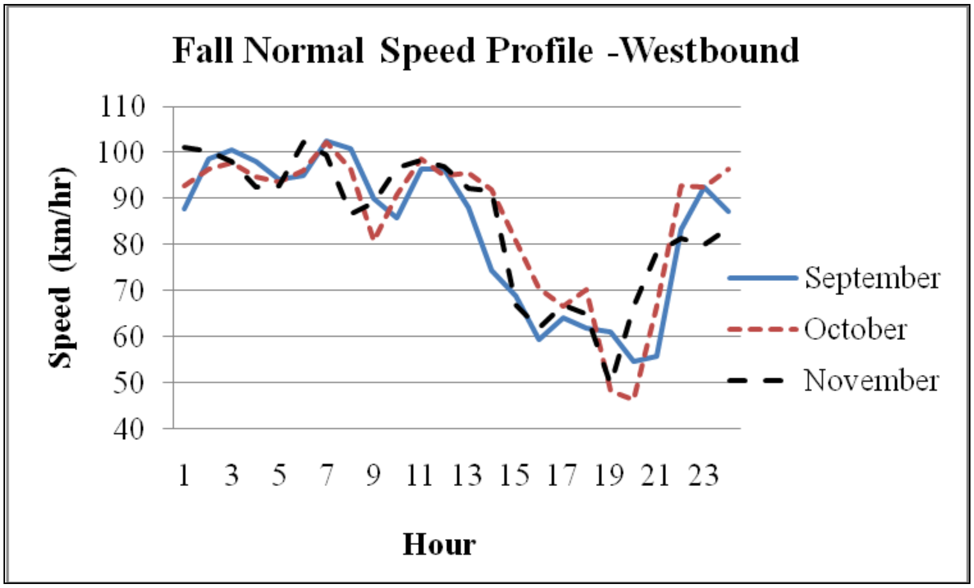


Figure 5- 12. Fall Normal Speed Profile in westbound direction.

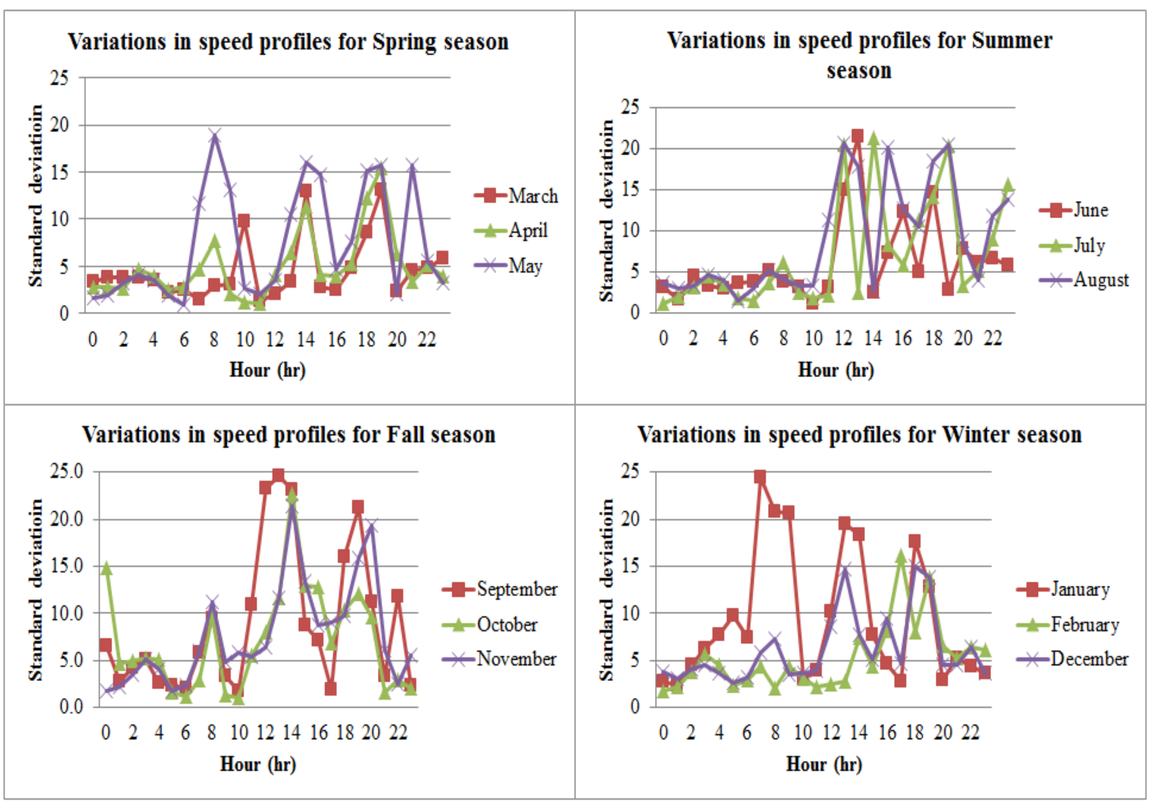


Figure 5- 13. Variations in speed profiles for westbound direction

The eastbound lanes Normal Speed Profile is shown in Figures 5-14 – 5-17. Here morning peak is at 7 a.m. to 11 a.m., and off morning peak from 1a.m – 6 am and an afternoon peak period at 4 pm to 9 pm. In the morning peak period, there is a slight reduction in speed. However, in the afternoon peak periods, speed significantly drops below free-flow speed of 100 km/hr. The speed observed for eastbound lane ranges from zero km/hr to 99 km/hr. Figure 5-18 show the speed variations are within 25 km/hr limit with higher variation occurred in the afternoon than in the morning period.

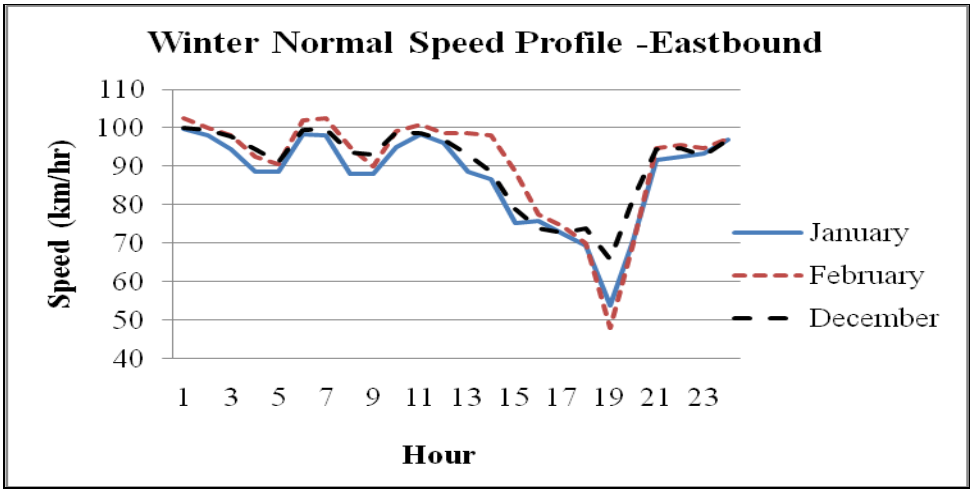


Figure 5- 14. Winter Normal Speed Profile in eastbound direction.

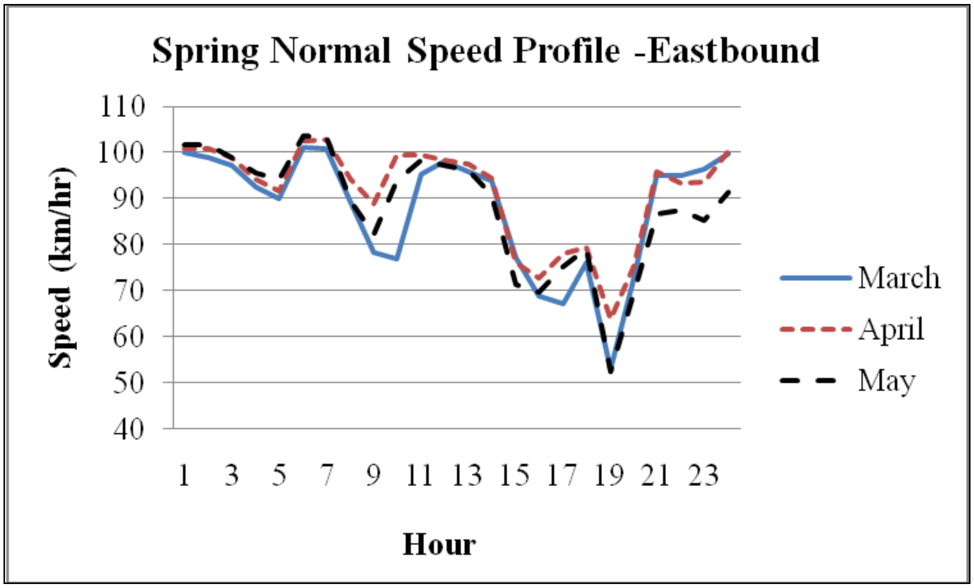


Figure 5- 15. Spring Normal Speed Profile in eastbound direction.

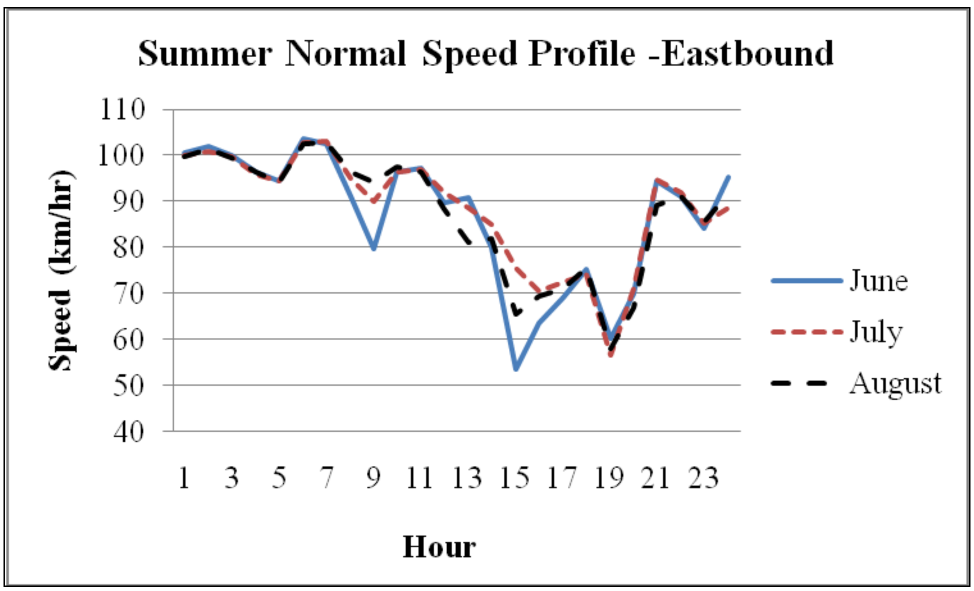


Figure 5- 16. Summer Normal Speed Profile in eastbound direction.

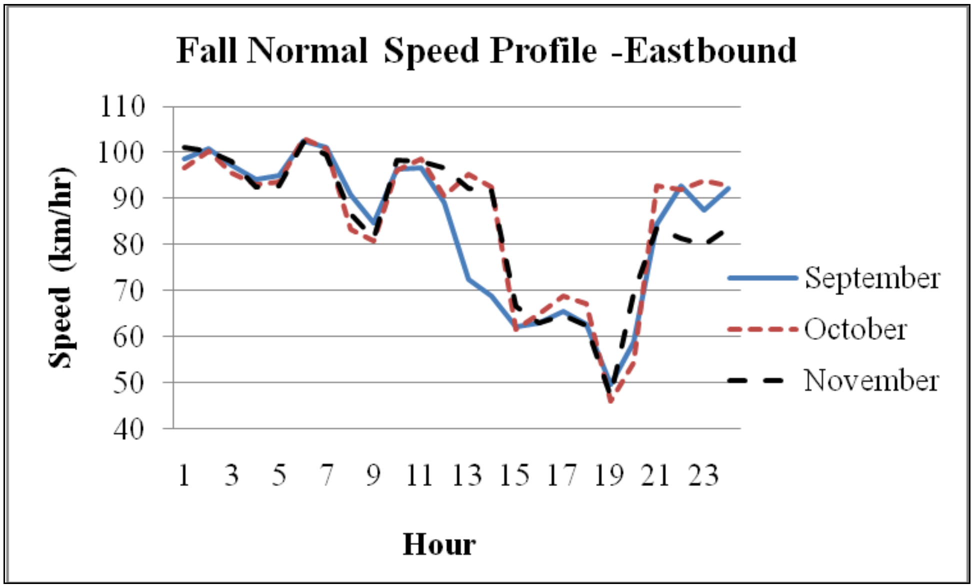


Figure 5- 17. Fall Normal Speed Profile in eastbound direction.

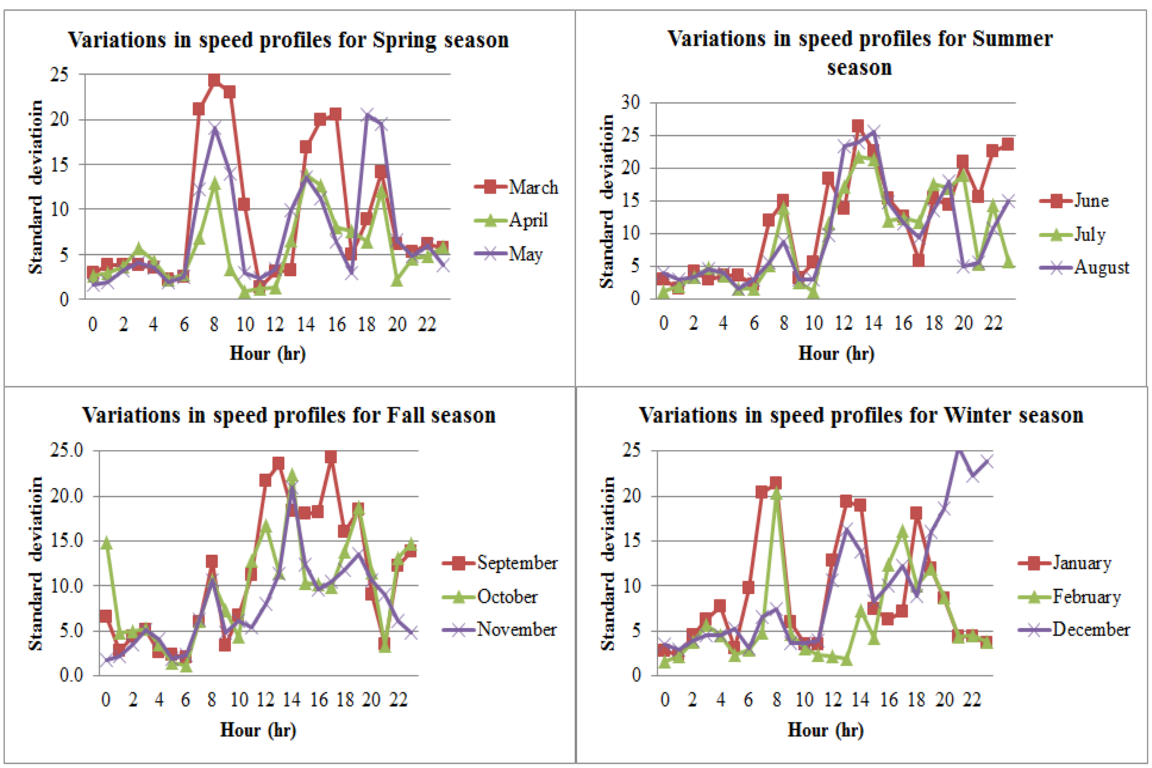


Figure 5- 18. Variations in speed profiles for eastbound direction.

Due to different peaks periods between westbound and eastbound, speed reduction was used for analysis. Noted the prolonged speed reduction in the afternoon is a specific characteristic to this freeway. The reason for this is due the ramp closure in the afternoon specifically from 3 p.m – 6 p.m. This ramp reopens at 6:00 p.m for both directions thus causes longer and lower afternoon peak than morning

The usage of speed reduction, in turn, will eliminate factors between congestion and un-congestion periods, whereby reflecting the delay of speed travelled.

5.4 RELATIONSHIP OF WEATHER AND SEASON WITH SPEED - RESULT OF CHI-SQUARE TEST

To determine whether the relationship between the observed speed and weather conditions was significant, the Chi-square test was performed. Lighting condition, precipitation, visibility, season and weather condition were related to speed and their association was assessed. The complete SAS output of all tests provided in Appendix C. However, the graphical results of the relationship between speed and the factors in Chi-square tests are shown below.

Figure 5-19 shows the relationship between speed and lighting condition. Based on the graphs in Figure 5-19, it was found that higher speed is more likely to occur at nighttime and lower speed occurs at daytime. This is due to less traffic volume on the road at nighttime as seen in Figure 5-20. In eastbound direction, the medium flow speed of 60-80 km/hr and 80-90 km/hr is constant, whereas it was marginally higher in nighttime then daytime in westbound. The association between speed reduction and lighting condition is significant at a 90% confidence interval (p-value ≤ 0.10).

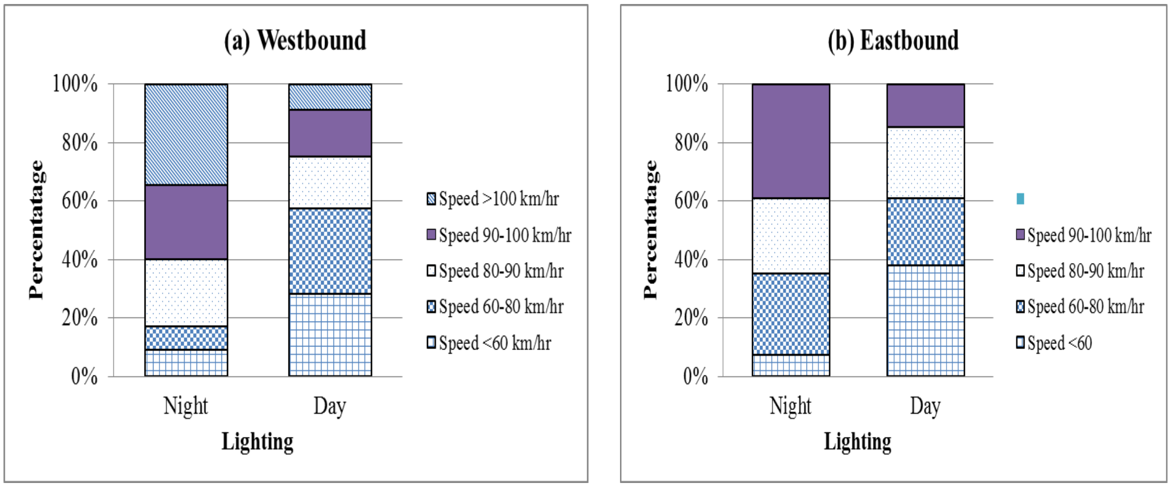


Figure 5- 19. Relationship between speed and lighting.Result of Chi-square test, relationship is significant at $p < 0.01$

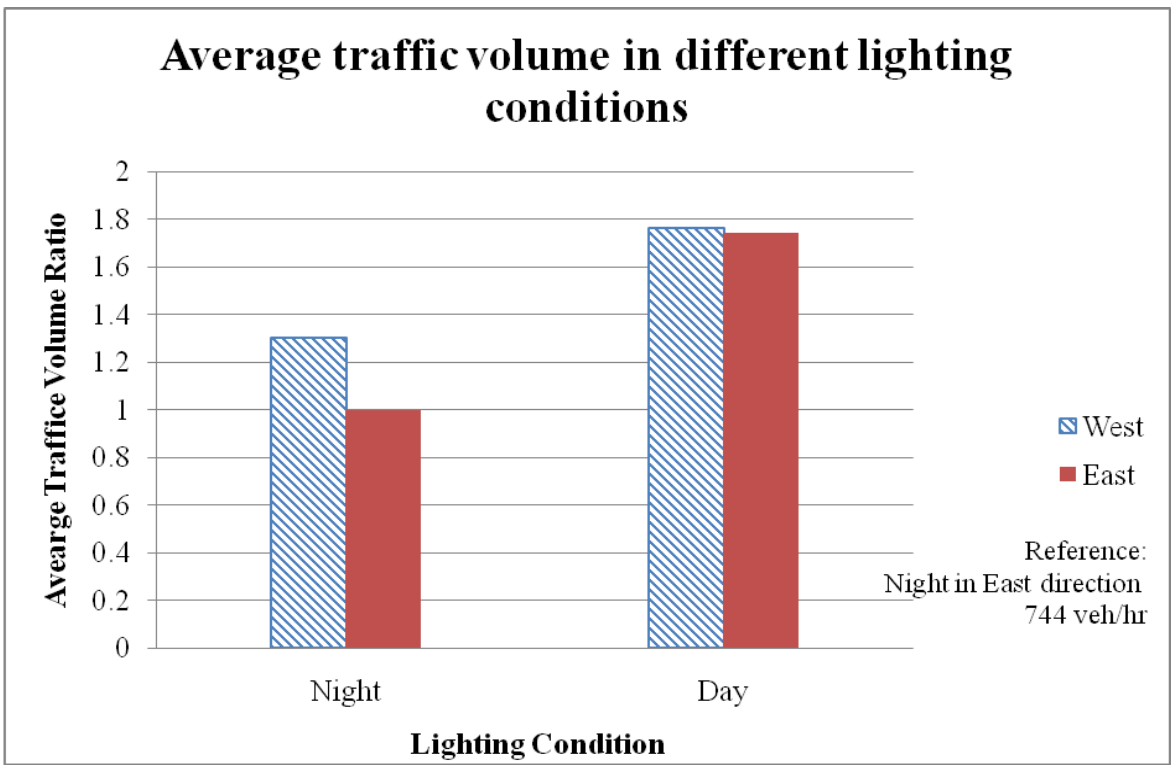


Figure 5- 20. Relationship between traffic volume and lighting condition.

Figure 5-21 shows the relationship between speed and precipitation. As seen, speed is likely to be higher at low precipitation as shown in Figure 5-21 (a) and (b). One inconsistency in westbound was high speed also occurred at high precipitation. At medium free-flow speed westbound show a consistent distribution throughout all precipitation rates. However, eastbound lanes provide a clear trend that the higher the precipitation rate the lower the observed speed. As expected, at low precipitation drivers have more control of the vehicle and the road surface friction is high. Again the correlation was significant at a 90% confidence interval (p-value ≤ 0.10).

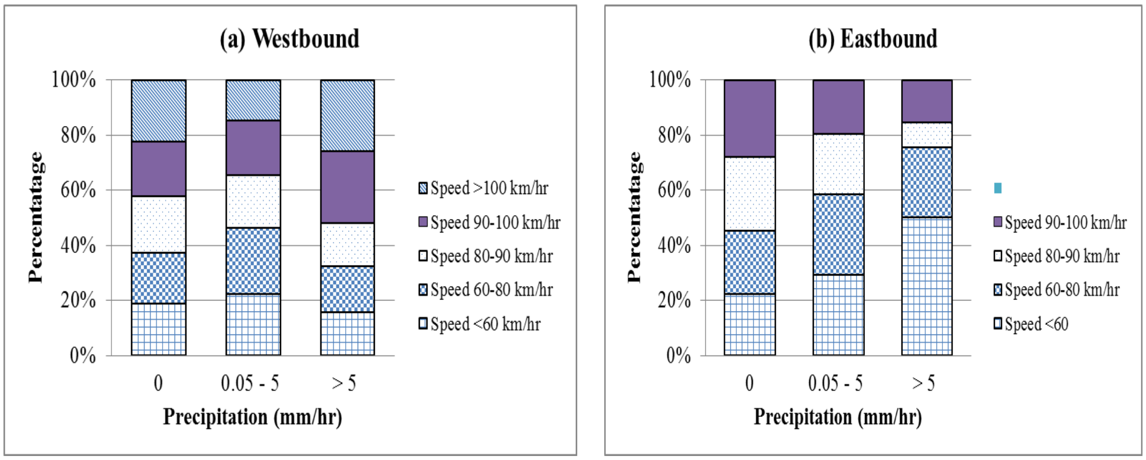


Figure 5- 21. Relationship between speed and precipitation. Result of Chi-square test, relationship is significant at $p < 0.1$

Figure 5-22 shows the relationship between speed and visibility. The Chi-square test shows a strong correlation between visibility and speed (p-value ≤ 0.10). In westbound [Figure 5-22 (a)] high speed is likely to occur at both high and low visibility. However, in eastbound [Figure 5-22 (b)] the lower speed is likely to occur at low visibility. Speed is constant in medium speed ranges of 60-80 and 80- 90 km/hr in both westbound and eastbound.

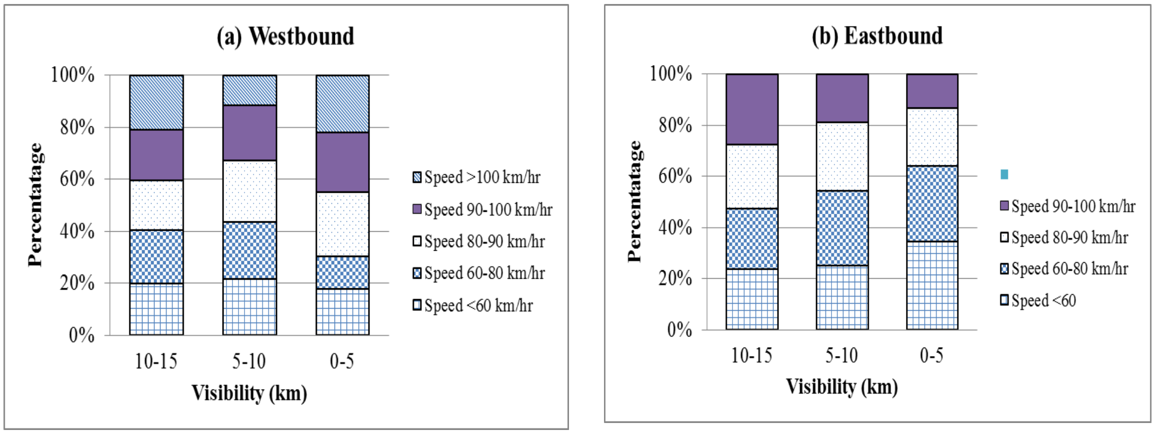


Figure 5- 22. Relationship between speed and visibility. Result of Chi-square test, relationship is significant at $p < 0.1$

Figure 5-23 shows the relationship between speed and season. On both westbound and eastbound directions, result indicates high speed is likely to occur in fall season than any other seasons and low speed is likely to be lower in summer. This is because traffic volume is lower in fall and high in summer when the outdoor activities are more frequent, as can be seen in Figure 5-24.

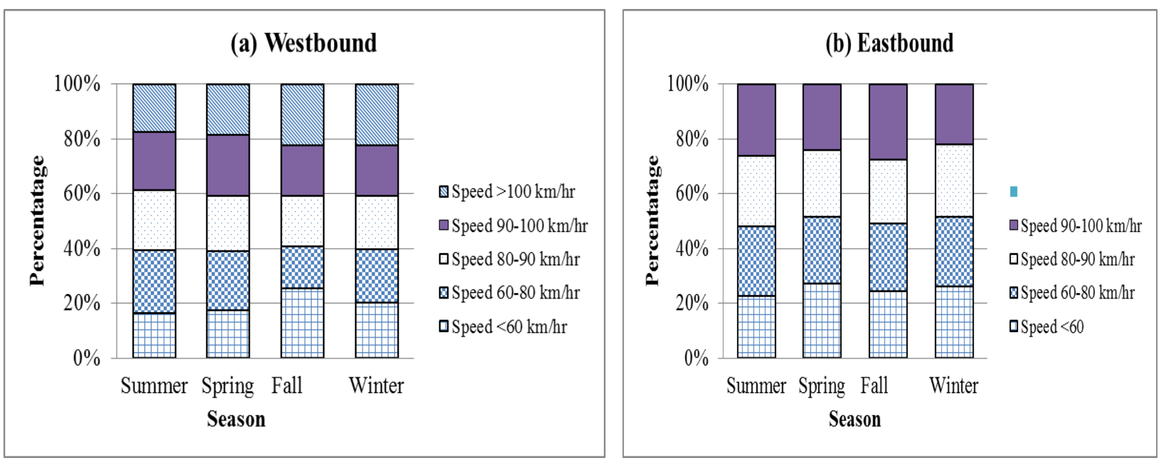


Figure 5- 23. Relationship between speed and season. Result of Chi-square test, relationship is significant at $p < 0.1$

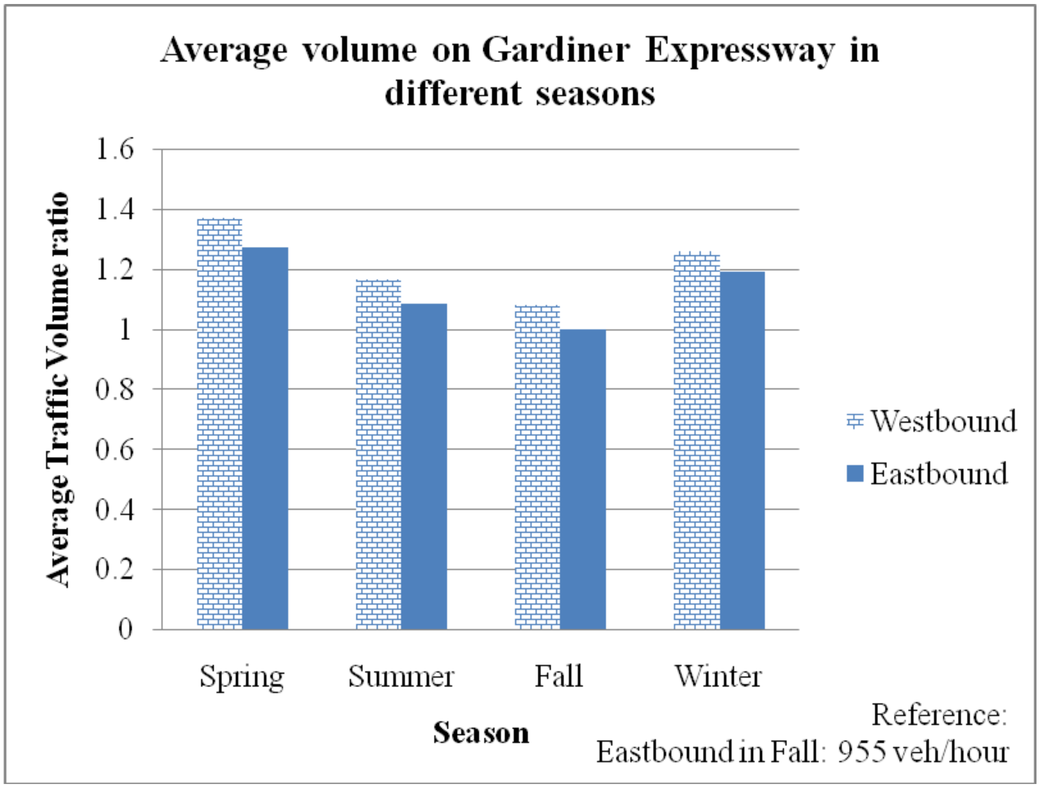
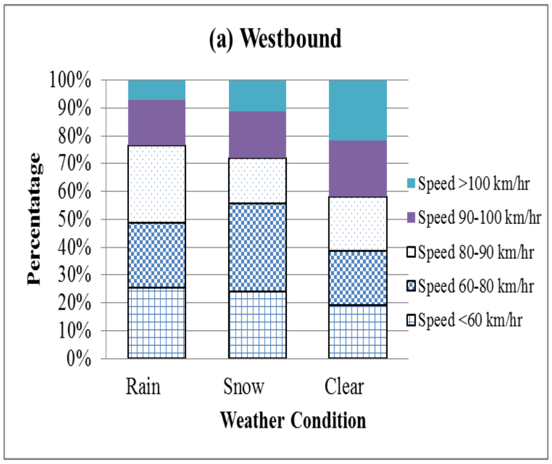


Figure 5- 24. Relationship between volume and season for westbound and eastbound direction.

Figure 5-25 shows the relationship between speed and weather classification. The Chi-square test shows a marginal relationship (p-value ≤ 0.10). Speed is likely to be higher in clear weather condition than adverse weather conditions. In adverse weather conditions, speed is likely to be lower in snowy condition than rainy condition, especially in eastbound direction. This may be due less surface friction on the road which cause slippery in snowy condition leading driver to be cautious. In westbound direction medium free-flow speed of 60-80 km/hr occurred in snowy condition, whereas it occurred in rainy condition for eastbound. All other speed range remains consistent in both directions.



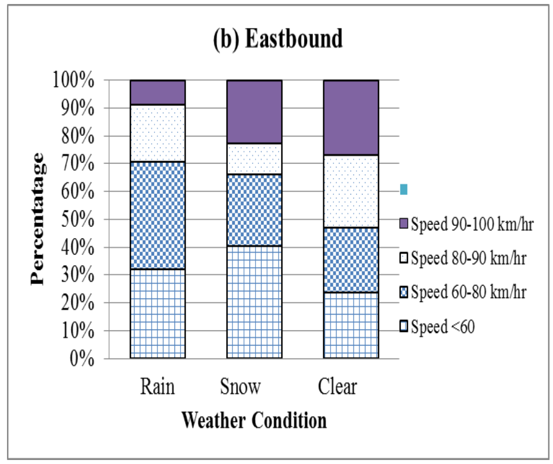


Figure 5- 25. Relationship between speed and weather conditions. Result of Chi-square test, relationship is significant at $p < 0.1$

5.5 RELATIONSHIP OF WEATHER AND SEASON WITH SPEED REDUCTION-RESULT OF CHI-SQUARE TEST

To eliminate the effect of congested and uncongested traffic on the highway, speed reduction between the Normal Speed Profile and the observed speed was calculated. The speed reduction is positive when the observed speed is lower than Normal Speed Profile. If the observed speed is higher than Normal Speed Profile, it is classify as no speed reduction. The results of the Chi-square tests are examined below.

Figure 5-26 shows the relationship between speed reduction and lighting condition. Speed reduction is likely to be higher at nighttime than daytime, especially in eastbound direction. This is mainly because of the volume difference between daytime and nighttime. Thus, the calculated average speed in Normal Speed Profile at daytime is lower than average speed at nighttime. Therefore, the observed speed at daytime is likely to be higher than the low average speed.

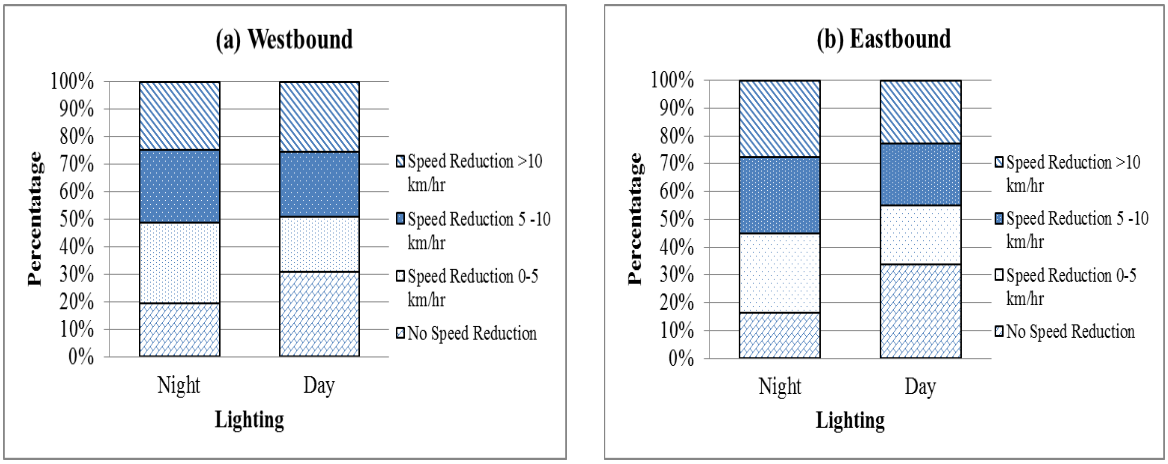


Figure 5- 26. Relationship between speed reduction and lighting. Result of Chi-square test, relationship is significant at $p < 0.1$

Figure 5-27 shows the relationship between speed reduction and precipitation. As precipitation increases, speed reduces. In other words, low speed is likely observed at high precipitation. This is expected since high precipitation reduces surface friction on the roads and drivers are likely to reduce speed.

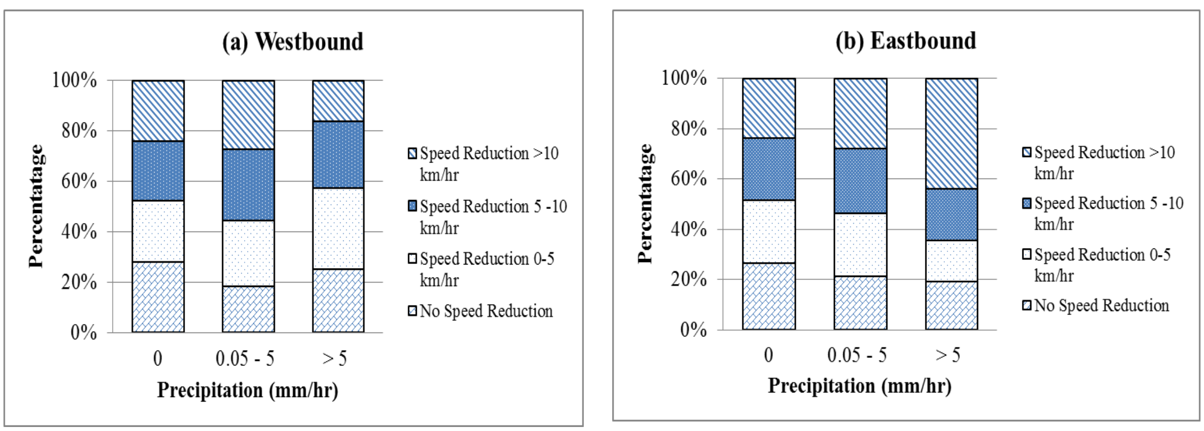


Figure 5- 27. Relationship between speed reduction and precipitation. Result of Chi-square test, relationship is significant at $p < 0.1$

Figure 5-28 shows the relationship between speed reduction and visibility. At higher visibility, speed reduction is likely to be lower. This result is expected because drivers take more cautious at lower visibility.

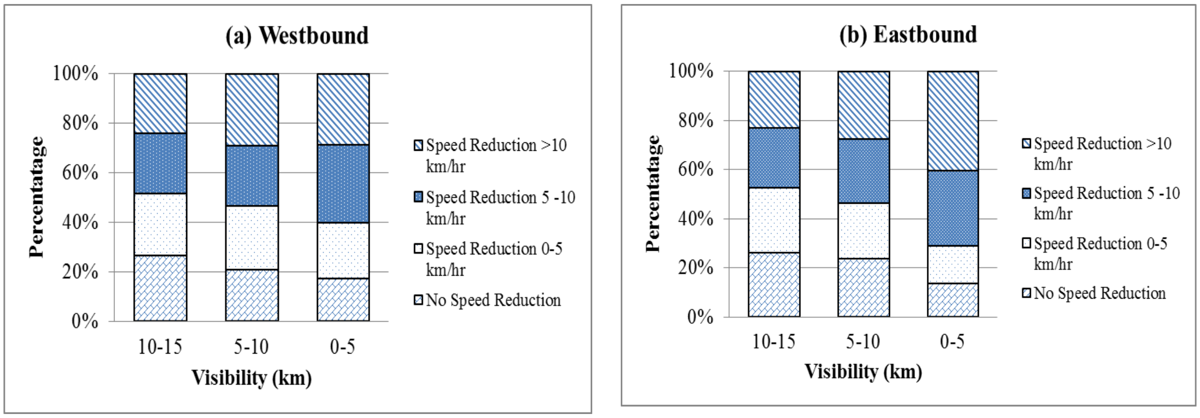


Figure 5- 28. Relationship between speed reduction and visibility. Result of Chi-square test, relationship is significant at $p < 0.1$

Figure 5-29 shows the relationship between speed reduction and season. High speed reduction is relatively consistence in all seasons. However, low speed reduction is likely to occur in summer than in all other seasons. This may be because high traffic volume in the summer time as compare to other seasons. In winter seasons, the most frequent reduction in speed is around 5-10 km/hr. This is a high reduction in speed and it may due to slippery road condition during winter months.

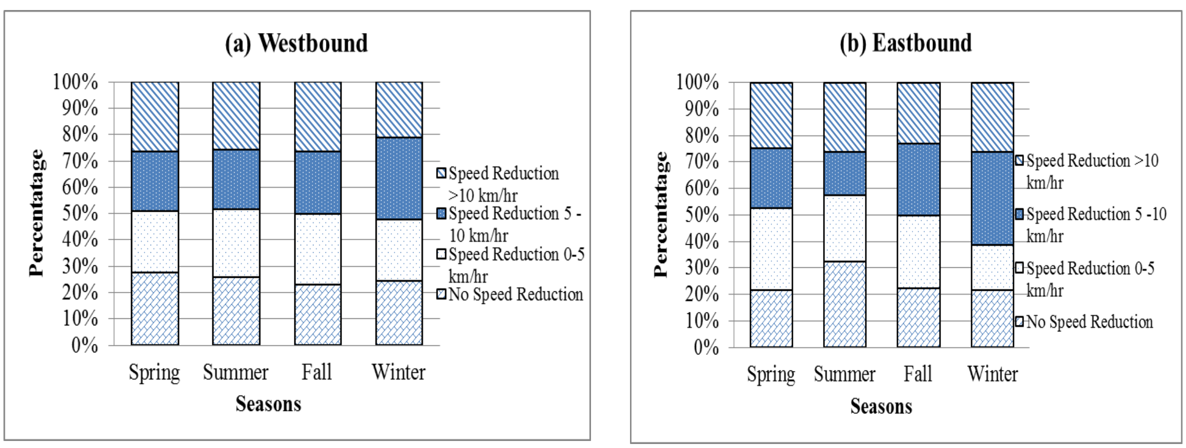


Figure 5- 29. Relationship between speed reduction and seasons. Result of Chi-square test, relationship is significant at $p < 0.1$

Figure 5-30 shows the relationship between speed reduction and weather classification. Speed reduction is likely to be higher in adverse weather condition than in clear weather condition for both eastbound and westbound. In other words, in clear weather conditions, there is less chance of speed being reduced.

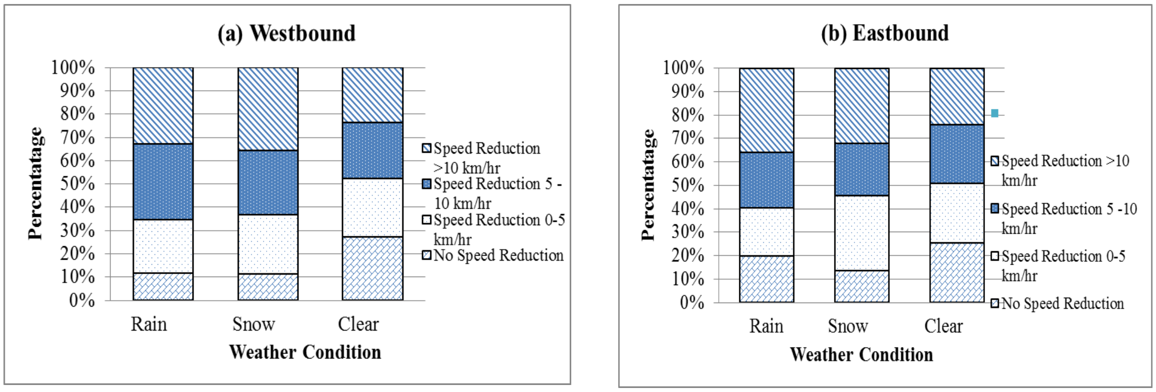


Figure 5- 30. Relationship between speed reduction and weather condition. Result of Chi-square test, relationship is significant at $p < 0.1$

5.6 ORDERED LOGISTIC REGRESSION

The Chi-square test shows that all factors investigated have strong relationship with speed reduction. To examine the combined effects of multiple factors on speed reduction, the ordered logistic regression model was developed. The ordered model was used because the category of speed reduction is ordinal i.e. higher category number indicates higher speed reduction and vice versa. The results of the regression models are shown for westbound and eastbound traffic separately in the following section. The parameters considered are: daylight, precipitation, visibility, season and weather conditions.

Table 5-2 shows the result of the ordered logistic regression model for the westbound traffic for those variables that show significance. The intercepts indicate the relative likelihood of each speed reduction categories compared to no speed reduction, if all other variables remain constant. Since the intercept for speed reduction between 0 and 5 km/hr is the highest (coefficient), it is most likely to occur. Similarly, speed reduction great than 10 km/hr is least likely to occur as indicated by lowest intercept.

A positive coefficient of the parameter and an odds ratio greater than one indicate that compared to the reference (0 levels in Table 5-2) speed reduction is higher. A negative coefficient indicates that the factor has lower speed reduction. The higher the coefficient and odd ratio values, the higher contrast in speed reduction between those two levels. For example, nighttine is designated 1 and daytime is 0. When compare nighttime to daytime (reference), the odd ratio is 1.623 which means nighttime condition is 1.6 times more likely to have reduced speeds than daytime. Between clear and snow (reference), the odd ratio is 0.386 which means snowy condition is 2.6 (1/0.386) times more likely to have reduced speeds than clear.

The results indicated that nighttime and falls have more speed reduction compared to daytime and winter. On the other hand, clear condition has less speed reduction compared to snowy condition. Nighttime reduce speed because of poor visibility. A snowy condition reduces speed due to the slippiness of the road. It was unknown as to why fall reduces speed compare to winter. Thus the order of impact from high to low based on odd ratio values are: snowy condition, nightime and fall season

Table 5- 2. Parameters estimation of the ordered logistic regression model (westbound)

Parameter	Coefficient	Chi-Square	Odds Ratios	P-value
Weather condition(1 = Clear, 0 = Snow)	-0.9515	130.849	0.386	<.0001
Intercept 4 (speed reduction >10 km/hr)	-0.6688	68.5512		<.0001
Intercept 2 (0 < speed reduction < 5 km/hr)	0.6023	56.0081		<.0001
Lighting (1= nighttime, 0=daytime)	0.2423	82.6204	1.623	<.0001
Intercept 3 (speed reduction 5-10 km/hr)	-0.2109	6.94330		0.0084
Fall (1=Fall, 0=Winter)	0.1604	6.75460	1.174	0.0094

Table 5-3 shows the result of the ordered regression model for the eastbound traffic. Similar to the westbound, Speed reduction is also higher at nighttime as compared to daytime, and clear condition decrease the chance of speed reduction. Unlike the westbound traffic, precipitation was found to be significant. Speed reduction is higher at higher precipitation rate. However, it is unknown as to why precipitation shows in eastbound and not westbound. Unlike the westbound direction, summer season not fall shows up as a significant factor here. It is believed that the increases in speed in summer are due to higher traffic volumes (Fig 5-24). It was unclear as to why the inconsistency existed in season between two directions. The order of the impact from high to low based on the odd ratios is: precipitation (1/0.412) , nighttime (2.056), snow (1/0.660) and summer season (1/0.703).

Table 5- 3. Parameters estimation of the ordered logistic regression model (eastbound)

Parameter	Coefficient	Chi-square	Odd ratios	Pr > ChiSq
Intercept 3 (speed reduction 5-10 km/hr)	1.1233	46.4095		<.0001
Intercept 2 (speed reduction <5km/hr)	1.5972	93.0792		<.0001
Intercept 4 (speed reduction >10 km/hr)	0.6250	14.4335		0.0001
Precipitation (1 = 0.05- 5 mm/hr, 0 = >5 mm/hr)	0.4433	9.776	0.412	0.0018
Weather condition (1=Clear, 0=Snow)	0.4148	21.3446	0.660	<.0001
Lighting (1=nighttime, 0=daytime)	0.3612	192.577	2.059	<.0001
Summer (1 = summer, 0 = winter)	0.3518	39.7241	0.703	<.0001

5.7 SUMMARY

In Chi-square test, the variables investigated were season, weather, visibility, lighting condition, and precipitation. All of these factors show strong correlation with speed and speed reduction at a 90% confidence level. However, when multiple variables were included in the ordered logistic regression model, only some factors have strong relationship with speed reduction. In the westbound lane of Gardiner Expressway, the statistically significant factors leading to higher speed reductions from high to low are: nighttime, snow and fall condition. Similarly, nighttime, summer, and snow conditions were significant in the eastbound direction. However, in the eastbound direction, precipitation was also significant. The significant factors listed in order for the eastbound direction are: precipitation, nighttime, snow and summer.

This study reflects that drivers are more sensitive to hour of day than the weather condition in selecting their speed. Speed reduction is more affected by snow than rainy condition.

CHAPTER VI

METHODOLOGY – DISPERSION MODELLING

6.1 AERMOD MODELING

The Industrial Source Complex and American Meteorological Regulatory Model (ISC- AERMOD) is an air dispersion modeling program. This model uses Gaussian steady-state approach to estimate ambient impacts from point, area, and volume sources up to 50 kilometres from the sources (Pierce, 2004). The program has two integrated interfaces: AERMOD and ISCST3. Both programs include algorithms that addressed many influential factors such as: building downwash effect, dry and wet deposition removal and terrain impact. However, AERMOD has an enhanced boundary layer meteorology consideration, turbulence parameter and uses terrain treatment method (Yang, 2007). AERMOD was chosen to simulate the dispersion pattern of NO_x in this project.

AERMOD requires two types of inputs: meteorological conditions and emission rates. The meteorological data must be in the pre-processor format of AERMET whereas the emission rate is in the unit of mass per time.

6.1.1 METEOROLOGY DATA

AERMOD requires two types of meteorological data files provided by the AERMET meteorological pre-processor program. One file consists of surface parameters, and the other consists of vertical profiles of meteorological data. These files were obtained from the Ministry of Environment (MOE, 2010). For samples of these dataset, refer to Table 3-2 and Table 3-3.

6.1.2 EMISSION FACTOR

The compound chosen in this project is NO_x which include NO and NO_2. During combustion, the nitrogen found in the fuel is released as Nitrogen, or Nitrogen Oxide (NO). In the presence of excess oxygen and sunlight, NO forms smog that affects visibility. Thus, NO_x was chosen because of environmental and respiration health impacts.

The emission factor was defined as the mass per km travelled per vehicle. The emission factors were obtained through the United States Environmental Protection Agency (U.S.EPA, 1998, 2001). These averages were based on the frequently maintained vehicle droved during the year collected, operating on a typical gasoline powered engine, and in an average summer day (22-36 ^oC) (EPA, 2001). The emission factors for 1997 and 2000 obtained from EPA are shown in Figures 6-1.

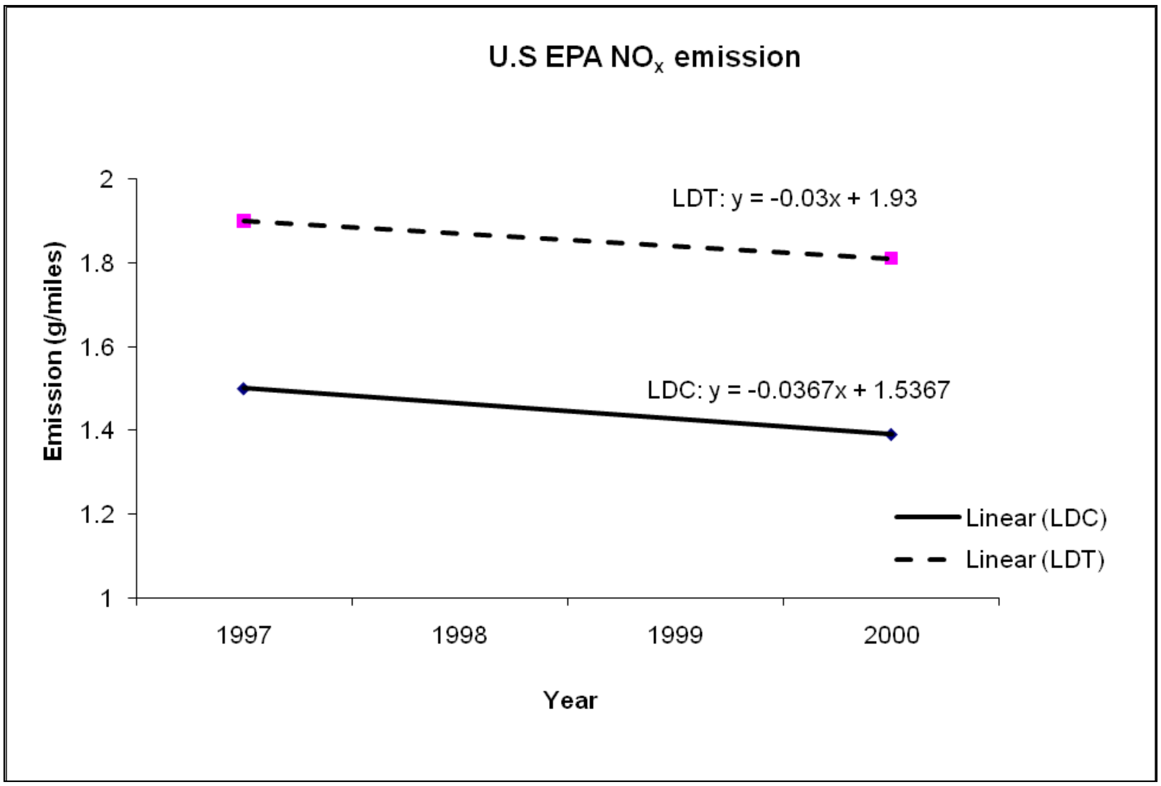


Figure 6- 1. NO_x emission factor for light duty car and truck in 1997 and 2000. (Reproduced using data from EPA, 2001)

LDC – Light duty cars LDT – Light duty trucks

From Figure 6-1 the emission factor for 1998 was calculated using the equations of the lines. The conversion unit of one mile is 1.609 km. The calculated values were compared with the roadway emission factors given by the City of Toronto (2010) with speed of 60 km/hr and under. Table 6-1 lists the estimated NO_x emission factor for light duty car (LDC) and light duty truck (LDT) from the EPA in comparison with the values obtained by the City of Toronto.

The percentage difference between the EPA values and the city of Toronto overall average was calculated based on the formula:

$$Percent(\%) = \frac{E_{Toronto} - E_{EPA}}{E_{Toronto}} \qquad (4)$$

where $E_{Toronto}$ = roadway emission factors from Toronto

E_{EPA} = highway emission factors from U.S EPA

Table 6- 1. Calculated NO_x emission factors from EPA and the City of Toronto.

Sources	LDC (g/km)	LDT (g/km)
From EPA highways for 1998 *	0.9	1.2
From Toronto roadways for 1998 **	1.1	1.2
Percentage difference (%)	18	0

* Calculated based on 1997 and 2000 values (from EPA, 2001)

** Source: City of Toronto (2011)

The percentage difference for emission factors is under 18%. Since the speed observed on highways taken from EPA closely reflects the speed on Gardiner Expressway than on roadways with speed equal to or less than 60 km/hr. The EPA values were used as the emission factors for 1998 on this highway. The average percentage of vehicle classification on this highway is 90% for car and 10% for trucks.

6.1.3 EMISSION RATE

The emission rate is defined as the amount of pollutant released into the atmosphere per kilometre traveled per vehicle. To map the dispersion pattern of emission over the highway, the emission rate was calculated based on the emission factor. This emission rate was inputted to the AERMOD model to obtain the dispersion patterns.

AERMOD can handle line, volume and point sources (ISC-AERMOD Guide, 2000). The vehicular emission is a line source. However, volume source was selected because the dispersion pattern is smoother when compared to line source. The hourly emission rates were calculated based on EPA emission factors and expressed as mass per time based on the following equation:

$$Er = V * EF * L \qquad (5)$$

where Er = Emission rate (g/sec)

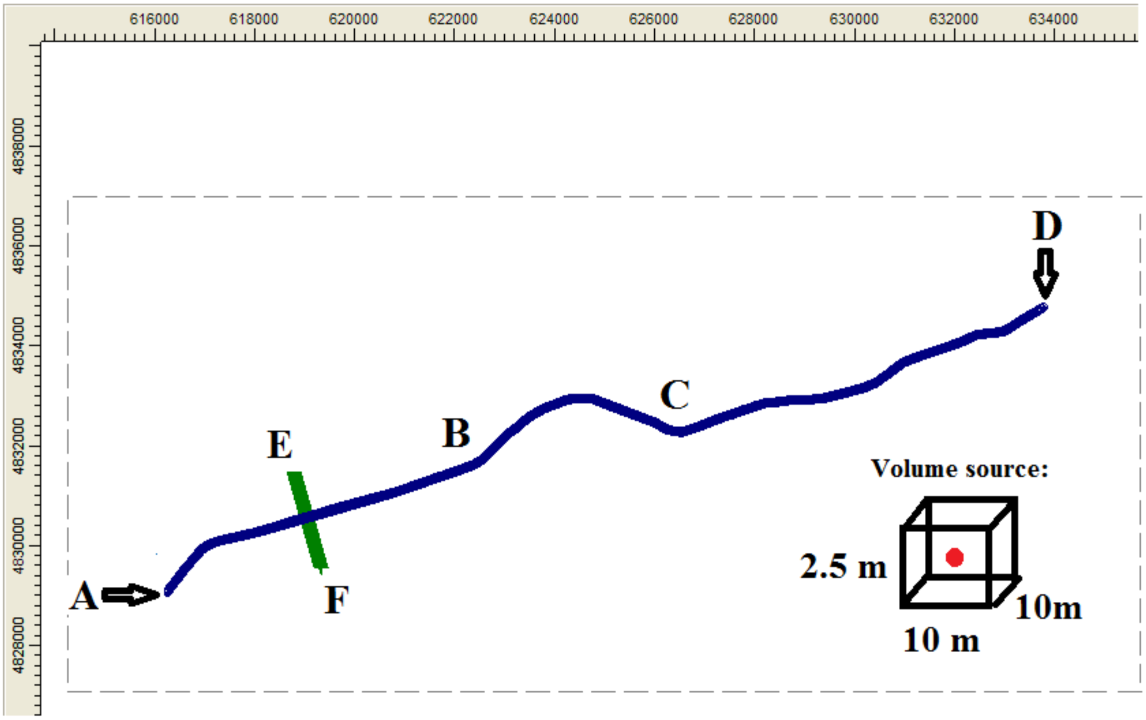
V = traffic volume (veh/sec)

EF = emission factor (g/km veh)

L = length of road section (km)

For example the emission rate of NO_x for a traffic volume of 1000 veh/hour, with a 10 km road section and emission factor of 0.9 g/km is 0.0025 g/sec. The emission rate was calculated based on hourly volume sources for all weather conditions. Calculations were done on two vehicle classes LDC and LDT. Due to the differences in traffic volume and speed on eastbound and westbound directions the emission estimation and simulation for each direction was ran separately. The total concentrations of NO_x were calculated for each direction using one hourly traffic data for the entire 21.6 km. The total emission rate for 5304 hours of NO_x on westbound is 2.66 kg/sec and eastbound is 2.47 kg/sec.

Before input the vehicular emission as volume sources into the AERMOD model, the road coordinates must be process in a specific format. First, the shape file for Gardiner Expressway is required and the Geographical Information System 4.4 (2010) software template was used. The Gardiner Expressway road shape is shown in Figure 6-2. Between point A to point D, shows the geography of the road and the between point E to F is the transitory receptor line. The dash line show the domain boundary selected for this highway and the values to the left on top are xy coordinates in Universal Transverse Mercator (UTM) in meters, respectively.



__ __ __Domain boundary axis - x and y coordinates in UTM (m)

Figure 6- 2. Gardiner Expressway road profile, transitory line (E-F) and domain setup in AERMOD.

This highway has approximately 3 lanes each on both east and westbound. The width of each direction is approximately 10 meter. Sequentially, all UTM coordinates along the Gardiner Expressway are discretized into uniform length as volume sources. This was done using Matlab. The width of the volume source is 10 m, and the length approximately 10 m. From the UTM coordinates extracted from GIS 4.4, the discretization result in 1956 links on eastbound and 1952 links on westbound. The height selected was 2.5 m (Held et. al., 2003). The emission release height was half of the volume height at 1.25 meter. For each hour in each direction, NO_x emission were represented by 1956 volume sources on eastbound and 1952 volume sources on westbound. These concentrations were inputted in AERMOD for simulation.

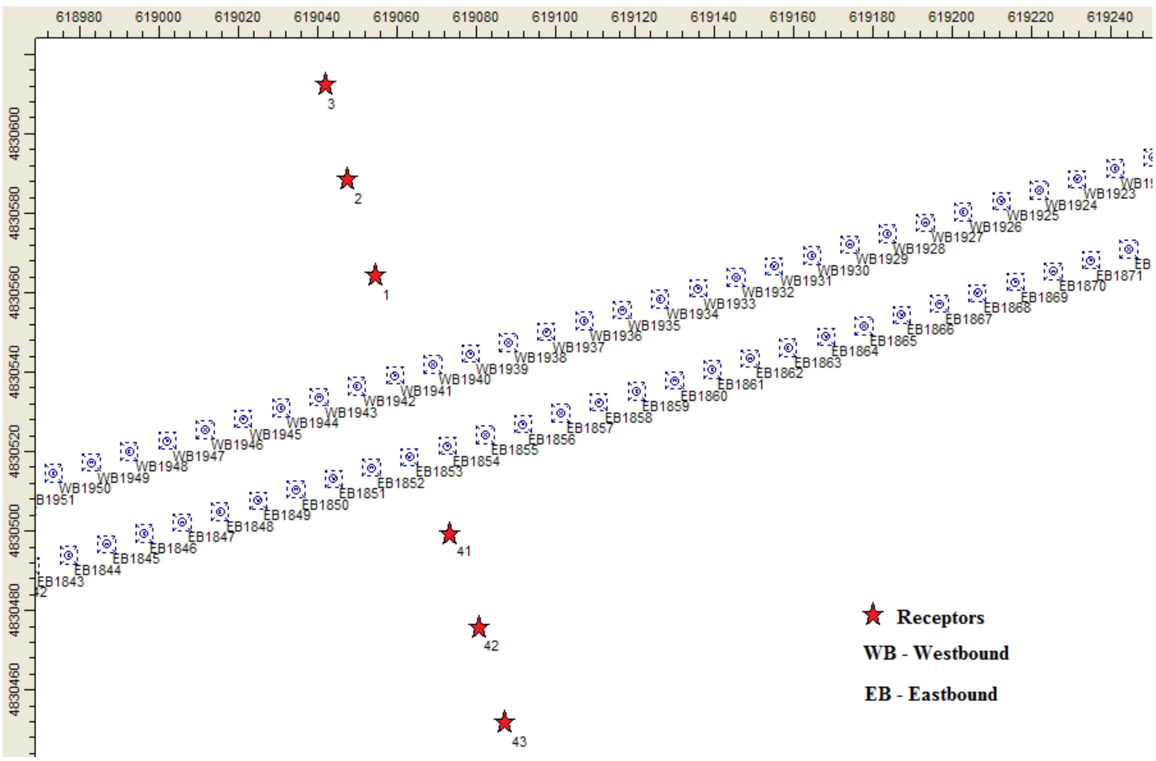
6.2 SIMULATION DESIGN

Table 6-2 listed the dispersion model setup parameters. From the shape profile generated from ArcGIS 4.4, the southwest coordinate on the Gardiner Expressway is located at -43.56^o N, 43.60 ^{o} W. To view the overall area of the highway, the domain was stretch by an extra of 2 km in both x and y directions. This causes the south-west corner to shift to -43.59^o N, 43.59 ^{o} W (614267 m, 4827054 m in UTM). The size of the domain stretches 21 km horizontally and 10 km vertically. For uniform Cartesian coordinates, a grid spacing of 100 m × 100 m was selected, leading to 210000 receptors. Additional receptors were also chosen to examine the dispersion rate of the pollutants. Those receptors were placed on a transitory line perpendicular to the road with 25 m spacing outwards. The transitory line was chosen on a straight stretch of road between points A & C in Figure 6-2, so as not to being affected by the end of the expressway and the curvature of the road. The overall diagram of the highway profile with its domain and receptor locations is shown in Figure 6-2. A zoomed-in view of the transitory receptors and the volume sources is shown in Figure 6-3.

Table 6- 2. Model setup parameters for AERMOD simulation.

Model Parameters	Settings
Domain setting	Grid uniform Cartesian South-west corner in UTM (zone 17N): 43.59^o N, 79.58^o W
Grid	Dimensions: 10km in north-south direction and 21km in east-west Grid spacing (DX, DY): 100 m × 100 m # of grid 210000 in west-east direction, 10000 in north-south direction
Emission source	Type: prepossessed volume source, road width = 10 m (x, y) center of volume Total emission rate in westbound 2.66 kg/sec and 2.47 kg/sec in eastbound. Release height= center of volume=1.25 m (Held et al., 2003) Initial lateral dimension σ_{y0}= road width/2.15 (EPA, 1995) Initial vertical dimension σ_{z0} = source vertical dimension/4.3= 0.58 m Variable emission rate based on hourly traffic counts in east and westbound, but invariable in the entire 21.6 km of the road
Meteorological files	Surface: Toronto Pearson Airport, Toronto (43.67^o N, 79.60^o W), hourly observation in 1998, Anemometer height=10 m Upper air: Buffalo, New York (42.93^o N, 78.73^o W) Pre-processed AERMOD-ready data from MoE (2010)
Terrain	Dispersion coefficient: rural (from AERMET) Terrain options: flat and simple terrain only
Output	Hourly-average concentration and period-average concentration contours and data files
Processes switched off	Dry deposition, wet deposition, plume depletion, and building downwash
Receptors	80 receptors - 1 km north side and south side

The transitory line stretches 1 km in each direction on the north side and south side from the reference points. The reference point is located at 43.653871° N, -79.34132° W for north side and 43.653579° N, -79.34121° W for south side. There are 40 receptors on each side of the highway. The first point in each direction is 25 m away from the corresponding reference point. The rest are placed at 25 m spacing extending to 1 km in each direction. The receptor coordinates in UTM are shown in Appendix D. Those receptors were used to plot NO_x concentrations. To investigate the dispersion pattern, the concentrations were normalized by dividing each concentration with the concentration at the first receptor in each direction.



Axis – x and y coordinates in UTM (meters)

Figure 6- 3. Transitory line receptors and volume sources on Gardiner Expressway

The major assumptions are listed as following:

- The average hourly traffic volumes reflect the volume of vehicle in that hour
- The vehicle mix of 90% passenger car and 10% trucks is consistent for all hours of 1998.

- The hourly traffic count collected at one station in each direction is constant throughout the 21.6 km stretch in this freeway.
- The emission factor is not a function of speed.
- There is no wet and dry deposition of pollutant of NO_x in any weather conditions
- NO_x does not undergo any chemical transformations
- Meteorological data collected from the Toronto Pearson Airport reflects the meteorological condition near the Gardiner Expressway.

In order to analyze the dispersion pattern between adverse weather and normal weather condition, three set of simulation designs were considered, as listed in Table 6-3. The total number of simulations is seven.

Table 6- 3. Simulation Design

Design scenarios	Simulation Run for East and West Direction
A.	Non-clear Hours (399) vs. clear hours (399) - Clear hours are select based on the hour subsequent to the day that rained or snow with visibility of 15 km (maximum). If the next rainy day did not meet the visibility condition, the following day was considered so on and so forth.
B.	B1. Snow hours (71) vs. clear weather (71) B2. Rainy hour (328) hours vs. clear weather (328) hours - Clear hours are select as described in design method 1.
C.	C1. Hourly rainy daytime (163) vs. hourly clear daytime (163) C2. Hourly rainy nighttime (165) vs. hourly clear nighttime (165) C3. Hourly snow daytime (41) vs. hourly clear daytime (41) C4. Hourly snow nighttime (30) vs. hourly clear nighttime (30) - Clear hours are select as described in design method 1.

CHAPTER VII

RESULTS OF POLLUTANT DISPERSION

7.1 COMPARISON BETWEEN CLEAR WEATHER CONDITIONS VS. SNOW AND RAIN CONDITIONS

Seven simulations (Table 6-3) were run in AERMOD using the meteorological data and the calculated NO_x emissions. The simulation outputs have two sets of concentrations based on the 80 receptors in the transitory line and the uniform Cartesian. The first output is the hourly maximum concentrations and the second output is the period average concentrations. The period average NO_x concentrations plot for clear condition compared to rain and snow conditions are shown in Figures 7-1 and 7-2, respectively. The dispersion pattern is similar in both conditions. Highest concentrations were observed on the road. The further the distance is from the roadway the less the NO_x concentrations. Clear weather condition has higher concentrations than rain and snow condition.

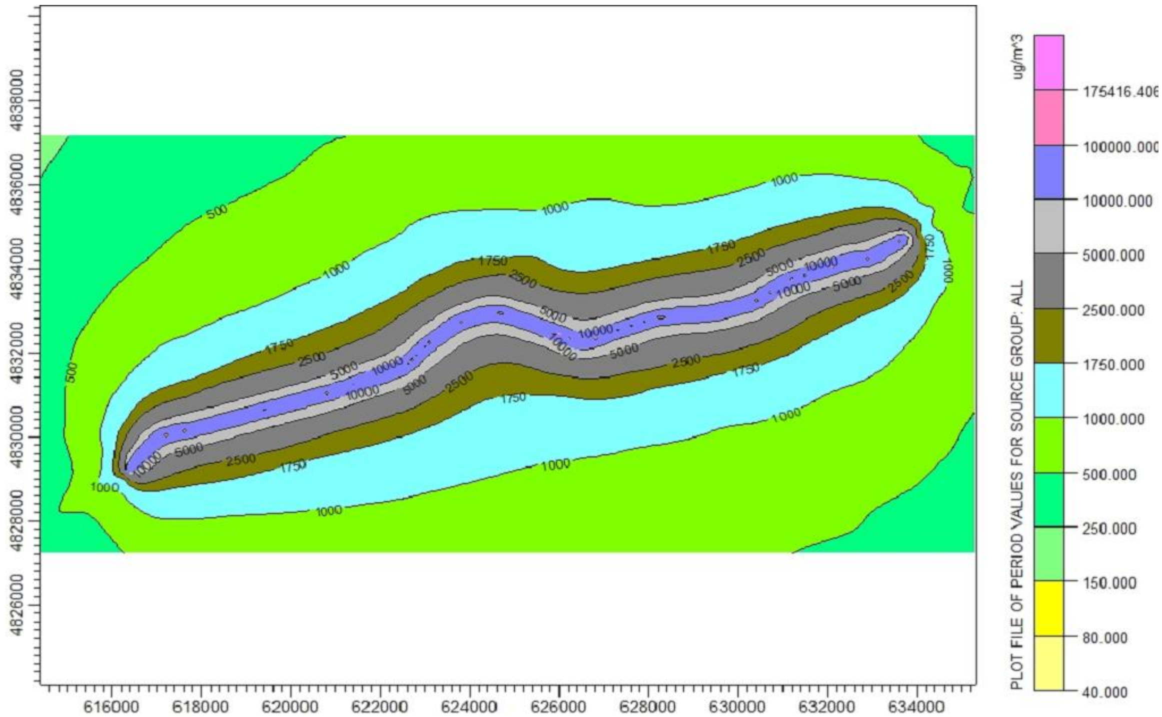


Figure 7- 1. Dispersion pattern of NO_x in clear condition surrounding the Gardiner Expressway

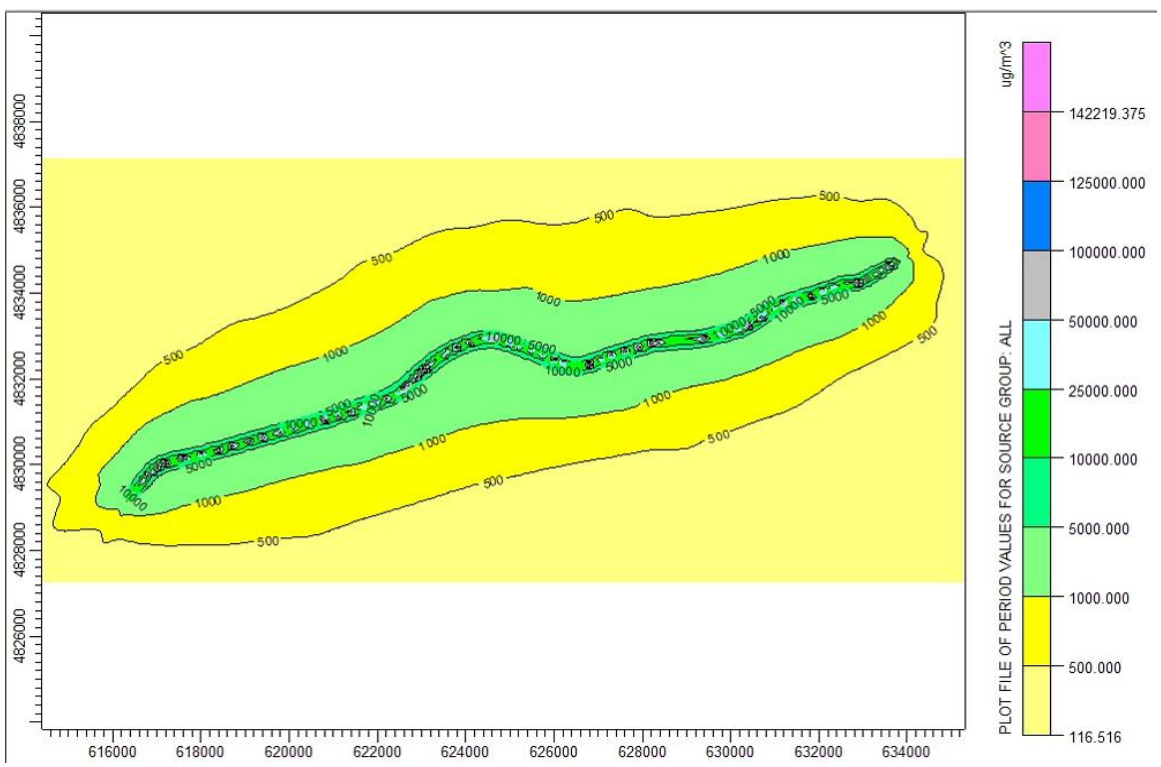


Figure 7- 2. Dispersion pattern of NO_x in rain and snow condition surrounding the Gardiner Expressway

The period average concentrations on the transit receptor are higher under clear condition than in adverse weather condition (Figure7-3b). This is due to the higher traffic volume in clear condition as compared to snow and rain, as shown in Figure 7-4. The hourly maximum concentration (Figure 7-3a) has higher values than the period average concentrations (Figure 7-3b), as expected.

Figures 7-5 shows the windrose. On rainy and snowy days the winds were from the East, whereas on clear day the winds were mainly from the North. Figure 7-6 shows the normalize concentrations. From the symmetrical shape, it can be concluded that the distribution of concentration is the same for both side of the road, even though the wind directions differ in both conditions. The dispersion pattern is almost the same in both conditions.

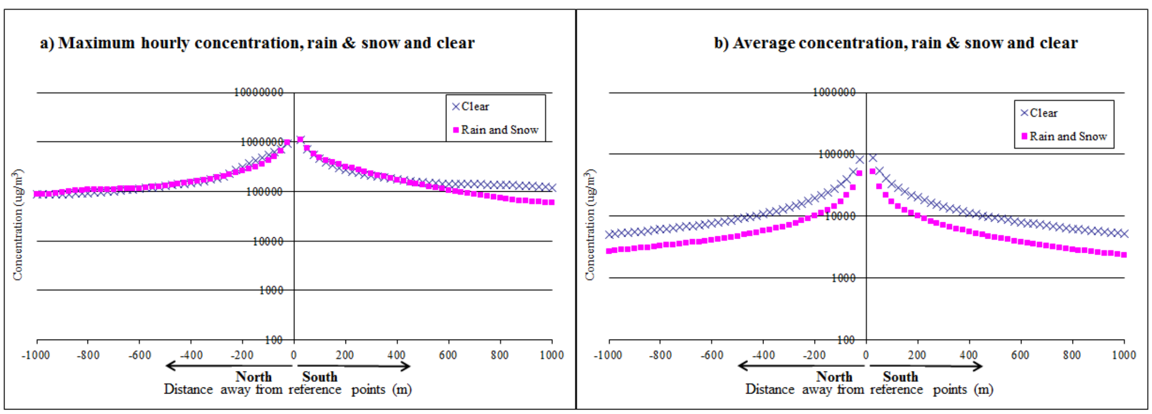


Figure 7- 3. Clear vs. rain and snow hours, (a) hourly maximum concentration (µg/m^3), (b) period average concentration (µg/m^3)

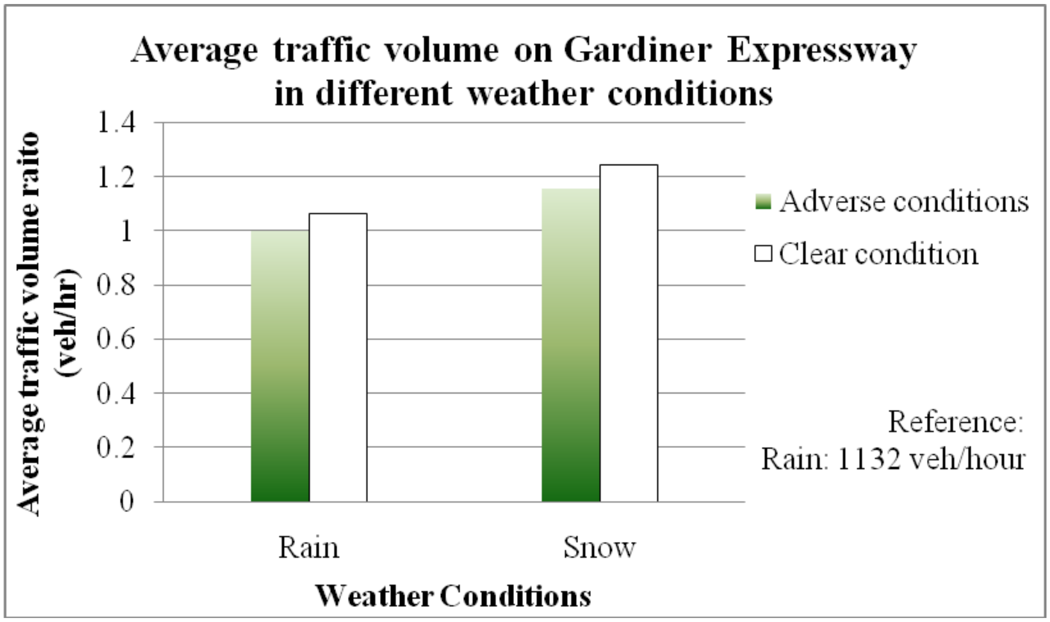


Figure 7- 4. Average traffic volume between clear and rainy snowy condition

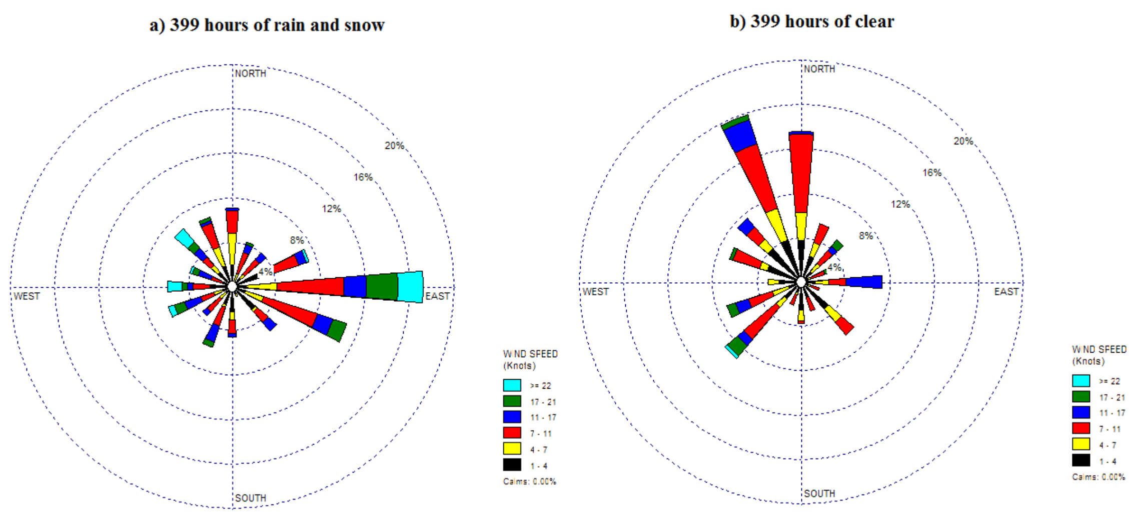


Figure 7- 5. Windrose of 399 hours of rain & snow and clear condition

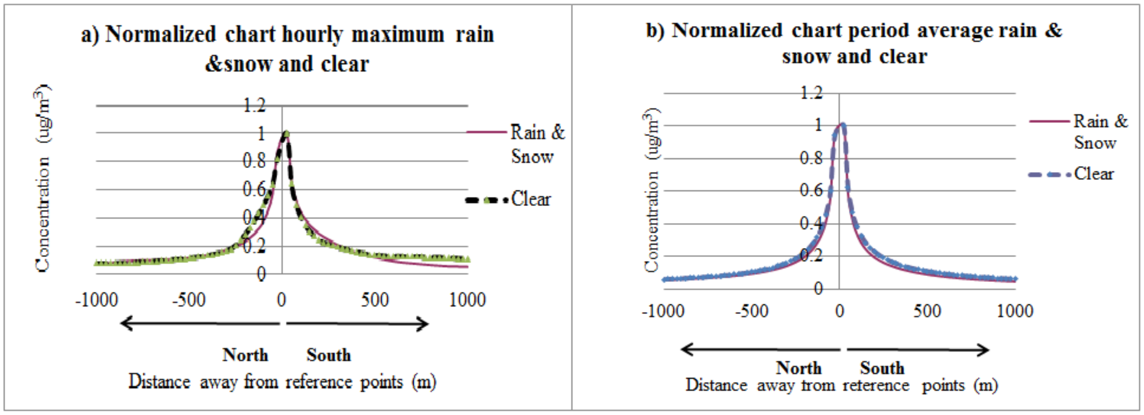


Figure 7- 6. Normalized hourly maximum concentration of rain and snow and clear condition. y is a concentration ratio which is dimensionless, x should have major markers, such as 500, 1000 (as in 7-3), please fix all normalized charts

7.2 COMPARISON BETWEEN SNOWY VS. CLEAR AND RAINY VS. CLEAR CONDITIONS

To narrow down the differences between each adverse weather condition and the clear condition, simulation designs B1 and B2 in Table 6-3 were ran. A total of 328 hours of rain was compared with the 328 hours of clear condition. The dispersion pattern away from roadway is shown in Figure 7-7. Similar result for concentration was found in rainy condition as it was in A1 simulation run of rainy and snow condition. The concentration in clear condition is marginally higher than in rainy condition (Figure 7-7b).

The windrose in Figure 7-8, shows that on clear condition the winds were from North and Northwest. In rainy condition the wind is from East and Southeast. The dispersion rate was even on both directions (Figure 7-9). Base on the symmetrical shape in Figure 7-9b, it can be concluded that the dispersion rate is similar in both weather conditions regardless of the wind directions.

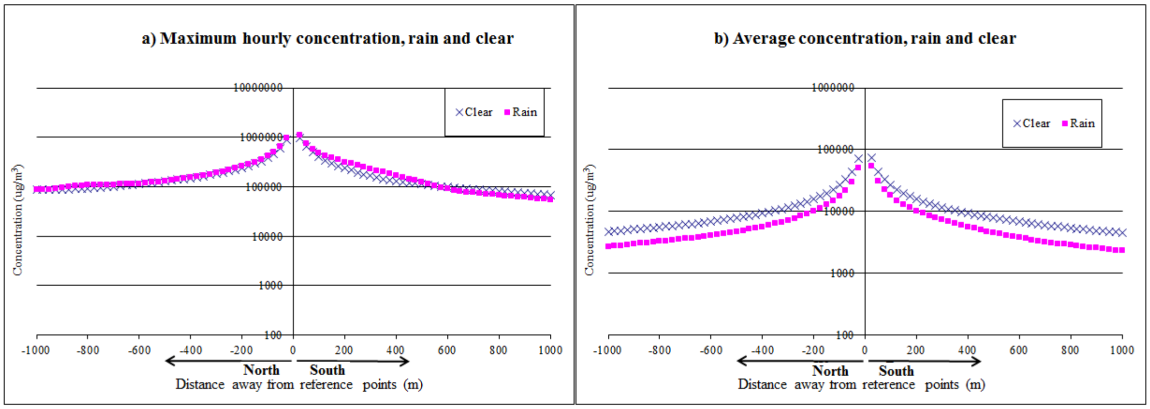


Figure 7- 7. Three-twenty-eight hours of clear vs. rainy condition, (a) hourly maximum concentration (μg/m^3), (b) period average concentration (μg/m^3)

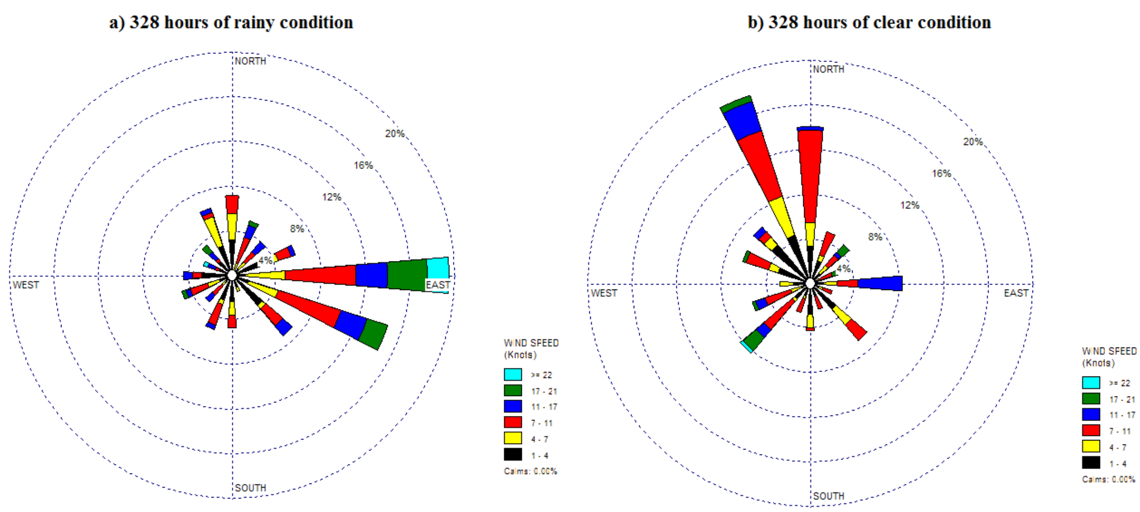


Figure 7- 8. Windrose of 328 hours of rain and clear condition

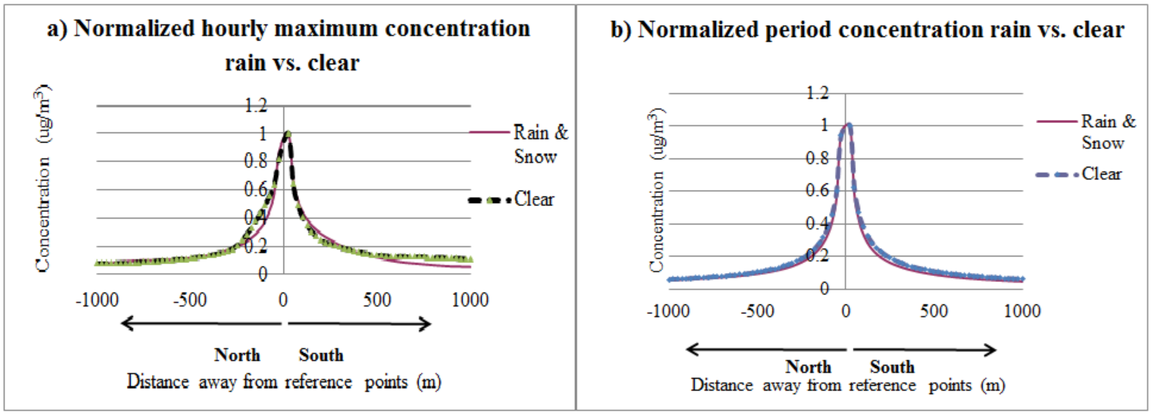


Figure 7- 9. Normalized concentration of rain and clear condition.

Similarly, the 71 hours of snowy condition was compared with 71 hours of clear condition. The concentration output is shown in Figure 7-10. NO_x concentration on clear condition is 5-10 times higher than snowy condition. Under clear condition the concentration is more disperse in the north-side than south-side as seen in Figure 7-11b. This is more likely cause by the difference in wind directions in these two conditions as seen in Figure 7-12. On clear condition is mostly from the southwest. However, on the snowy condition the wind direction varies from west, southwest and east.

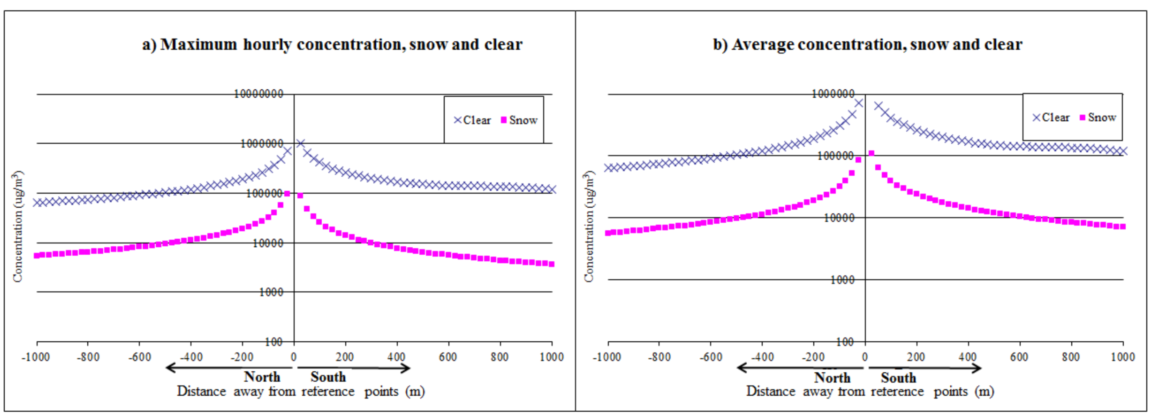


Figure 7- 10. Seventy-one hours of clear vs. snowy condition, (a) hourly maximum concentration (µg/m^3), (b) period average concentration (µg/m^3)

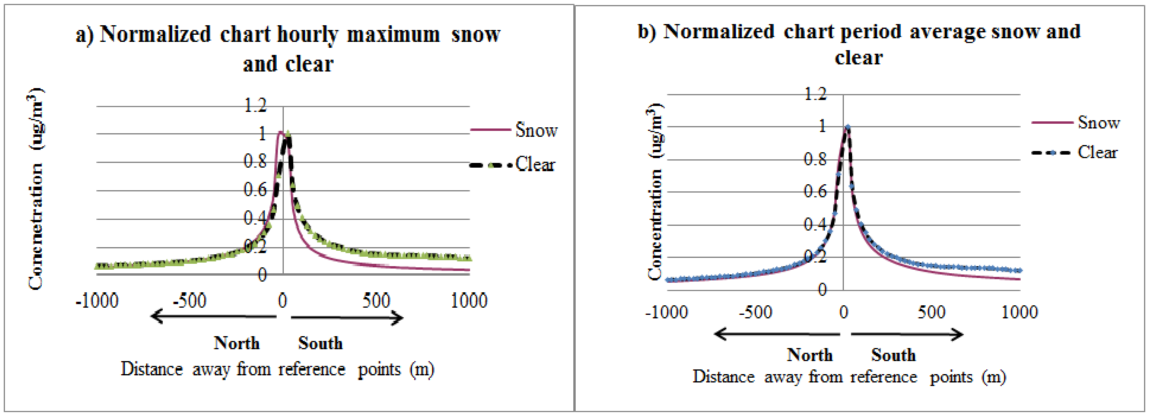


Figure 7- 11. Normalized hourly maximum concentration of snow and clear condition.

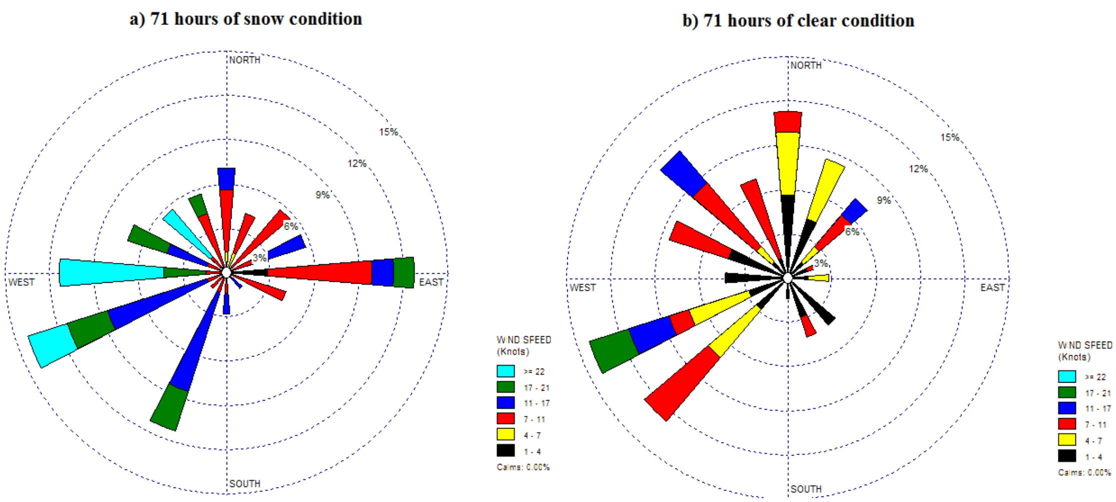


Figure 7- 12. Windrose of 71 hours of snowy and clear condition

7.3 COMPARISON BETWEEN DAYTIME AND NIGHTTIME CONDITON IN RAIN AND CLEAR AND SNOW AND CLEAR CONDITION.

The simulation design C was used to compare between daytime and nighttime situations in both adverse weather conditions. The daytime and nighttime concentrations for rainy condition and clear condition are shown in Figures 7-13 and 7-16, respectively. In these two Figures, similar results for NO_x concentrations were found for rainy condition and clear conditions. Base on the symmetry seen in Figures 7-14b and 7-17b, the dispersion pattern was concluded as the same in both conditions. The difference in wind speed between rain and clear conditions is very small (Table 7-2). The windrose is shown in Figure 7-15 for daytime and nighttime in Figure 7-18. However, regardless of wind directions the dispersion pattern is the same in all four weather conditions.

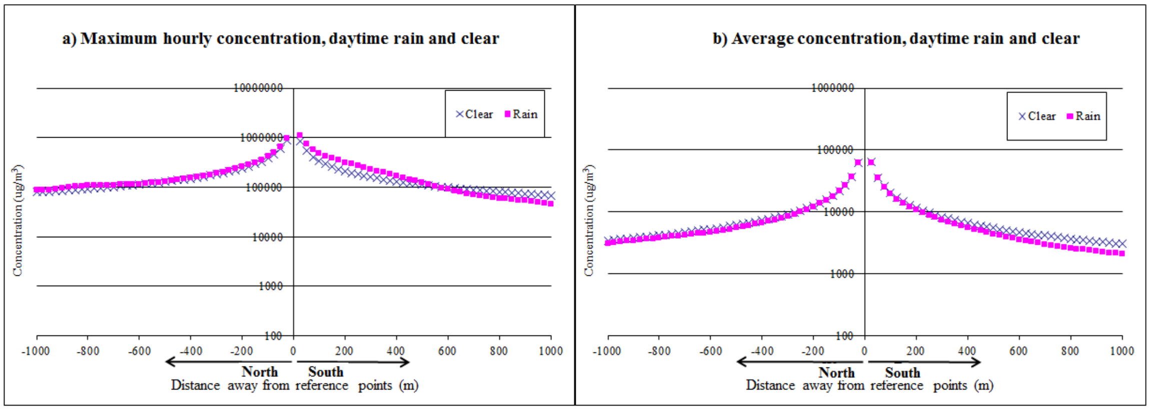


Figure 7- 13. One hundred sixty three hours of daytime clear vs. rainy condition, (a) hourly maximum concentration (b) period average concentration (µg/m^3)

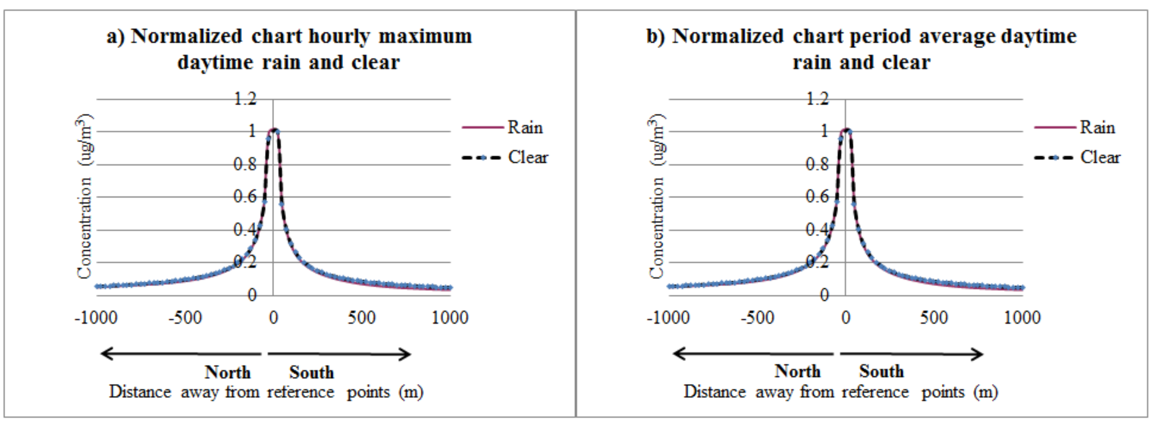


Figure 7- 14. Daytime normalized concentrations for rain and clear.

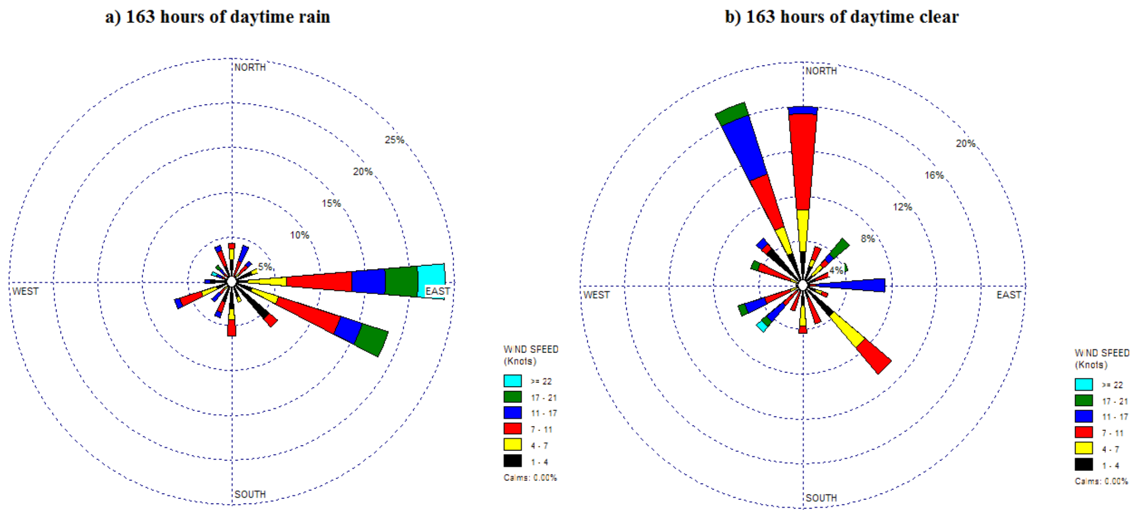


Figure 7- 15. Windrose of 163 daytime hours in rainy and clear condition.

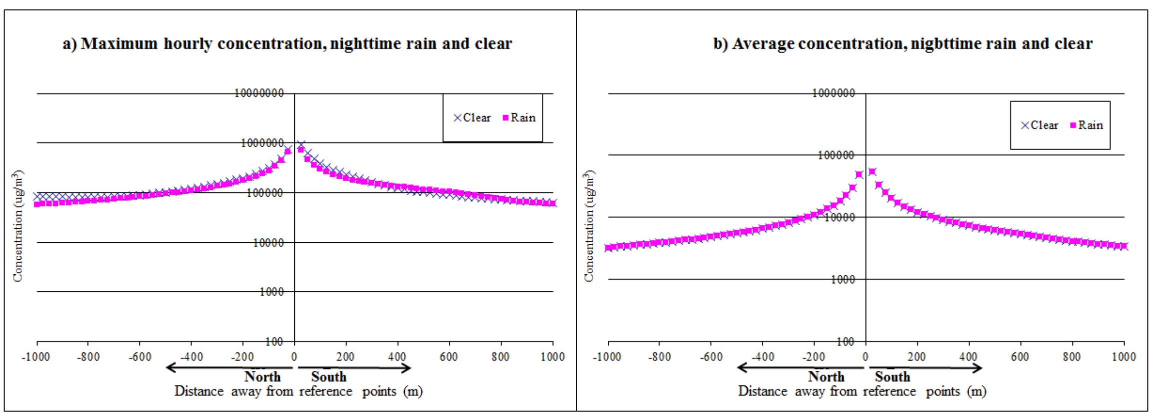


Figure 7- 16. One sixty five hours of nighttime clear vs. rainy condition, (a) hourly maximum concentration (b) period average concentration (μg/m^3)

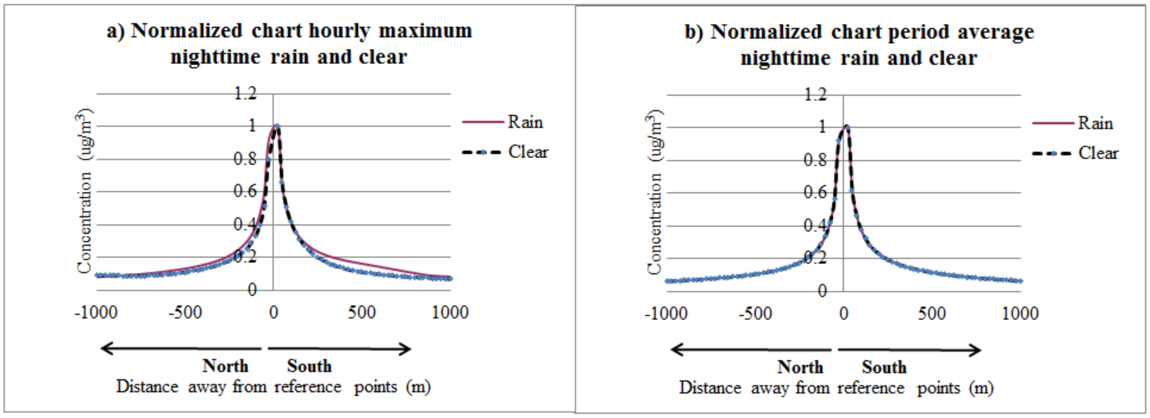


Figure 7- 17. Nighttime normalized concentrations for rain and clear.

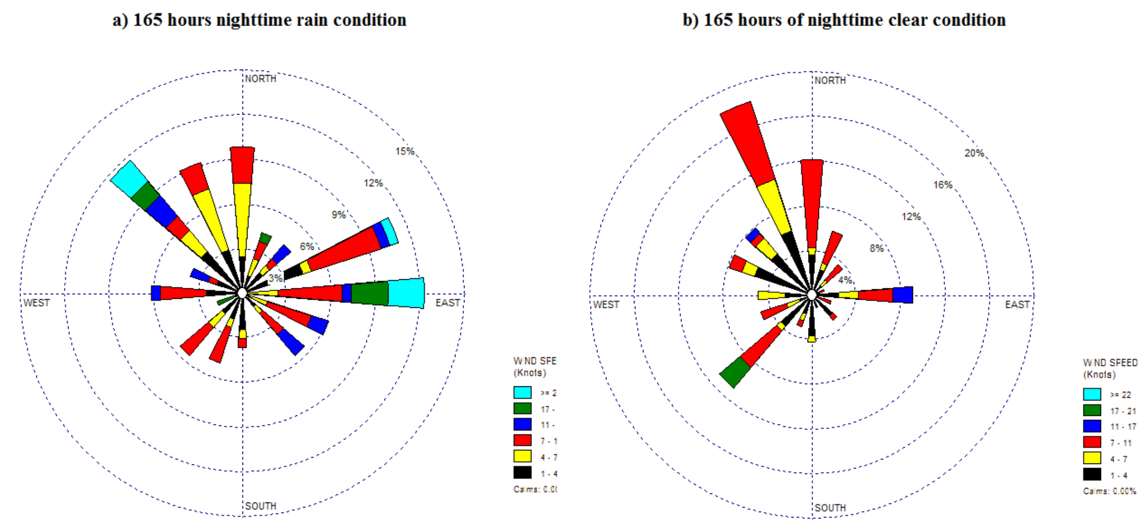


Figure 7- 18. Windrose of 165 nighttime hours in rainy and clear condition.

In snowy condition, the NO_x concentrations for daytime and nighttime were 5 to 10 times lower than clear condition as seen in Figures 7-19b and 7-22b, respectively. Normalized concentrations under clear conditions were more dispersed in the northside than southside as shown in Figure 7-20b and 7-23b. Figure 7-25 shows that clear have slightly higher traffic volume than snow conditions. However, the wind speed in snowy conditions is higher than in clear condition (Table 7-1); this leads to the lower NO_x concentrations.

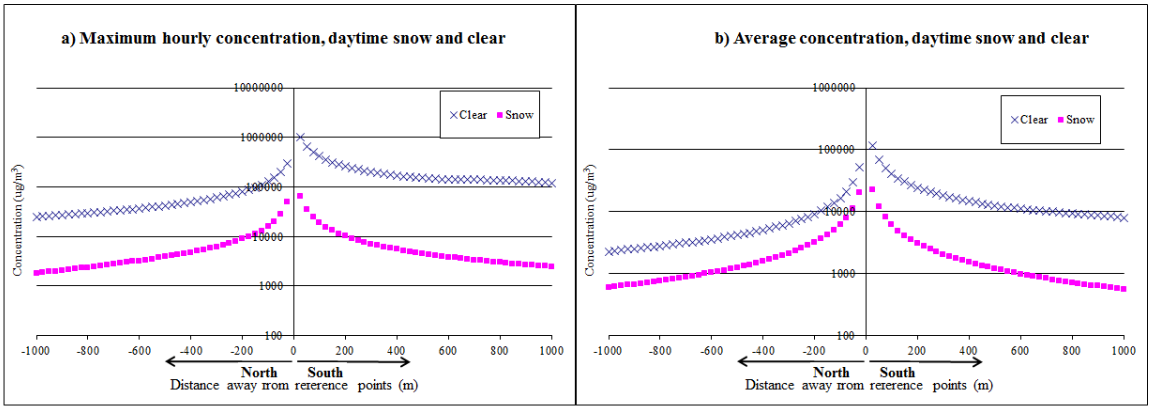


Figure 7- 19. Forty one hours of daytime clear vs. snowy condition, (a) hourly maximum concentration (µg/m^3), (b) period average concentration (µg/m^3)

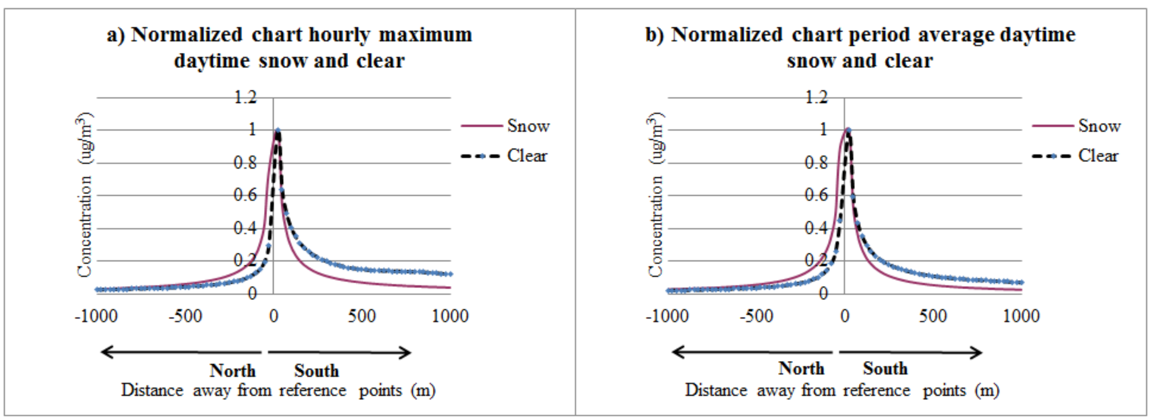


Figure 7- 20. Daytime normalized concentrations for snow and clear.

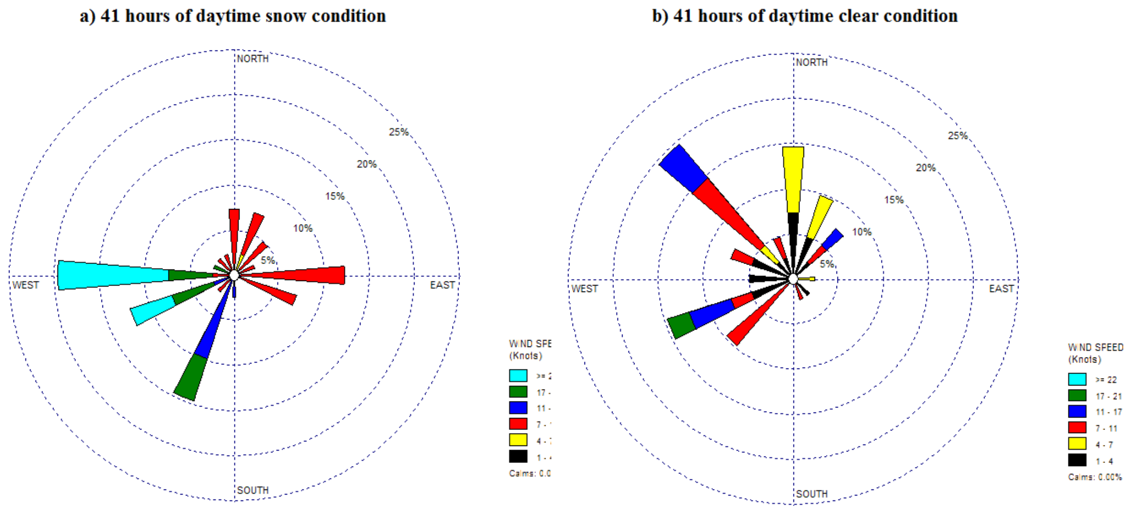


Figure 7- 21. Windrose of 41 daytime hours in snow and clear condition.

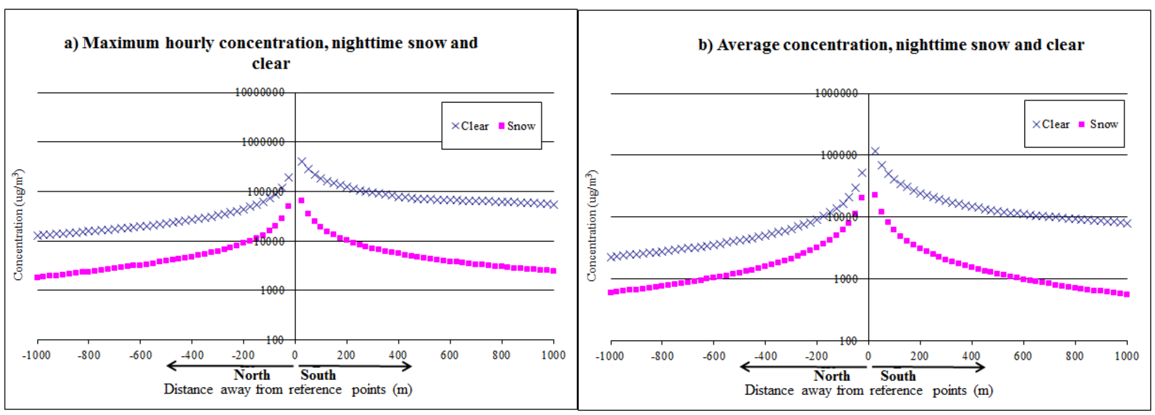


Figure 7- 22. Thirty hours of nighttime clear vs. snowy condition, (a) hourly maximum concentration (b) period average concentration (μg/m^3)

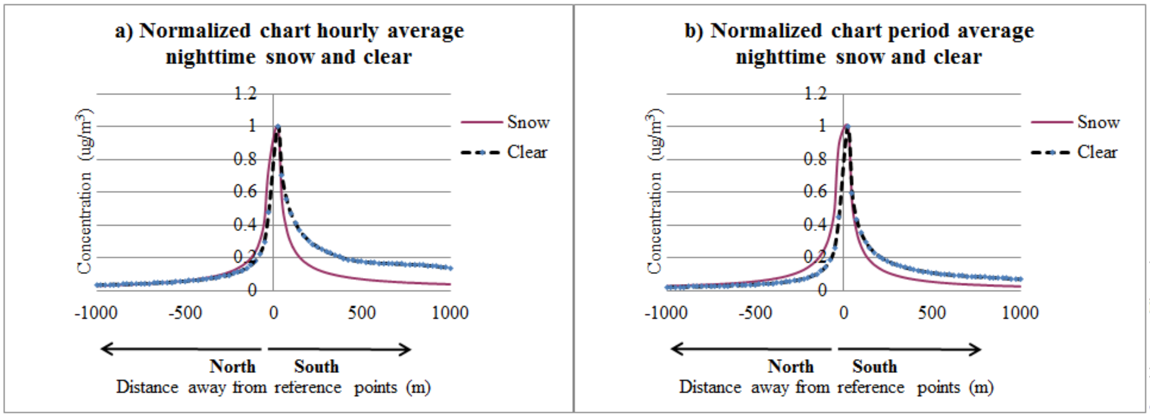


Figure 7- 23. Nighttime normalized concentrations for snow and clear.

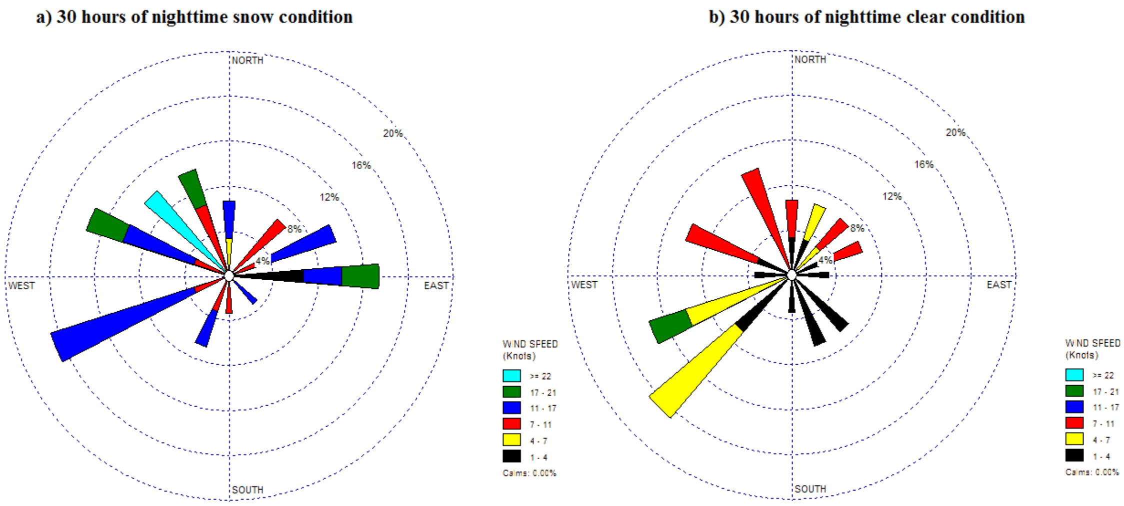


Figure 7- 24. Windrose of 30 nighttime hours in snow and clear condition.

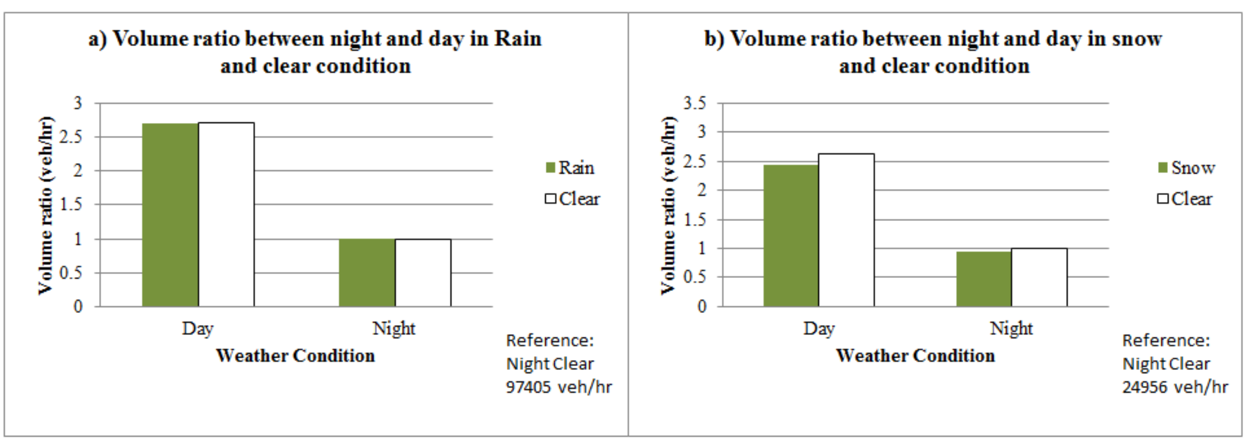


Figure 7- 25. Traffic volume ratio between different conditions

Table 7- 1. Wind speed and directions in rain, snow, and clear conditions.

esign		Average wind speed (m/s)	St. Dev (m/s)	Max wind speed (m/s)	Wind Directions
1	Daytime rain (163 hrs)	4.47	2.86	12.4	East
	Daytime clear (163 hrs)	4.45	2.43	12.4	North
2	Nighttime rain (165 hrs)	4.21	2.77	12.4	Northwest, East
	Nighttime clear (165 hrs)	3.15	1.92	10.8	North
3	Daytime snow (41 hrs)	7.30	3.19	14.9	West
	Daytime clear (41 hrs)	3.66	2.18	9.80	North, West
4	Nighttime snow (30 hrs)	6.65	2.70	12.9	West, Northwest, East
	Nighttime clear (30 hrs)	2.90	0.77	8.80	West, southwest

Table 7- 2. Emission and Concentration ratios

Design	Conditions	Concentration	Emission
A	Clear vs. Nonclear	0.53	1.05
B1	Clear vs. rain	0.64	0.96
B2	Clear vs. snow	0.09	0.94
C1	Daytime clear vs. rain	0.93	0.99
C2	Nighttime clear vs. rain	1.00	1.05
C3	Daytime clear vs. snow	0.19	0.97
C4	Nighttime clear vs. snow	0.14	0.98

Based on the difference in emission and concentration ratios listed in Table 7-2, it can be seen that emission ratios are close to 1 indicating traffic volumes are proximately the same in clear and adverse weather conditions. However, the concentration ratio varies by a factor of 10 indicating the degree by which meteorological condition influences NO_x concentration varies greatly. In cases C1 and C2 (rain and clear), both ratios are similar suggesting emissions predominantly influence the NO_x concentration. In cases A (clear vs. Nonclear) and B1 (clear vs. rain), emissions and meteorological conditions have similar influence because the concentration ratios are 0.53 and 0.64, respectively. For cases B2 (clear and snow), C3 (daytime clear vs. snow) and C4 (nighttime clear vs. snow), meteorological conditions have greater influence on NO_x concentration since the concentration is 5 to 10 times lower in adverse weather. All three cases (B2, C3 and C4) are having snow conditions and higher wind speeds therefore more dispersion, as discussed previously,

Table 7-3 summarizes the dispersion patterns in all cases studied.

Table 7- 3. Summary of dispersion pattern in all cases studied

Design	Simulation Run for North and South side of the Gardiner Expressways	
A.	Non-clear hours (399) vs. clear hours (399)	
	Concentration	Clear > Nonclear (2x higher)
	Shape	Symmetrical
	Dispersion	NOx is similarly dispersed in both conditions
	Ratio at 500 m *	0.097
	Predominant wind	Clear = North Nonclear = West
B.	B1. Snow hours (71) vs. clear weather hours (71) could be B2	
	Concentration	Clear > Nonclear (10x)
	Shape	Symmetrical
	Dispersion	Similar in both conditions.
	Ratio at 500 m	Snow:0.083 Clear: 0.125
	Predominant wind	Clear = North Snow = West
	B2. Rainy hours (328) vs. clear weather hours (328)	
	Concentration	Clear > Nonclear (2x)
	Shape	Symmetrical for snow ; skew to southside for clear
	Dispersion	More on the north side then south side for both conditions
	Ratio at 500 m	0.118
	Predominant wind	Clear = North, Northeast Rain = West, Southwest
C.	C1. Rainy daytime hours (163) vs. clear daytime hours (163)	
	Concentration	Clear ~ Nonclear
	Shape	Symmetrical
	Dispersion	Similar in both conditions.
	Ratio at 500 m	0.084
	Predominant wind	Clear = North Rain = East
	C2. Rainy nighttime hours (165) vs. clear nighttime hours (165)	
	Concentration	Clear ~ Nonclear
	Shape	Symmetrical
	Dispersion	Similar in both conditions.
	Ratio at 500 m	Rain: 0.146 Clear: 0.109 see Fig 7-17, they looked the same to me, could you please check the #s
	Predominant wind	Clear = North Rain = East, Northwest
	C3. Snowy daytime hours (41) vs. clear daytime hours (41)	
	Concentration	Clear > Nonclear (5-10x)
	Shape	Symmetrical for snow; skew to southside for clear condition
	Dispersion	More on the north side then south side for both conditions
	Ratio at 500 m	Snow: 0.063 Clear: 0.095
	Predominant wind	Clear = North, West Snow = West
	C4. Snowy nighttime hours (30) vs. clear nighttime hours (30)	
	Concentration	Clear > Nonclear (5-10x)
	Shape	Symmetrical for snow; skew to southside for clear condition
	Dispersion	More on the north side then south side for both conditions
	Ratio at 500 m	Snow: 0.063 Clear: 0.116
	Predominant wind	Clear = West, Southwest Snow = West, Northwest, East

*Concentration ratio = concentration at 500 m away from the road/ concentration at reference point which is the edge of the road

7.4 SUMMARY

When comparing clear condition with adverse weather condition, it was found that the concentrations in clear condition are 5 times higher in snowy condition and 2 times higher in rainy condition. In rainy condition, the concentration disperses evenly in both directions the same as it was in clear condition. However, in snowy condition, NO_x concentration is more dispersed in the North side than in the Southside of Gardiner Expressway. This is due to different prevalent wind during these two conditions as seen in Table 7-1. In snowy condition, the prevalent wind is from the west with greater wind speed causing more dispersion of the pollutant in the west side.

Similar results were found for daylight condition as in adverse weather and clear condition. The dispersion pattern in evenly disperse in both direction in rainy condition. However, in snowy condition, result indicates NO_x concentration is more disperses in the North side in both daylight and nighttime. Since Gardiner Expressway locates near the Lake Ontario; therefore the contribution of wind gust influences the concentration in adverse weather condition.

Two main factors effecting the dispersion of pollutant concentration is emission and metrological factor such as wind speed and wind direction. In adverse weather condition such as snow or rain, it is expected that the concentration is high due to low mixing. However, the results show 5 times lower concentration in snowy condition and 2 times lower concentration in rainy condition. This result indicates emission is the main factor that influences the dispersion of NO_x in rainy condition, whereas meteorological was the main influence in snowy condition.

CHAPTER VIII

CONCLUSIONS AND RECOMMENDATIONS

The objective of this thesis was to identify the effect of weather conditions on variations in traffic speed on the Gardiner Expressway in Toronto, Ontario. This thesis also analyzed the dispersion patterns of NO_x produced from traffic in different weather conditions.

The analyses showed speed and speed reductions were correlated to time of day, visibility, precipitation, season, rain, snow and clear condition. To identify the effect of the factors on speed reduction, the ordered logistic regression model was developed. Results of the model show that, the speed reduction was lower in daytime than nighttime. Statistically significant speed reduction occurred with precipitation on the eastbound but not on westbound. The seasonal effect on speed reduction was different between eastbound and westbound. Fall was significant on the westbound whereas summer was significant on the eastbound. Visibility and rainy condition was not significant in ordered logistic regression model.

The results of dispersion modelling show that NO_x concentrations were higher in clear weather conditions than rainy and snowy weather conditions. This is due to higher traffic volume in clear weather conditions than adverse weather conditions, higher emissions produced from traffic, and consequently higher NO_x concentrations. There was no significant difference in NO_x concentrations between daytime and nighttime. However, due to higher wind speeds under snowy weather condition, NO_x concentration was more dispersed in snowy weather condition than the clear weather condition. As a result the concentration was much lower in snowy condition.

Based on the concentration and emission ratios, it is concluded that emission has the predominant influence on NO_x concentration in rainy and clear weather conditions. In snowy weather condition, meteorological parameters such as higher wind speeds have greater influence on NO_x concentrations which are five times lower than NO_x concentrations in clear weather condition. These results are pertained only to this freeway during the study period.

There are some limitations in this study. One limitation was that hourly weather conditions were assumed to be consistent based on weather conditions recorded during that hour. However, it is possible that precipitation events in the previous hours affected speed in the current hour in normal weather conditions. Another limitation was a lack of consideration of fog in the analysis. However, low visibility during normal weather and good lighting conditions is potentially due to the effect of fog. In other words, co-linearity should be handled when both visibility and fog are considered. This thesis has identified the relationship between season and speed reduction, but has yet found the reasons behind the relationship between the two.

Recommended future works include more in-depth analysis of the relationship between the seasonal factors of weather and speed reduction to identify which season has a greater effect on speed reduction and why. In addition, the vehicular emission factors should vary with season and speed as well as the degree of congestion. Further research should also take into consideration the removal of air pollutants in the form of wet disposition in the presence of precipitation.

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APPENDICES

APPENDIX A

VISUAL BASIC CODING

<u>Generate Seasons base on the date and month of the year</u>:

```
Dim i, j, k, l, counter As Integer
counter = 0
For i = 3 To 5306 Step 1
   'For j = 5 To 28 Step 1
      'For k = 3 To 223 Step 1
        ' For l = 1 To 7 Step 1
            If ((Worksheets("sheet1").Cells(i, 3) <= 2) Or (Worksheets("sheet1").Cells(i, 3)
= 12)) Then
                  Worksheets("sheet1").Cells(i, 11) = "W"

            ElseIf ((Worksheets("sheet1").Cells(i, 3) >= 3) And
(Worksheets("sheet1").Cells(i, 3) <= 5)) Then
                  Worksheets("sheet1").Cells(i, 11) = "Spr"

            ElseIf ((Worksheets("sheet1").Cells(i, 3) >= 6) And
(Worksheets("sheet1").Cells(i, 3) <= 8)) Then
                  Worksheets("sheet1").Cells(i, 11) = "Su"

            ElseIf ((Worksheets("sheet1").Cells(i, 3) >= 9) And
(Worksheets("sheet1").Cells(i, 3) <= 11)) Then
                  Worksheets("sheet1").Cells(i, 11) = "F"
            End If
   'Next k
Next i
End Sub
```

Generate Weather condition base on the weather observation data:

```
Private Sub CommandButton3_Click()
Dim i, j, k, l, counter As Integer
counter = 0
For i = 5001 To 5306 Step 1
    'For j = 1 To 3 Step 1
        For k = 3 To 8806 Step 1
          'For l = 1 To 3 Step 1
              If ((Worksheets("sheet1").Cells(i, 1) = Worksheets("Weather").Cells(k, 1))
And (Worksheets("sheet1").Cells(i, 2) = Worksheets("Weather").Cells(k, 2)) And
(Worksheets("sheet1").Cells(i, 3) = Worksheets("Weather").Cells(k, 3))) Then
                    If (Worksheets("Weather").Cells(k, 6) = "C") Then
                       Worksheets("sheet1").Cells(i, 5) = 1
                    Else
                       Worksheets("sheet1").Cells(i, 5) = 0
                    End If
                    If (Worksheets("Weather").Cells(k, 6) = "R") Then
                       Worksheets("sheet1").Cells(i, 8) = 1
                    Else
                       Worksheets("sheet1").Cells(i, 8) = 0
                    End If
                    If (Worksheets("Weather").Cells(k, 6) = "S") Then
                       Worksheets("sheet1").Cells(i, 9) = 1
                    Else
                       Worksheets("sheet1").Cells(i, 9) = 0
                    End If
                    If ((Worksheets("Weather").Cells(k, 6) = "ZR") Or
(Worksheets("Weather").Cells(k, 6) = "L")) Then
                       Worksheets("sheet1").Cells(i, 10) = 1
                    Else
                       Worksheets("sheet1").Cells(i, 10) = 0
                    End If
```

```
            End If
'           Next l
            Next k
    'Next j
 Next i
 End Sub
```

<u>Filtered the incidents from Incident Log file and matched with the hour to the day happened.</u>

```
 Private Sub CommandButton1_Click()
 Dim i, j, k, h, counter, counter1, counter2, counter3, counter4, counter5, counter6,
counter7, counter8, counter9, counter10, counter11 As Integer

 For i = 3 To 378 Step 1
 counter = 28
 counter11 = 28
    For j = 2 To 100 Step 1

        '------------------------------------------------------for JAN
        If (Worksheets("speed by date").Cells(i, 3) = Worksheets("JAN_W").Cells(j, 14)
And Worksheets("speed by date").Cells(i, 4) = Worksheets("JAN_W").Cells(j, 13)) Then
        counter11 = counter11 + 1
            Worksheets("speed by date").Cells(i, counter11) =
Worksheets("JAN_W").Cells(j, 16)

        End If
    Next j
 Next i

        '------------------------repeat for all other months.
```

Color the indecent time with the speed data at the hour it happened.

```
Private Sub CommandButton3_Click()
Dim i, j, k, h, counter As Integer

For i = 5 To 28 Step 1

counter = 28
   For j = 3 To 378 Step 1
      For k = 29 To 106 Step 1

         If (Worksheets("speed by date").Cells(2, i) = Worksheets("speed by
date").Cells(j, k)) Then
            Worksheets("speed by date").Cells(j, i).Interior.ColorIndex = 24

         End If
      Next k
   Next j
Next i

End Sub
```

Delete the speed when the incidents occurred base on matching the hour.

```
Private Sub CommandButton4_Click()
Dim i, j, k, h, counter As Integer

For i = 5 To 28 Step 1

counter = 28
```

```
    For j = 3 To 378 Step 1
        For k = 29 To 106 Step 1

            If (Worksheets("speed by date").Cells(2, i) = Worksheets("speed by date").Cells(j, k)) Then
                Worksheets("speed by date").Cells(j, i) = ""

            End If
        Next k
    Next j
Next i
End Sub
```

<u>Filtered the accidents from crash file and matched with the hour to the day happened.</u>

```
Private Sub CommandButton5_Click()
Dim i, j, k, h, counter14 As Integer

For i = 3 To 378 Step 1
counter14 = 82

    For j = 2 To 100 Step 1
        If (Worksheets("speed by date").Cells(i, 3) = Worksheets("Crash_W").Cells(j, 14) And Worksheets("speed by date").Cells(i, 4) = Worksheets("Crash_W").Cells(j, 13)) Then
        counter14 = counter14 + 1
            Worksheets("speed by date").Cells(i, counter14) = Worksheets("Crash_W").Cells(j, 16)

        End If
    Next j
Next i
End Sub
```

Colored the Weather condition base on color code chosen.

```
Private Sub CommandButton6_Click()
Dim i, j, counter As Integer

For i = 3 To 378 Step 1
   For j = 5 To 28 Step 1

         If (Worksheets("Weather").Cells(i, j) = "R") Then
            Worksheets("speed by date").Cells(i, j).Interior.ColorIndex = 36
         End If
         If (Worksheets("Weather").Cells(i, j) = "S") Then
            Worksheets("speed by date").Cells(i, j).Interior.ColorIndex = 39
         End If
         If (Worksheets("Weather").Cells(i, j) = "L") Then
            Worksheets("speed by date").Cells(i, j).Interior.ColorIndex = 43
         End If
         If (Worksheets("Weather").Cells(i, j) = "ZR") Then
            Worksheets("speed by date").Cells(i, j).Interior.ColorIndex = 46
         End If
   Next j
Next i
End Sub
```

Delete the speed where there is a record of weather condition.

```
Private Sub CommandButton7_Click()
Dim i, j, counter As Integer
```

```
For i = 3 To 378 Step 1
   For j = 5 To 28 Step 1

         If (Worksheets("Weather").Cells(i, j) = "R") Then
            Worksheets("speed by date").Cells(i, j) = ""
         End If
         If (Worksheets("Weather").Cells(i, j) = "S") Then
            Worksheets("speed by date").Cells(i, j) = ""
         End If
         If (Worksheets("Weather").Cells(i, j) = "L") Then
            Worksheets("speed by date").Cells(i, j) = ""
         End If
         If (Worksheets("Weather").Cells(i, j) = "ZR") Then
            Worksheets("speed by date").Cells(i, j) = ""
         End If
   Next j
Next i
End Sub
```

APPENDIX B

STATISTICAL ANALYSIS CODING

Input Headings:

Example :

```
input Hour Date Month Day_1 Clear_1 Speed volumePrecip Season$
Weather$ Visibility Speed Reduction
```

Categorization of data:

```
data Name_of_data;
set Speed Reduction_Weather;
if Speed <= 60 then Speed = 1;
else if Speed > 60 and Speed <=80 then Speed = 2;
else if Speed > 80 and Speed <=90 then Speed =3;
else if Speed >90 and Speed <=100 then Speed =4;
else Speed = 5 ;

if Speed Reduction <= 0 then Speed Reduction =1 ;
else if Speed Reduction > 0 and Speed Reduction <5 then Speed Reduction = 2;
else if Speed Reduction > 5 and Speed Reduction <10 then Speed Reduction =3;
else Speed Reduction = 4 ;

if Season = "Spr" then Spr =1;
else Spr = 0;
if Season = "Su" then Su =1;
else Su = 0;
if Season = "F" then F =1;
else F = 0;

if Precip < 0.04 then Precip= 1;
```

```
else if Precip >=0.05 and Precip <=5 then Precip= 2;
else if Precip >5 and Precip <=10 then Precip= 3;
else Precip = 4;

if Visibility  >=0 and Visibility  <=5 then Visibility = 1;
else if Visibility  >5 and Visibility  <=10 then Visibility = 2;
else Visibility = 3;
```

Run Chi-square test (speed) with each parameter command:

```
PROC freq DATA= Speed Reduction_Weather2;
table Speed*Day_1 /chisq;
RUN;
PROC freq DATA= Speed Reduction_Weather2;
table Speed*Precip /chisq;
RUN;
PROC freq DATA= Speed Reduction_Weather2;
table Speed*Visibility /chisq;
RUN;
PROC freq DATA= Speed Reduction_Weather2;
table Speed*Season /chisq;
RUN;
PROC freq DATA= Speed Reduction_Weather2;
table Speed*Weather /chisq;
RUN;
```

Run Ordered Logistic command:

```
proc logistic descending data = Speed Reduction_Weather2;
  class Day_1   Precip  Season Weather          Visibility;
  model Speed Reduction =    Day_1 Precip Su F R S Visibility;
run;
```

APPENDIX C

SAS OUTPUTS

CHI-SQUARE TEST IN WESTBOUND DIRECTION BETWEEN SPEED AND WEATHER FACTORS

```
      The FREQ Procedure

    Table of Speed by Day_1

Speed     Day_1

Frequency|
Percent  |
Row Pct  |
Col Pct  |       0|       1|  Total
---------+--------+--------+
       1 |     89 |    355 |    444
         |   1.68 |   6.69 |   8.37
         |  20.05 |  79.95 |
         |   3.48 |  12.92 |
---------+--------+--------+
       2 |    128 |    591 |    719
         |   2.41 |  11.14 |  13.56
         |  17.80 |  82.20 |
         |   5.01 |  21.51 |
---------+--------+--------+
       3 |    658 |    664 |   1322
         |  12.41 |  12.52 |  24.92
         |  49.77 |  50.23 |
         |  25.73 |  24.17 |
---------+--------+--------+
       4 |   1201 |    980 |   2181
         |  22.64 |  18.48 |  41.12
         |  55.07 |  44.93 |
         |  46.97 |  35.68 |
---------+--------+--------+
       5 |    481 |    157 |    638
         |   9.07 |   2.96 |  12.03
         |  75.39 |  24.61 |
         |  18.81 |   5.72 |
---------+--------+--------+
Total        2557     2747     5304
            48.21    51.79   100.00
```

The FREQ Procedure

Statistics for Table of Speed by Day_1

Statistic	DF	Value	Prob
Chi-square	4	638.4826	<.0001
Likelihood Ratio Chi-square	4	681.9243	<.0001
Mantel-Haenszel Chi-square	1	566.6384	<.0001
Phi Coefficient		0.3470	
Contingency Coefficient		0.3278	
Cramer's V		0.3470	

Sample Size = 5304

***Note: Column headings : 0 = Nighttime 1 = Daytime

Row Headings: 1 = Speed < 60km/hr 2= Speed 60-80 k,/hr

3 = Speed 80-90km/hr4 = Speed 90-100 km/hr

5 = Speed >100 km/hr

The FREQ Procedure

Table of Speed by Precip

Speed Precip

Frequency,
Percent |
Row Pct |
Col Pct |

Speed	1	2	3	Total
1	292	149	3	444
	5.51	2.81	0.06	8.37
	65.77	33.56	0.68	
	7.90	9.55	6.25	
2	460	254	5	719
	8.67	4.79	0.09	13.56
	63.98	35.33	0.70	
	12.45	16.28	10.42	
3	938	375	9	1322
	17.68	7.07	0.17	24.92
	70.95	28.37	0.68	
	25.38	24.04	18.75	
4	1513	644	24	2181
	28.53	12.14	0.45	41.12
	69.37	29.53	1.10	
	40.94	41.28	50.00	
5	493	138	7	638
	9.29	2.60	0.13	12.03
	77.27	21.63	1.10	
	13.34	8.85	14.58	
Total	3696	1560	48	5304
	69.68	29.41	0.90	100.00

The FREQ Procedure

Statistics for Table of Speed by Precip

Statistic	DF	Value	Prob
Chi-square	8	37.2547	<.0001
Likelihood Ratio Chi-square	8	37.9455	<.0001
Mantel-Haenszel Chi-square	1	15.7939	<.0001
Phi Coefficient		0.0838	
Contingency Coefficient		0.0835	
Cramer's V		0.0593	

Sample Size = 5304

***Note: Column headings: 1 = No precipitation 2 = 0-5 mm/hr 3 = >5 mm/hr

Row Headings: 1 = Speed < 60km/hr 2= Speed 60-80 k,/hr

3 = Speed 80-90km/hr4 = Speed 90-100 km/hr

5 = Speed >100 km/hr

The FREQ Procedure

Table of Speed by Visibility

Speed Visibility

Frequency|
Percent |
Row Pct |
Col Pct |

Speed	1	2	3	Total
1	33	52	359	444
	0.62	0.98	6.77	8.37
	7.43	11.71	80.86	
	7.07	8.77	8.46	
2	37	84	598	719
	0.70	1.58	11.27	13.56
	5.15	11.68	83.17	
	7.92	14.17	14.09	
3	133	167	1022	1322
	2.51	3.15	19.27	24.92
	10.06	12.63	77.31	
	28.48	28.16	24.08	
4	207	251	1723	2181
	3.90	4.73	32.48	41.12
	9.49	11.51	79.00	
	44.33	42.33	40.60	
5	57	39	542	638
	1.07	0.74	10.22	12.03
	8.93	6.11	84.95	
	12.21	6.58	12.77	
Total	467	593	4244	5304
	8.80	11.18	80.02	100.00

The FREQ Procedure

Statistics for Table of Speed by Visibility

Statistic	DF	Value	Prob
Chi-square	8	37.4298	<.0001
Likelihood Ratio Chi-square	8	42.0579	<.0001
Mantel-Haenszel Chi-square	1	0.7854	0.3755
Phi Coefficient		0.0840	
Contingency Coefficient		0.0837	
Cramer's V		0.0594	

Sample Size = 5304

***Note: Column headings: 1 = 0-5 km 2 = 5-10km 3 = 10-15km

Row Headings: 1 = Speed < 60km/hr 2= Speed 60-80 k,/hr

3 = Speed 80-90km/hr4 = Speed 90-100 km/hr

5 = Speed >100 km/hr

The FREQ Procedure

Table of Speed by Season

Speed	Frequency / Percent / Row Pct / Col Pct	F	Spr	Su	W	Total
1	Frequency	144	79	111	110	444
	Percent	2.71	1.49	2.09	2.07	8.37
	Row Pct	32.43	17.79	25.00	24.77	
	Col Pct	11.34	7.16	6.64	8.74	
2	Frequency	138	155	255	171	719
	Percent	2.60	2.92	4.81	3.22	13.56
	Row Pct	19.19	21.56	35.47	23.78	
	Col Pct	10.87	14.04	15.25	13.59	
3	Frequency	305	267	441	309	1322
	Percent	5.75	5.03	8.31	5.83	24.92
	Row Pct	23.07	20.20	33.36	23.37	
	Col Pct	24.02	24.18	26.38	24.56	
4	Frequency	504	486	695	496	2181
	Percent	9.50	9.16	13.10	9.35	41.12
	Row Pct	23.11	22.28	31.87	22.74	
	Col Pct	39.69	44.02	41.57	39.43	
5	Frequency	179	117	170	172	638
	Percent	3.37	2.21	3.21	3.24	12.03
	Row Pct	28.06	18.34	26.65	26.96	
	Col Pct	14.09	10.60	10.17	13.67	
Total		1270	1104	1672	1258	5304
		23.94	20.81	31.52	23.72	100.00

The FREQ Procedure

Statistics for Table of Speed by Season

Statistic	DF	Value	Prob
Chi-square	12	52.0475	<.0001
Likelihood Ratio Chi-square	12	51.5587	<.0001
Mantel-Haenszel Chi-square	1	0.0006	0.9801
Phi Coefficient		0.0991	
Contingency Coefficient		0.0986	
Cramer's V		0.0572	

Sample Size = 5304

***Note: Column headings: F = Fall Season Spr = Spring Su = Summer
W = Winter

Row Headings: 1 = Speed < 60km/hr 2= Speed 60-80 k,/hr
3 = Speed 80-90km/hr4 = Speed 90-100 km/hr
5 = Speed >100 km/hr

The FREQ Procedure

Table of Speed by Weather

```
Speed     Weather

Frequency|
Percent  |
Row Pct  |
Col Pct  |C       |R       |S       |  Total
---------+--------+--------+--------+
       1 |    384 |     48 |     12 |    444
         |   7.24 |   0.90 |   0.23 |   8.37
         |  86.49 |  10.81 |   2.70 |
         |   8.08 |  10.86 |  11.01 |
---------+--------+--------+--------+
       2 |    624 |     70 |     25 |    719
         |  11.76 |   1.32 |   0.47 |  13.56
         |  86.79 |   9.74 |   3.48 |
         |  13.13 |  15.84 |  22.94 |
---------+--------+--------+--------+
       3 |   1142 |    156 |     24 |   1322
         |  21.53 |   2.94 |   0.45 |  24.92
         |  86.38 |  11.80 |   1.82 |
         |  24.03 |  35.29 |  22.02 |
---------+--------+--------+--------+
       4 |   1992 |    149 |     40 |   2181
         |  37.56 |   2.81 |   0.75 |  41.12
         |  91.33 |   6.83 |   1.83 |
         |  41.91 |  33.71 |  36.70 |
---------+--------+--------+--------+
       5 |    611 |     19 |      8 |    638
         |  11.52 |   0.36 |   0.15 |  12.03
         |  95.77 |   2.98 |   1.25 |
         ,  12.86 ,   4.30 ,   7.34 ,
---------+--------+--------+--------+
Total        4753      442      109     5304
            89.61     8.33     2.06   100.00
```

The FREQ Procedure

Statistics for Table of Speed by Weather

Statistic	DF	Value	Prob
Chi-square	8	68.8360	<.0001
Likelihood Ratio Chi-square	8	72.9441	<.0001
Mantel-Haenszel Chi-square	1	38.5698	<.0001
Phi Coefficient		0.1139	
Contingency Coefficient		0.1132	
Cramer's V		0.0806	

Sample Size = 5304

***Note: Column headings: C= Clear R = Rain S = Snow

Row Headings: 1 = Speed < 60km/hr 2= Speed 60-80 k,/hr

3 = Speed 80-90km/hr4 = Speed 90-100 km/hr

5 = Speed >100 km/hr

CHI-SQUARE TEST IN WESTBOUND DIRECTION BETWEEN SPEED REDUCTION AND WEATHER FACTORS

```
        The FREQ Procedure

      Table of Speed Reduction by Day_1

Speed Reduction     Day_1

Frequency|
Percent  |
Row Pct  |
Col Pct  |       0|       1|  Total
---------+--------+--------+
       1 |   1208 |   1717 |   2925
         |  22.78 |  32.37 |  55.15
         |  41.30 |  58.70 |
         |  47.24 |  62.50 |
---------+--------+--------+
       2 |    586 |    355 |    941
         |  11.05 |   6.69 |  17.74
         |  62.27 |  37.73 |
         |  22.92 |  12.92 |
---------+--------+--------+
       3 |    233 |    186 |    419
         |   4.39 |   3.51 |   7.90
         |  55.61 |  44.39 |
         |   9.11 |   6.77 |
---------+--------+--------+
       4 |    530 |    489 |   1019
         |   9.99 |   9.22 |  19.21
         |  52.01 |  47.99 |
         |  20.73 |  17.80 |
---------+--------+--------+
Total        2557     2747     5304
            48.21    51.79   100.00
```

Statistics for Table of Speed Reduction by Day_1

Statistic	DF	Value	Prob
Chi-square	3	145.5838	<.0001
Likelihood Ratio Chi-square	3	146.4433	<.0001
Mantel-Haenszel Chi-square	1	52.3610	<.0001
Phi Coefficient		0.1657	
Contingency Coefficient		0.1634	
Cramer's V		0.1657	

Sample Size = 5304

***Note: Column headings: 0 = Nighttime 1 = Daytime

Row Headings: 1 = No Speed Reduction 2= Speed Reduction 0-5 km/hr

3 = Speed Reduction 5-10 km/hr 4 = Speed Reduction > 10km/hr

The FREQ Procedure

Table of Speed Reduction by Precip

Speed Reduction / Frequency / Percent / Row Pct / Col Pct	Precip 1	2	3	Total
1	2182	716	27	2925
	41.14	13.50	0.51	55.15
	74.60	24.48	0.92	
	59.04	45.90	56.25	
2	608	322	11	941
	11.46	6.07	0.21	17.74
	64.61	34.22	1.17	
	16.45	20.64	22.92	
3	259	156	4	419
	4.88	2.94	0.08	7.90
	61.81	37.23	0.95	
	7.01	10.00	8.33	
4	647	366	6	1019
	12.20	6.90	0.11	19.21
	63.49	35.92	0.59	
	17.51	23.46	12.50	
Total	3696	1560	48	5304
	69.68	29.41	0.90	100.00

Statistics for Table of Speed Reduction by Precip

Statistic	DF	Value	Prob
Chi-square	6	79.7820	<.0001
Likelihood Ratio Chi-square	6	79.5075	<.0001
Mantel-Haenszel Chi-square	1	51.0287	<.0001
Phi Coefficient		0.1226	
Contingency Coefficient		0.1217	
Cramer's V		0.0867	

Sample Size = 5304

***Note: Column headings: 1 = No precipitation 2 = 0-5 mm/hr

Row Headings: 1 = No Speed Reduction 2= Speed Reduction 0-5 km/hr

3 = Speed Reduction 5-10 km/hr 4 = Speed Reduction > 10km/hr

The FREQ Procedure

Table of Speed Reduction by Visibility

Speed Reduction Visibility

Speed Reduction	Frequency / Percent / Row Pct / Col Pct	1	2	3	Total
1	Frequency	207	291	2427	2925
	Percent	3.90	5.49	45.76	55.15
	Row Pct	7.08	9.95	82.97	
	Col Pct	44.33	49.07	57.19	
2	Frequency	87	115	739	941
	Percent	1.64	2.17	13.93	17.74
	Row Pct	9.25	12.22	78.53	
	Col Pct	18.63	19.39	17.41	
3	Frequency	54	48	317	419
	Percent	1.02	0.90	5.98	7.90
	Row Pct	12.89	11.46	75.66	
	Col Pct	11.56	8.09	7.47	
4	Frequency	119	139	761	1019
	Percent	2.24	2.62	14.35	19.21
	Row Pct	11.68	13.64	74.68	
	Col Pct	25.48	23.44	17.93	
Total	Frequency	467	593	4244	5304
	Percent	8.80	11.18	80.02	100.00

Statistics for Table of Speed Reduction by Visibility

Statistic	DF	Value	Prob
Chi-square	6	46.1183	<.0001
Likelihood Ratio Chi-square	6	44.7622	<.0001
Mantel-Haenszel Chi-square	1	41.0369	<.0001
Phi Coefficient		0.0932	
Contingency Coefficient		0.0928	
Cramer's V		0.0659	

Sample Size = 5304

***Note: Column headings: 1 = 0-5 km   2 = 5-10km   3 = 10-15km

Row Headings: 1 = No Speed Reduction   2= Speed Reduction 0-5 km/hr
3 = Speed Reduction 5-10 km/hr   4 = Speed Reduction > 10km/hr

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```
The FREQ Procedure

Table of Speed Reduction by Season

Speed Reduction     Season

Frequency|
Percent  |
Row Pct  |
Col Pct  |F       |Spr     |Su      |W       |  Total
---------+--------+--------+--------+--------+
       1 |    659 |    642 |    926 |    698 |   2925
         |  12.42 |  12.10 |  17.46 |  13.16 |  55.15
         |  22.53 |  21.95 |  31.66 |  23.86 |
         |  51.89 |  58.15 |  55.38 |  55.48 |
---------+--------+--------+--------+--------+
       2 |    247 |    173 |    302 |    219 |    941
         |   4.66 |   3.26 |   5.69 |   4.13 |  17.74
         |  26.25 |  18.38 |  32.09 |  23.27 |
         |  19.45 |  15.67 |  18.06 |  17.41 |
---------+--------+--------+--------+--------+
       3 |     98 |     76 |    117 |    128 |    419
         |   1.85 |   1.43 |   2.21 |   2.41 |   7.90
         |  23.39 |  18.14 |  27.92 |  30.55 |
         |   7.72 |   6.88 |   7.00 |  10.17 |
---------+--------+--------+--------+--------+
       4 |    266 |    213 |    327 |    213 |   1019
         |   5.02 |   4.02 |   6.17 |   4.02 |  19.21
         |  26.10 |  20.90 |  32.09 |  20.90 |
         |  20.94 |  19.29 |  19.56 |  16.93 |
---------+--------+--------+--------+--------+
Total        1270     1104     1672     1258     5304
            23.94    20.81    31.52    23.72   100.00
```

Statistics for Table of Speed Reduction by Season

Statistic	DF	Value	Prob
Chi-square	9	26.1847	0.0019
Likelihood Ratio Chi-square	9	25.7763	0.0022
Mantel-Haenszel Chi-square	1	2.7649	0.0964
Phi Coefficient		0.0703	
Contingency Coefficient		0.0701	
Cramer's V		0.0406	

Sample Size = 5304

***Note: Column headings: F = Fall Season Spr = Spring Su = Summer W = Winter

Row Headings: 1 = No Speed Reduction 2= Speed Reduction 0-5 km/hr 3 = Speed Reduction 5-10 km/hr 4 = Speed Reduction > 10km/hr

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The FREQ Procedure

Table of Speed Reduction by Weather

Speed Reduction   Weather

Frequency|
Percent |
Row Pct |
Col Pct |

Speed Reduction	C	R	S	Total
1	2745	146	34	2925
	51.75	2.75	0.64	55.15
	93.85	4.99	1.16	
	57.75	33.03	31.19	
2	823	93	25	941
	15.52	1.75	0.47	17.74
	87.46	9.88	2.66	
	17.32	21.04	22.94	
3	348	59	12	419
	6.56	1.11	0.23	7.90
	83.05	14.08	2.86	
	7.32	13.35	11.01	
4	837	144	38	1019
	15.78	2.71	0.72	19.21
	82.14	14.13	3.73	
	17.61	32.58	34.86	
Total	4753	442	109	5304
	89.61	8.33	2.06	100.00

Statistics for Table of Speed Reduction by Weather

Statistic	DF	Value	Prob
Chi-square	6	142.5609	<.0001
Likelihood Ratio Chi-square	6	138.2608	<.0001
Mantel-Haenszel Chi-square	1	121.7829	<.0001
Phi Coefficient		0.1639	
Contingency Coefficient		0.1618	
Cramer's V		0.1159	

Sample Size = 5304

***Note: Column headings: C= Clear R = Rain S = Snow

Row Headings: 1 = No Speed Reduction 2= Speed Reduction 0-5 km/hr

3 = Speed Reduction 5-10 km/hr 4 = Speed Reduction > 10km/hr

CHI-SQUARE TEST IN EASTBOUND DIRECTION BETWEEN SPEED AND WEATHER FACTORS

The FREQ Procedure

Table of Speed by Day_1

```
Speed     Day_1
Frequency|
Percent  |
Row Pct  |
Col Pct  |       0|       1|  Total
---------+--------+--------+
       1 |     73 |    486 |    559
         |   1.38 |   9.16 |  10.54
         |  13.06 |  86.94 |
         |   2.85 |  17.69 |
---------+--------+--------+
       2 |    460 |    500 |    960
         |   8.67 |   9.43 |  18.10
         |  47.92 |  52.08 |
         |  17.99 |  18.20 |
---------+--------+--------+
       3 |    965 |   1237 |   2202
         |  18.19 |  23.32 |  41.52
         |  43.82 |  56.18 |
         |  37.74 |  45.03 |
---------+--------+--------+
       4 |   1059 |    524 |   1583
         |  19.97 |   9.88 |  29.85
         |  66.90 |  33.10 |
         |  41.42 |  19.08 |
---------+--------+--------+
Total        2557     2747     5304
            48.21    51.79   100.00
```

Statistics for Table of Speed by Day_1

Statistic	DF	Value	Prob
Chi-square	3	515.0641	<.0001
Likelihood Ratio Chi-square	3	554.6708	<.0001
Mantel-Haenszel Chi-square	1	404.7343	<.0001
Phi Coefficient		0.3116	
Contingency Coefficient		0.2975	
Cramer's V		0.3116	

Sample Size = 5304

***Note: Column headings : 0 = Nighttime 1 = Daytime

Row Headings: 1 = Speed < 60km/hr 2= Speed 60-80 k,/hr 3 = Speed 80-90km/hr

4 = Speed 90-100 km/hr 5 = Speed >100 km/hr

The FREQ Procedure

Table of Speed by Precip

Speed Precip

Frequency Percent Row Pct Col Pct	1	2	3	Total
1	338	207	14	559
	6.37	3.90	0.26	10.54
	60.47	37.03	2.50	
	9.15	13.27	29.17	
2	594	354	12	960
	11.20	6.67	0.23	18.10
	61.88	36.88	1.25	
	16.07	22.69	25.00	
3	1580	612	10	2202
	29.79	11.54	0.19	41.52
	71.75	27.79	0.45	
	42.75	39.23	20.83	
4	1184	387	12	1583
	22.32	7.30	0.23	29.85
	74.79	24.45	0.76	
	32.03	24.81	25.00	
Total	3696	1560	48	5304
	69.68	29.41	0.90	100.00

Statistics for Table of Speed by Precip

Statistic	DF	Value	Prob
Chi-square	6	89.3336	<.0001
Likelihood Ratio Chi-square	6	84.2974	<.0001
Mantel-Haenszel Chi-square	1	72.3833	<.0001
Phi Coefficient		0.1298	
Contingency Coefficient		0.1287	
Cramer's V		0.0918	

Sample Size = 5304

***Note:	Column headings :	1 = No precipitation	2 = 0-5 mm/hr	3 = >5 mm/hr
	Row Headings:	1 = Speed < 60km/hr	2= Speed 60-80 k,/hr	3 = Speed 80-90km/hr
		4 = Speed 90-100 km/hr	5 = Speed >100 km/hr	

The FREQ Procedure

Table of Speed by Visibility

Speed \ Visibility (Frequency / Percent / Row Pct / Col Pct)	1	2	3	Total
1	76	64	419	559
	1.43	1.21	7.90	10.54
	13.60	11.45	74.96	
	16.27	10.79	9.87	
2	113	126	721	960
	2.13	2.38	13.59	18.10
	11.77	13.13	75.10	
	24.20	21.25	16.99	
3	196	269	1737	2202
	3.70	5.07	32.75	41.52
	8.90	12.22	78.88	
	41.97	45.36	40.93	
4	82	134	1367	1583
	1.55	2.53	25.77	29.85
	5.18	8.46	86.36	
	17.56	22.60	32.21	
Total	467	593	4244	5304
	8.80	11.18	80.02	100.00

Statistics for Table of Speed by Visibility

Statistic	DF	Value	Prob
Chi-square	6	76.6335	<.0001
Likelihood Ratio Chi-square	6	78.3773	<.0001
Mantel-Haenszel Chi-square	1	65.4013	<.0001
Phi Coefficient		0.1202	
Contingency Coefficient		0.1193	
Cramer's V		0.0850	

Sample Size = 5304

***Note: Column headings : 1 = 0-5 km 2 = 5-10km 3 = 10-15km

Row Headings: 1 = Speed < 60km/hr 2= Speed 60-80 k,/hr 3 = Speed 80-90km/hr 4 = Speed 90-100 km/hr 5 = Speed >100 km/hr

The FREQ Procedure

Table of Speed by Season

Speed Season

Speed	Frequency / Percent / Row Pct / Col Pct	F	Spr	Su	W	Total
1	Frequency	132	129	157	141	559
	Percent	2.49	2.43	2.96	2.66	10.54
	Row Pct	23.61	23.08	28.09	25.22	
	Col Pct	10.39	11.68	9.39	11.21	
2	Frequency	227	199	303	231	960
	Percent	4.28	3.75	5.71	4.36	18.10
	Row Pct	23.65	20.73	31.56	24.06	
	Col Pct	17.87	18.03	18.12	18.36	
3	Frequency	493	455	699	555	2202
	Percent	9.29	8.58	13.18	10.46	41.52
	Row Pct	22.39	20.66	31.74	25.20	
	Col Pct	38.82	41.21	41.81	44.12	
4	Frequency	418	321	513	331	1583
	Percent	7.88	6.05	9.67	6.24	29.85
	Row Pct	26.41	20.28	32.41	20.91	
	Col Pct	32.91	29.08	30.68	26.31	
Total		1270	1104	1672	1258	5304
		23.94	20.81	31.52	23.72	100.00

Statistics for Table of Speed by Season

Statistic	DF	Value	Prob
Chi-square	9	18.3317	0.0315
Likelihood Ratio Chi-square	9	18.4511	0.0303
Mantel-Haenszel Chi-square	1	2.6477	0.1037
Phi Coefficient		0.0588	
Contingency Coefficient		0.0587	
Cramer's V		0.0339	

Sample Size = 5304

***Note: Column headings : F = Fall Season Spr = Spring Su = Summer W = Winter

Row Headings: 1 = Speed < 60km/hr 2= Speed 60-80 k,/hr 3 = Speed 80-90km/hr 4 = Speed 90-100 km/hr 5 = Speed >100 km/hr

The FREQ Procedure

Table of Speed by Weather

Speed / Weather (Frequency, Percent, Row Pct, Col Pct)	C	R	S	Total
1	466	70	23	559
	8.79	1.32	0.43	10.54
	83.36	12.52	4.11	
	9.80	15.84	21.10	
2	791	144	25	960
	14.91	2.71	0.47	18.10
	82.40	15.00	2.60	
	16.64	32.58	22.94	
3	2003	174	25	2202
	37.76	3.28	0.47	41.52
	90.96	7.90	1.14	
	42.14	39.37	22.94	
4	1493	54	36	1583
	28.15	1.02	0.68	29.85
	94.31	3.41	2.27	
	31.41	12.22	33.03	
Total	4753	442	109	5304
	89.61	8.33	2.06	100.00

Statistics for Table of Speed by Weather

Statistic	DF	Value	Prob
Chi-square	6	144.2327	<.0001
Likelihood Ratio Chi-square	6	145.2493	<.0001
Mantel-Haenszel Chi-square	1	80.0184	<.0001
Phi Coefficient		0.1649	
Contingency Coefficient		0.1627	
Cramer's V		0.1166	

Sample Size = 5304

***Note: Column headings : C= Clear R = Rain S = Snow

Row Headings: 1 = Speed < 60km/hr 2= Speed 60-80 k,/hr 3 = Speed 80-90km/hr

4 = Speed 90-100 km/hr 5 = Speed >100 km/hr

CHI-SQUARE TEST IN EASTBOUND DIRECTION BETWEEN SPEED REDUCTION AND WEATHER FACTORS

The FREQ Procedure

Table of Speed Reduction by Day_1

Speed Reduction	Day_1: Frequency / Percent / Row Pct / Col Pct	0	1	Total
1	Frequency	723	1366	2089
	Percent	13.63	25.75	39.39
	Row Pct	34.61	65.39	
	Col Pct	28.28	49.73	
2	Frequency	342	238	580
	Percent	6.45	4.49	10.94
	Row Pct	58.97	41.03	
	Col Pct	13.38	8.66	
3	Frequency	351	265	616
	Percent	6.62	5.00	11.61
	Row Pct	56.98	43.02	
	Col Pct	13.73	9.65	
4	Frequency	1141	878	2019
	Percent	21.51	16.55	38.07
	Row Pct	56.51	43.49	
	Col Pct	44.62	31.96	
Total		2557	2747	5304
		48.21	51.79	100.00

Statistics for Table of Speed Reduction by Day_1

Statistic	DF	Value	Prob
Chi-square	3	256.3538	<.0001
Likelihood Ratio Chi-square	3	259.5115	<.0001
Mantel-Haenszel Chi-square	1	190.3537	<.0001
Phi Coefficient		0.2198	
Contingency Coefficient		0.2147	
Cramer's V		0.2198	

Sample Size = 5304

***Note: Column headings : 0 = Nighttime 1 = Daytime

Row Headings: 1 = No Speed Reduction 2= Speed Reduction 0-5 km/hr

3 = Speed Reduction 5-10 km/hr 4 = Speed Reduction > 10km/hr

The FREQ Procedure

Table of Speed Reduction by Precip

Speed Reduction	Frequency / Percent / Row Pct / Col Pct	Precip 1	Precip 2	Precip 3	Total
1	Frequency	1542	534	13	2089
	Percent	29.07	10.07	0.25	39.39
	Row Pct	73.82	25.56	0.62	
	Col Pct	41.72	34.23	27.08	
2	Frequency	407	170	3	580
	Percent	7.67	3.21	0.06	10.94
	Row Pct	70.17	29.31	0.52	
	Col Pct	11.01	10.90	6.25	
3	Frequency	424	188	4	616
	Percent	7.99	3.54	0.08	11.61
	Row Pct	68.83	30.52	0.65	
	Col Pct	11.47	12.05	8.33	
4	Frequency	1323	668	28	2019
	Percent	24.94	12.59	0.53	38.07
	Row Pct	65.53	33.09	1.39	
	Col Pct	35.80	42.82	58.33	
Total		3696	1560	48	5304
		69.68	29.41	0.90	100.00

Statistics for Table of Speed Reduction by Precip

Statistic	DF	Value	Prob
Chi-square	6	38.6875	<.0001
Likelihood Ratio Chi-square	6	38.5406	<.0001
Mantel-Haenszel Chi-square	1	36.0881	<.0001
Phi Coefficient		0.0854	
Contingency Coefficient		0.0851	
Cramer's V		0.0604	

Sample Size = 5304

***Note: Column headings : 1 = No precipitation 2 = 0-5 mm/hr
Row Headings: 1 = No Speed Reduction 2= Speed Reduction 0-5 km/hr
3 = Speed Reduction 5-10 km/hr 4 = Speed Reduction > 10km/hr

The FREQ Procedure

Table of Speed Reduction by Visibility

Speed Reduction: rows; Visibility: columns. Cells: Frequency / Percent / Row Pct / Col Pct

Speed Reduction		1	2	3	Total
1	Frequency	97	221	1771	2089
	Percent	1.83	4.17	33.39	39.39
	Row Pct	4.64	10.58	84.78	
	Col Pct	20.77	37.27	41.73	
2	Frequency	30	57	493	580
	Percent	0.57	1.07	9.29	10.94
	Row Pct	5.17	9.83	85.00	
	Col Pct	6.42	9.61	11.62	
3	Frequency	64	71	481	616
	Percent	1.21	1.34	9.07	11.61
	Row Pct	10.39	11.53	78.08	
	Col Pct	13.70	11.97	11.33	
4	Frequency	276	244	1499	2019
	Percent	5.20	4.60	28.26	38.07
	Row Pct	13.67	12.09	74.24	
	Col Pct	59.10	41.15	35.32	
Total		467	593	4244	5304
		8.80	11.18	80.02	100.00

Statistics for Table of Speed Reduction by Visibility

Statistic	DF	Value	Prob
Chi-square	6	125.3975	<.0001
Likelihood Ratio Chi-square	6	127.6384	<.0001
Mantel-Haenszel Chi-square	1	111.7694	<.0001
Phi Coefficient		0.1538	
Contingency Coefficient		0.1520	
Cramer's V		0.1087	

Sample Size = 5304

***Note: Column headings : 1 = 0-5 km 2 = 5-10km 3 = 10-15km

Row Headings: 1 = No Speed Reduction 2= Speed Reduction 0-5 km/hr 3 = Speed Reduction 5-10 km/hr 4 = Speed Reduction > 10km/hr

The FREQ Procedure

Table of Speed Reduction by Season

Speed Reduction / Frequency / Percent / Row Pct / Col Pct	F	Spr	Su	W	Total
1	472	394	781	442	2089
	8.90	7.43	14.72	8.33	39.39
	22.59	18.86	37.39	21.16	
	37.17	35.69	46.71	35.14	
2	161	156	167	96	580
	3.04	2.94	3.15	1.81	10.94
	27.76	26.90	28.79	16.55	
	12.68	14.13	9.99	7.63	
3	168	123	115	210	616
	3.17	2.32	2.17	3.96	11.61
	27.27	19.97	18.67	34.09	
	13.23	11.14	6.88	16.69	
4	469	431	609	510	2019
	8.84	8.13	11.48	9.62	38.07
	23.23	21.35	30.16	25.26	
	36.93	39.04	36.42	40.54	
Total	1270	1104	1672	1258	5304
	23.94	20.81	31.52	23.72	100.00

Statistics for Table of Speed Reduction by Season

Statistic	DF	Value	Prob
Chi-square	9	128.9437	<.0001
Likelihood Ratio Chi-square	9	130.5934	<.0001
Mantel-Haenszel Chi-square	1	0.5993	0.4389
Phi Coefficient		0.1559	
Contingency Coefficient		0.1541	
Cramer's V		0.0900	

Sample Size = 5304

***Note: Column headings : F = Fall Season Spr = Spring Su = Summer W = Winter

Row Headings: 1 = No Speed Reduction 2= Speed Reduction 0-5 km/hr
3 = Speed Reduction 5-10 km/hr 4 = Speed Reduction > 10km/hr

The FREQ Procedure

Table of Speed Reduction by Weather

Speed Reduction / Frequency / Percent / Row Pct / Col Pct	C	R	S	Total
1	1933	131	25	2089
	36.44	2.47	0.47	39.39
	92.53	6.27	1.20	
	40.67	29.64	22.94	
2	526	38	16	580
	9.92	0.72	0.30	10.94
	90.69	6.55	2.76	
	11.07	8.60	14.68	
3	558	46	12	616
	10.52	0.87	0.23	11.61
	90.58	7.47	1.95	
	11.74	10.41	11.01	
4	1736	227	56	2019
	32.73	4.28	1.06	38.07
	85.98	11.24	2.77	
	36.52	51.36	51.38	
Total	4753	442	109	5304

89.61 8.33 2.06 100.00

Statistics for Table of Speed Reduction by Weather

Statistic	DF	Value	Prob
Chi-square	6	53.0288	<.0001
Likelihood Ratio Chi-square	6	52.9058	<.0001
Mantel-Haenszel Chi-square	1	42.8940	<.0001
Phi Coefficient		0.1000	
Contingency Coefficient		0.0995	
Cramer's V		0.0707	

Sample Size = 5304

***Note:	Column headings:	C= Clear	R = Rain	S = Snow
	Row Headings:	1 = No Speed Reduction	2= Speed Reduction 0-5 km/hr	
		3 = Speed Reduction 5-10 km/hr	4 = Speed Reduction > 10km/hr	

ORDERED LOGISTIC REGRESSION IN WESTBOUND DIRECTION BETWEEN SPEED REDUCTION AND WEATHER FACTORS – ALL PARAMETERS

The SAS System 1

The LOGISTIC Procedure

Model Information

Data Set	WORK.DELAY_WEATHER2
Response Variable	Delay
Number of Response Levels	4
Model	cumulative logit
Optimization Technique	Fisher's scoring

Number of Observations Read	5304
Number of Observations Used	5304

Response Profile

Ordered Value	Delay	Total Frequency
1	4	1019
2	3	419
3	2	941
4	1	2925

Probabilities modeled are cumulated over the lower Ordered Values.

Class Level Information

Class	Value	Design Variables		
Day_1	0	1		
	1	-1		
Precip	2	1		
	3	-1		
Season	F	1	0	0
	Spr	0	1	0

	Su	0	0	1
	W	-1	-1	-1

Weather	C	1	0
	R	0	1
	S	-1	-1
Visibility	1	1	0
	2	0	1
	3	-1	-1

The SAS System 2

The LOGISTIC Procedure

Model Convergence Status

Convergence criterion (GCONV=1E-8) satisfied.

Score Test for the Proportional Odds Assumption

Chi-Square	DF	Pr > ChiSq
89.9284	18	<.0001

Model Fit Statistics

Criterion	Intercept Only	Intercept and Covariates
AIC	12231.317	12019.628
SC	12251.046	12098.543
-2 Log L	12225.317	11995.628

Testing Global Null Hypothesis: BETA=0

Test	Chi-Square	DF	Pr > ChiSq
Likelihood Ratio	229.6887	9	<.0001
Score	236.1018	9	<.0001
Wald	221.3869	9	<.0001

Type 3 Analysis of Effects

Effect	DF	Wald Chi-Square	Pr > ChiSq
Day_1	1	79.6452	<.0001
Precip	1	0.0937	0.7596
Season	3	7.0550	0.0702
Weather	2	105.2705	<.0001
Visibility	2	5.5770	0.0615

The SAS System 3

The LOGISTIC Procedure

Analysis of Maximum Likelihood Estimates

Parameter		DF	Estimate	Standard Error	Wald Chi-Square	Pr > ChiSq
Intercept	4	1	-0.9212	0.1588	33.6579	<.0001
Intercept	3	1	-0.4627	0.1583	8.5483	0.0035
Intercept	2	1	0.3515	0.1582	4.9348	0.0263
Day_1	0	1	0.2388	0.0268	79.6452	<.0001
Precip	2	1	0.0438	0.1430	0.0937	0.7596
Season	F	1	0.1218	0.0465	6.8600	0.0088
Season	Spr	1	-0.0686	0.0497	1.9033	0.1677
Season	Su	1	-0.0256	0.0431	0.3522	0.5529
Weather	C	1	-0.6205	0.0693	80.1268	<.0001
Weather	R	1	0.2418	0.0845	8.1868	0.0042
Visibility	1	1	0.0940	0.0662	2.0156	0.1557
Visibility	2	1	0.0143	0.0641	0.0500	0.8230

Odds Ratio Estimates

Effect		Point Estimate	95% Wald Confidence Limits	
Day_1	0 vs 1	1.612	1.452	1.791
Precip	2 vs 3	1.092	0.623	1.912
Season	F vs W	1.161	0.999	1.350
Season	Spr vs W	0.960	0.820	1.124
Season	Su vs W	1.002	0.869	1.155

Weather	C vs S	0.368	0.260	0.522
Weather	R vs S	0.872	0.593	1.282
Visibility	1 vs 3	1.224	1.015	1.476
Visibility	2 vs 3	1.130	0.946	1.351

Association of Predicted Probabilities and Observed Responses

Percent Concordant	54.5	Somers' D	0.184
Percent Discordant	36.2	Gamma	0.202
Percent Tied	9.3	Tau-a	0.114
Pairs	8738694	c	0.592

ORDERED LOGISTIC REGRESSION IN WESTBOUND DIRECTION BETWEEN SPEED REDUCTION AND WEATHER FACTORS – SIGNIFICANT PARAMETERS

The SAS System 4

The LOGISTIC Procedure

Model Information

Data Set	WORK.DELAY_WEATHER2
Response Variable	Delay
Number of Response Levels	4
Model	cumulative logit
Optimization Technique	Fisher's scoring

Number of Observations Read	5304
Number of Observations Used	5304

Response Profile

Ordered Value	Delay	Total Frequency
1	4	1019
2	3	419
3	2	941
4	1	2925

Probabilities modeled are cumulated over the lower Ordered Values.

Class Level Information

Class	Value	Design Variables
Day_1	0	1
	1	-1

Model Convergence Status

Convergence criterion (GCONV=1E-8) satisfied.

Score Test for the Proportional Odds Assumption

Chi-Square	DF	Pr > ChiSq
70.5721	8	<.0001

The SAS System 5

The LOGISTIC Procedure

Model Fit Statistics

Criterion	Intercept Only	Intercept and Covariates
AIC	12231.317	12015.672
SC	12251.046	12061.705
-2 Log L	12225.317	12001.672

Testing Global Null Hypothesis: BETA=0

Test	Chi-Square	DF	Pr > ChiSq
Likelihood Ratio	223.6453	4	<.0001
Score	230.2795	4	<.0001
Wald	215.8967	4	<.0001

Type 3 Analysis of Effects

Effect	DF	Wald Chi-Square	Pr > ChiSq
Day_1	1	82.7095	<.0001
F	1	6.7792	0.0092
C	1	33.3149	<.0001
R	1	0.2144	0.6433

Analysis of Maximum Likelihood Estimates

Parameter		DF	Estimate	Standard Error	Wald Chi-Square	Pr > ChiSq
Intercept	4	1	-0.5963	0.1761	11.4714	0.0007
Intercept	3	1	-0.1384	0.1758	0.6199	0.4311
Intercept	2	1	0.6748	0.1761	14.6938	0.0001
Day_1	0	1	0.2424	0.0267	82.7095	<.0001
F		1	0.1607	0.0617	6.7792	0.0092
C		1	-1.0241	0.1774	33.3149	<.0001
R		1	-0.0904	0.1953	0.2144	0.6433

The SAS System 6

The LOGISTIC Procedure

Odds Ratio Estimates

Effect	Point Estimate	95% Wald Confidence Limits	
Day_1 0 vs 1	1.624	1.463	1.803
F	1.174	1.041	1.325
C	0.359	0.254	0.508
R	0.914	0.623	1.340

Association of Predicted Probabilities and Observed Responses

Percent Concordant	47.1	Somers' D	0.182
Percent Discordant	28.8	Gamma	0.240
Percent Tied	24.1	Tau-a	0.113
Pairs	8738694	c	0.591

The SAS System 7

ORDERED LOGISTIC REGRESSION IN WESTBOUND DIRECTION BETWEEN SPEED REDUCTION AND WEATHER FACTORS – FINAL MODEL

The LOGISTIC Procedure

Model Information

Data Set	WORK.DELAY_WEATHER2
Response Variable	Delay
Number of Response Levels	4
Model	cumulative logit
Optimization Technique	Fisher's scoring

Number of Observations Read	5304
Number of Observations Used	5304

Response Profile

Ordered Value	Delay	Total Frequency
1	4	1019
2	3	419
3	2	941
4	1	2925

Probabilities modeled are cumulated over the lower Ordered Values.

Class Level Information

Class	Value	Design Variables
Day_1	0	1
	1	-1

Model Convergence Status

Convergence criterion (GCONV=1E-8) satisfied.

Score Test for the Proportional Odds Assumption

Chi-Square	DF	Pr > ChiSq
69.7251	6	<.0001

The LOGISTIC Procedure

Model Fit Statistics

Criterion	Intercept Only	Intercept and Covariates
AIC	12231.317	12013.893
SC	12251.046	12053.350
-2 Log L	12225.317	12001.893

Testing Global Null Hypothesis: BETA=0

Test	Chi-Square	DF	Pr > ChiSq
Likelihood Ratio	223.4245	3	<.0001
Score	230.0919	3	<.0001
Wald	215.6667	3	<.0001

Type 3 Analysis of Effects

Effect	DF	Wald Chi-Square	Pr > ChiSq
Day_1	1	82.6204	<.0001
F	1	6.7546	0.0094
C	1	130.8486	<.0001

Analysis of Maximum Likelihood Estimates

Parameter		DF	Estimate	Standard Error	Wald Chi-Square	Pr > ChiSq
Intercept	4	1	-0.6688	0.0808	68.5512	<.0001
Intercept	3	1	-0.2109	0.0800	6.9433	0.0084
Intercept	2	1	0.6023	0.0805	56.0081	<.0001
Day_1	0	1	0.2423	0.0267	82.6204	<.0001
F		1	0.1604	0.0617	6.7546	0.0094
C		1	-0.9515	0.0832	130.8486	<.0001

Odds Ratio Estimates

Effect	Point Estimate	95% Wald Confidence Limits	
Day_1 0 vs 1	1.623	1.462	1.802
F	1.174	1.040	1.325
C	0.386	0.328	0.455

The SAS System 9

The LOGISTIC Procedure

Association of Predicted Probabilities and Observed Responses

Percent Concordant	47.0	Somers' D	0.182
Percent Discordant	28.8	Gamma	0.240
Percent Tied	24.2	Tau-a	0.113
Pairs	8738694	c	0.591

ORDERED LOGISTIC REGRESSION IN EASTBOUND DIRECTION BETWEEN SPEED REDUCTION AND WEATHER FACTORS – ALL PARAMETERS

The SAS System 13

The LOGISTIC Procedure

Model Information

Data Set	WORK.DELAY_WEATHER2
Response Variable	Delay
Number of Response Levels	4
Model	cumulative logit
Optimization Technique	Fisher's scoring

Number of Observations Read	5304
Number of Observations Used	5304

Response Profile

Ordered Value	Delay	Total Frequency
1	4	2019
2	3	616
3	2	580
4	1	2089

Probabilities modeled are cumulated over the lower Ordered Values.

Class Level Information

Class	Value	Design Variables		
Day_1	0	1		
	1	-1		
Precip	2	1		
	3	-1		
Season	F	1	0	0

	Spr	0	1	0
	Su	0	0	1
	W	-1	-1	-1
Weather	C	1	0	
	R	0	1	
	S	-1	-1	
Visibility	1	1	0	
	2	0	1	
	3	-1	-1	

The SAS System 14

The LOGISTIC Procedure

Model Convergence Status

Convergence criterion (GCONV=1E-8) satisfied.

Score Test for the Proportional Odds Assumption

Chi-Square	DF	Pr > ChiSq
197.7450	18	<.0001

Model Fit Statistics

Criterion	Intercept Only	Intercept and Covariates
AIC	13018.855	12662.026
SC	13038.583	12740.940
-2 Log L	13012.855	12638.026

Testing Global Null Hypothesis: BETA=0

Test	Chi-Square	DF	Pr > ChiSq
Likelihood Ratio	374.8289	9	<.0001
Score	359.4120	9	<.0001

Wald	351.5341	9	<.0001

Type 3 Analysis of Effects

Effect	DF	Wald Chi-Square	Pr > ChiSq
Day_1	1	194.7650	<.0001
Precip	1	9.6247	0.0019
Season	3	45.6218	<.0001
Weather	2	22.0178	<.0001
Visibility	2	70.0342	<.0001

The LOGISTIC Procedure

Analysis of Maximum Likelihood Estimates

Parameter		DF	Estimate	Standard Error	Wald Chi-Square	Pr > ChiSq
Intercept	4	1	0.4392	0.1586	7.6659	0.0056
Intercept	3	1	0.9387	0.1590	34.8445	<.0001
Intercept	2	1	1.4135	0.1596	78.4083	<.0001
Day_1	0	1	0.3638	0.0261	194.7650	<.0001
Precip	2	1	-0.4397	0.1417	9.6247	0.0019
Season	F	1	-0.00363	0.0455	0.0064	0.9363
Season	Spr	1	0.0895	0.0478	3.5100	0.0610
Season	Su	1	-0.2645	0.0419	39.8341	<.0001
Weather	C	1	-0.3173	0.0723	19.2552	<.0001
Weather	R	1	0.0465	0.0889	0.2734	0.6011
Visibility	1	1	0.5255	0.0690	57.9939	<.0001
Visibility	2	1	-0.2175	0.0640	11.5284	0.0007

Odds Ratio Estimates

Effect	Point Estimate	95% Wald Confidence Limits	
Day_1 0 vs 1	2.070	1.869	2.293

Precip	2 vs 3	0.415	0.238	0.723
Season	F vs W	0.833	0.720	0.965
Season	Spr vs W	0.915	0.786	1.065
Season	Su vs W	0.642	0.559	0.737
Weather	C vs S	0.555	0.385	0.802
Weather	R vs S	0.799	0.532	1.201
Visibility	1 vs 3	2.301	1.893	2.797
Visibility	2 vs 3	1.095	0.919	1.304

Association of Predicted Probabilities and Observed Responses

Percent Concordant	58.1	Somers' D	0.237
Percent Discordant	34.4	Gamma	0.256
Percent Tied	7.5	Tau-a	0.160
Pairs	9488139	c	0.619

ORDERED LOGISTIC REGRESSION IN EASTBOUND DIRECTION BETWEEN SPEED REDUCTION AND WEATHER FACTORS – SIGNIFICANT PARAMETERS

The SAS System 16

The LOGISTIC Procedure

Model Information

Data Set	WORK.DELAY_WEATHER2
Response Variable	Delay
Number of Response Levels	4
Model	cumulative logit
Optimization Technique	Fisher's scoring

Number of Observations Read	5304
Number of Observations Used	5304

Response Profile

Ordered Value	Delay	Total Frequency
1	4	2019
2	3	616
3	2	580
4	1	2089

Probabilities modeled are cumulated over the lower Ordered Values.

Class Level Information

Class	Value	Design Variables	
Day_1	0	1	
	1	-1	
Precip	2	1	
	3	-1	
Visibility	1	1	0
	2	0	1

3 -1 -1

Model Convergence Status

Convergence criterion (GCONV=1E-8) satisfied.

The LOGISTIC Procedure

Score Test for the Proportional Odds Assumption

Chi-Square	DF	Pr > ChiSq
183.7691	16	<.0001

Model Fit Statistics

Criterion	Intercept Only	Intercept and Covariates
AIC	13018.855	12666.091
SC	13038.583	12738.429
-2 Log L	13012.855	12644.091

Testing Global Null Hypothesis: BETA=0

Test	Chi-Square	DF	Pr > ChiSq
Likelihood Ratio	368.7640	8	<.0001
Score	354.6479	8	<.0001
Wald	345.5838	8	<.0001

Type 3 Analysis of Effects

Effect	DF	Wald Chi-Square	Pr > ChiSq
Day_1	1	192.2292	<.0001
Precip	1	9.8104	0.0017
Spr	1	0.0015	0.9691
Su	1	34.8126	<.0001
R	1	1.2987	0.2544
C	1	10.2495	0.0014

Visibility	2	70.2244	<.0001

The LOGISTIC Procedure

Analysis of Maximum Likelihood Estimates

Parameter		DF	Estimate	Standard Error	Wald Chi-Square	Pr > ChiSq
Intercept	4	1	0.8138	0.2363	11.8573	0.0006
Intercept	3	1	1.3125	0.2367	30.7362	<.0001
Intercept	2	1	1.7866	0.2373	56.6950	<.0001
Day_1	0	1	0.3611	0.0260	192.2292	<.0001
Precip	2	1	-0.4441	0.1418	9.8104	0.0017
Spr		1	0.00262	0.0677	0.0015	0.9691
Su		1	-0.3508	0.0595	34.8126	<.0001
R		1	-0.2367	0.2077	1.2987	0.2544
C		1	-0.5998	0.1874	10.2495	0.0014
Visibility	1	1	0.5258	0.0690	58.1081	<.0001
Visibility	2	1	-0.2172	0.0640	11.5144	0.0007

Odds Ratio Estimates

Effect	Point Estimate	95% Wald Confidence Limits	
Day_1 0 vs 1	2.059	1.859	2.280
Precip 2 vs 3	0.411	0.236	0.717
Spr	1.003	0.878	1.145
Su	0.704	0.627	0.791
R	0.789	0.525	1.186
C	0.549	0.380	0.792
Visibility 1 vs 3	2.303	1.895	2.800
Visibility 2 vs 3	1.096	0.920	1.305

Association of Predicted Probabilities and Observed Responses

Percent Concordant	53.5	Somers' D	0.232
Percent Discordant	30.3	Gamma	0.277
Percent Tied	16.3	Tau-a	0.156

Pairs	9488139	c	0.616

ORDERED LOGISTIC REGRESSION IN EASTBOUND DIRECTION BETWEEN SPEED REDUCTION AND WEATHER FACTORS – FINAL MODEL

The SAS System 19

The LOGISTIC Procedure

Model Information

Data Set	WORK.DELAY_WEATHER2
Response Variable	Delay
Number of Response Levels	4
Model	cumulative logit
Optimization Technique	Fisher's scoring

Number of Observations Read	5304
Number of Observations Used	5304

Response Profile

Ordered Value	Delay	Total Frequency
1	4	2019
2	3	616
3	2	580
4	1	2089

Probabilities modeled are cumulated over the lower Ordered Values.

Class Level Information

Class	Value	Design Variables	
Day_1	0	1	
	1	-1	
Precip	2	1	
	3	-1	
Visibility	1	1	0
	2	0	1
	3	-1	-1

Model Convergence Status

Convergence criterion (GCONV=1E-8) satisfied.

The LOGISTIC Procedure

Score Test for the Proportional Odds Assumption

Chi-Square	DF	Pr > ChiSq
158.2375	12	<.0001

Model Fit Statistics

Criterion	Intercept Only	Intercept and Covariates
AIC	13018.855	12663.423
SC	13038.583	12722.609
-2 Log L	13012.855	12645.423

Testing Global Null Hypothesis: BETA=0

Test	Chi-Square	DF	Pr > ChiSq
Likelihood Ratio	367.4314	6	<.0001
Score	352.7429	6	<.0001
Wald	344.9701	6	<.0001

Type 3 Analysis of Effects

Effect	DF	Wald Chi-Square	Pr > ChiSq
Day_1	1	192.5774	<.0001
Precip	1	9.7760	0.0018
Su	1	39.7241	<.0001
C	1	21.3446	<.0001
Visibility	2	69.1493	<.0001

Analysis of Maximum Likelihood Estimates

Parameter	DF	Estimate	Standard Error	Wald Chi-Square	Pr > ChiSq

Intercept	4	1	0.6245	0.1644	14.4335	0.0001
Intercept	3	1	1.1233	0.1649	46.4095	<.0001
Intercept	2	1	1.5972	0.1656	93.0792	<.0001
Day_1	0	1	0.3612	0.0260	192.5774	<.0001
Precip	2	1	-0.4433	0.1418	9.7760	0.0018
Su		1	-0.3518	0.0558	39.7241	<.0001
C		1	-0.4148	0.0898	21.3446	<.0001

The LOGISTIC Procedure

Analysis of Maximum Likelihood Estimates

Parameter	DF	Estimate	Standard Error	Wald Chi-Square	Pr > ChiSq
Visibility 1	1	0.5222	0.0689	57.4122	<.0001
Visibility 2	1	-0.2192	0.0640	11.7245	0.0006

Odds Ratio Estimates

Effect	Point Estimate	95% Wald Confidence Limits	
Day_1 0 vs 1	2.059	1.860	2.280
Precip 2 vs 3	0.412	0.236	0.718
Su	0.703	0.631	0.785
C	0.660	0.554	0.788
Visibility 1 vs 3	2.282	1.879	2.772
Visibility 2 vs 3	1.087	0.914	1.294

Association of Predicted Probabilities and Observed Responses

Percent Concordant	53.4	Somers' D	0.231
Percent Discordant	30.3	Gamma	0.276
Percent Tied	16.3	Tau-a	0.156
Pairs	9488139	c	0.615

APPENDIX D

RECEPTORS COORDINATES

Receptors coordinate in UTM (meter)

North side Coordinates						Southside coordinates					
Pt	x	y	Pt	x	y	Pt	x	y	Pt	x	y
1	619050	4830582	21	618914	4831064	1	619079	4830479	1	619215	4829997
2	619043	4830607	22	618907	4831088	2	619086	4830454	2	619222	4829973
3	619036	4830631	23	618900	4831112	3	619093	4830430	3	619229	4829949
4	619029	4830655	24	618894	4831136	4	619100	4830406	4	619235	4829925
5	619023	4830679	25	618887	4831160	5	619106	4830382	5	619242	4829901
6	619016	4830703	26	618880	4831184	6	619113	4830358	6	619249	4829877
7	619009	4830727	27	618873	4831208	7	619120	4830334	7	619256	4829853
8	619002	4830751	28	618866	4831232	8	619127	4830310	8	619263	4829829
9	618995	4830775	29	618860	4831256	9	619134	4830286	9	619269	4829805
10	618989	4830799	30	618853	4831280	10	619140	4830262	10	619276	4829781
11	618982	4830823	31	618846	4831304	11	619147	4830238	11	619283	4829757
12	618975	4830847	32	618839	4831328	12	619154	4830214	12	619290	4829733
13	618968	4830871	33	618832	4831352	13	619161	4830190	13	619297	4829709
14	618961	4830895	34	618826	4831376	14	619167	4830166	14	619303	4829685
15	618955	4830919	35	618819	4831400	15	619174	4830142	15	619310	4829661
16	618948	4830943	36	618812	4831425	16	619181	4830118	16	619317	4829636
17	618941	4830967	37	618805	4831449	17	619188	4830094	17	619324	4829612
18	618934	4830991	38	618798	4831473	18	619195	4830070	18	619331	4829588
19	618928	4831016	39	618792	4831497	19	619201	4830045	19	619337	4829564
20	618921	4831040	40	618785	4831521	20	619208	4830021	20	619344	4829540

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