Exploring the Effect of Weather on Nighttime Road Collisions

Ajhay Sathiyanarayanan

A Thesis

in

The Department

of

Civil, Building and Environmental Engineering

Presented in Partial Fulfillment of the Requirements

for the Degree of Master of Applied Science (Civil Engineering) at

Concordia University

Montreal, Quebec, Canada

November 2018

CONCORDIA UNIVERSITY

School of Graduate Studies

This is to certify that the thesis prepared

By: Ajhay Sathiyanarayanan

Entitled: Exploring the Effect of Weather on Nighttime Road Collisions

submitted in partial fulfillment of the requirements for the degree of

Master of Applied Science (Civil Engineering)

Complies with the regulations of the University and meets the accepted standards with respect to originality and quality.

Signed by the final examining committee:

______________________________ Chair
Dr. Lan Lin

______________________________ External Examiner
Dr. Gerard Gouw

______________________________ Examiner
Dr. Anjan Bhowmick

______________________________ Examiner
Dr. Lan Lin

______________________________ Supervisor
Dr. Luis Amador

Approved by ______________________________
Dr. F. Haghighat, GPD
Chair of Department or Graduate Program Director

____
Dr. Amir Asif, Dean
Gina Cody School of Engineering and Computer Science

Date: November 2nd, 2018

Abstract

Exploring the impact of weather on lighting during nighttime accidents

Ajhay Sathiyanarayanan, 2018

Roadway artificial lighting assists drivers to navigate to their final destination at night time. Despite less traffic during such period of time, most fatal accidents occur at dark conditions. Factors such as fatigue, impaired driving, poor visibility and excessive speed contribute to make driving during night more dangerous than any other time of day. The impact of weather conditions on lighting to explain road collisions has not been investigated in the literature. This thesis explores weather at the time of road collisions during night time for accidents observed at Victoria Ville in Quebec. Available data encompassed various characteristics including values of illuminance measured during 2014 for the entire network in one night. Values of various lighting parameters were measured again at different weather conditions and attached to the database. Two analyses were conducted: One with the change in lighting conditions for roads in the region and the other without making any changes to understand the impact of weather on visibility issues leading to collisions. Two methods of representation of collisions and various road segment sizes were tested.

The results show that the recommended approach is to consider weather dependent illuminance, luminance and Unified Glare Index values for each individual collision. If the analysis is based on collisions frequency, then 100 meter segments are recommended, if the analysis is based on collisions severity, then 500 meters segments are advisable.

Acknowledgements

This dissertation was completed in November 2018 at Concordia University, Montreal, Quebec, Canada. First, I would like to express my deepest gratitude to Dr. Luis Amador for his kind encouragement and support during the period of my MASc study. Under his guidance, I gained invaluable experience in performing scientific research and learned how to overcome various type of research problems.

Second, I very much appreciate the Ministry of Transportation of Quebec (MTQ) for kindly providing me with and letting me use the data that they have extensively collected for a long time.

Last but not least, I express my deepest acknowledgement to my supportive and caring parents, my brother and my friends. Without their support, I would certainly not be able to finish this interesting but challenging research.

I would like to dedicate this thesis to my loving parents and my supportive brother …

Declaration

I hereby declare that except where specific reference is made to the work of others, the contents of this dissertation are original and have not been submitted in whole or in part for consideration for any other degree or qualification in this, or any other university. This dissertation is my own work and contains nothing which is the outcome of work done in collaboration with others, except as specified in the text and Acknowledgements. This dissertation contains fewer than 65,000 words including appendices, bibliography, footnotes, tables and equations and has fewer than 150 figures.

Ajhay Sathiyanarayanan

December 2018

Table of Contents

List of Figures

List of Tables

Nomenclature

Acronyms / Abbreviations

.shpShape file

AADTAnnual Average Daily Traffic

BCBritish Columbia

CADCanadian dollars

CDCCenter for Disease Control and Prevention

DALYsDisability-adjusted life years

DOTDepartment of Transportation

EEMEconomic Evaluation Manual

GDPGross Domestic Product

IESNAIlluminating Engineering Society of North America

NCANational Climate Assessment

NHTSANational Highway Traffic Safety Administration

NOAANational Oceanic and Atmospheric Administration

NRCan Natural Resources Canada

NRCC National Research Council of Canada

NZTA New Zealand Transport Agency

OECD Organization for Economic Cooperation and Development

RSPA The Royal Society for the Prevention of Accidents

RSS Road Safety Strategy

SAAQ Société de L'assurance automobile Québec

TAC Transportation Association of Canada

UGI Unified Glare Index

USNO United States Naval Observatory

US United States

WHO World Health Organization

ZINB Zero Inflated Negative Binomial

1. Introduction

1.1 Background

A collision occurs when a vehicle hits a human, animal, obstruction or other vehicles. Road collisions have a negative impact on the society. Road collisions affect the people involved in the accident and their families. The participants of the collision suffer physical and psychological shocks. The families of the accident victims suffer psychological impacts. The mental impact is due to injuries, fatal losses or monetary losses.

Road crashes impact the society more than poverty (Gorea 2016) and each year there are nearly 1.3 million fatalities and 50 million injuries globally due to traffic crashes (WHO 2015). Around 2 to 5 % of GDP in many countries account for economic costs due to road collisions (World Bank 2015). The number of accidents in Canada during the year 2016 were 160,315 (Statistics Canada 2016). The number of fatalities and serious injuries were 1898 and 10,322 respectively (Statistics Canada).The fatality rate per 100,000 people is 5.2, and the fatality rate per billion vehicle-Kilometres is 5.1 for the year 2016 (Statistics Canada). While in Quebec the above values stand at 4.2 and 4.6 (Statistics Canada 2016). During the year 2016, the number of fatalities in Quebec due to road collisions stands at 351 (SAAQ). It is estimated that a Canadian household spends 13% on road transit of its total budget on average (Andrey et al. 1998).

The risks of traffic crashes that occur during the night for young drivers aged 20 to 44 is greater by a factor of four than daytime accidents(Peden et al. 2004). Over one-third of mortality of the bicycle riders occurs during the dark hours where the there is low or no light (Transport Canada 2011). It is estimated that over 90% of cyclist involving night-time mortalities have poor lighting conditions (Statistics Canada). Nearly one-fourth of the people using cars travel between 7 pm and 8 am, but this period accounts for 40% of deaths and serious injuries (Ward et al. 2005). Visibility during night-time is limited because of the glare and the issues with the range (NHTSA 2007). In the areas of poor illumination, More than 40% of the drivers had trouble seeing the pedestrian leading to casualties (Peden et al. 2004). Poor illumination is the dominant cause of night-time road collisions (Murray et al. 2016). The availability of road lighting reduces the severity of the injuries by a factor of 3 (Plainis et al. 2016). Improving the lighting conditions helps in reducing the percentage of road crashes by 35% (NZTA EEM). There have been years of research trying to reduce the number of nighttime accidents.

Weather (Andrey et al. 2001) and visibility (Mouyid Bin Islam et al. 2008)influence road collisions. The risk of collision is above 50% during precipitation (Andrey et al. 2001). Severity of road collisions is an important aspect considering the physical and psychological effects it inflicts upon the society. Majority of weather-related crashes happen on wet pavement.(US DOT 2017) It is estimated that 43% of all weather related crashes occur during rainfall (US DOT 2017). 17% of all weather-related accidents occur due to snow or sleet (US DOT 2017). Only 3% of weather-related accidents occur due to fog (US Department of Transportation). The monetary cost of collision due to weather is roughly $1 billion dollar per year in Canada (Andrey et al. 2001).

Weather and illumination levels, as separate entities contribute to the rate of collisions during night-time. This research explores the effect of weather on lighting conditions during the time of a crash. The study is done in Quebec which follows lighting guidelines from TAC (Transportation Association of Canada).

Luminance, Illuminance and UGI are the three parameters that are being used for this research as they represent the various dimensions of artificial lighting. The Illuminance of a road is the amount of light falling on the surface of the road from the street lighting system and it correlates with how the human eye perceives the brightness from that surface (IESNA 2000). The Luminance of road lighting is the amount of light reflected in the path of the driver from a road (IESNA 2000). This character defines the brightness of the roadway(IESNA 2000). The glare is the effect of the excess of variation of light that is scattered within the eye of the observer resulting in extra light added to the retinal areas from the glare source (Vos 2003). This glare causes disability to view the light source or the objects surrounding that source. Glare is very problematic in places with other sources of light on the road (NHTSA 2007). Glare during night from the approaching vehicles affect the vision of the drivers over 50 years of age (NHTSA 2007).

1.2 Problem Statement

There are many studies dealing with the separate entities of weather and visibility in nighttime accidents. There is no study that considers if the weather at the time of the collision has an effect on lighting conditions and consequently into road collisions. Often weather at the time of the collisions is ignored or only considered through the skid resistance of the pavement surface.

1.3 Research Objective

1.3.1 Overall Goal

The overall goal of this research is to explore if weather has an impact on road lighting during night-time.

1.3.2 Objectives

- Investigate if there is an impact of weather on artificial road lighting.
- Assess if the characterization of lighting considering weather at the time of the accident produces a significant deviation in road safety performance.
- Investigate size of the segment on understanding the impact of weather on artificial roadway lighting.
- Examine if the modeling of nighttime weather dependent collisions should be based over average characteristics on segments (and of which size), or individual points
- Investigate whether frequency or severity of accidents explains the impact of weather on night time collisions.

1.3.3 Tasks

- Measure and collect artificial lighting (Illuminance, luminance, UGI) at various climatic conditions: clear, sky, rainy and snowy.
- Prepare a database that update previous observations to further characterize lighting according to the weather condition observed at the time of the collision.

- Test the methods through a case study to identify the correlation between weather and lighting.
- Examine the contribution of significant factors that explain safety performance of roads

1.4 Scope and Limitations

1.4.1 Scope

This research examines the evidence statistically between weather and lighting during the time of road collisions. The available road collisions data available is during the year 2007-2011. The data is available for the region Arthabaska, including street, arterial and highway road collisions. Posted speed ranges between 40 to 100 km/h. The database contains Luminance values during the night time observed during a single day (weather non-dependent). Measurements of various lighting parameters such as Luminance, Illuminance and UGI (weather-dependent) were measured during the night time for different climatic conditions. AADT (Annual Average Daily Traffic) is available from the year 2007 to 2011. This data is for motorized accidents where the motorized vehicle hits an object or another vehicle. Accident severity index is calculated to determine the severity of a particular accident which in turn helps in analyzing the correlation between accident severity and lighting parameters. The climatic condition at the time of the accident is available that aids in comparing the weather dependent and weather independent data.

This research proposes two different methods to identify the relation between weather and lighting. These methods are used in Victoriaville, in the municipality of Arthabaska with the coordinates 46°05’N and 71°57’W (Comission de toponymie of Quebec, 2013). It is given in the form of a case study explaining the correlation between weather and lighting. The proposed methods are applicable for any case studies in and around the world.

1.4.2 Limitations

The geometrical and functional characteristics are assumed to be unchanged during the study period due to unavailability of such data. In particular we ignore if the lighting system suffered an improvement. This research focuses only on motorized vehicles. The expense of the damages representing the severity of the accident were kept the same for a particular level of severity as sufficient data on the expense of a particular collision was not available.

As it is very difficult to observe the lighting parameters for the large stretch of the Arthabaska region during each and every climatic condition, those lighting parameters were observed at similar roads assuming the lighting from source is the same. The mean of the lighting parameters for a particular type of weather condition is used as the weather dependent data for a particular accident as the values of the lighting parameters were not available.

1.5 Research Significance

The contributions of the research are,

- It compares two traditional methods for analyzing the safety performance data, identifying and recommending one of them.
- Explains the correlation between weather and street lighting.
- This pilot research is the first step in identifying the impact of weather condition in road collisions under various artificial lighting levels. Further extended and deep research can be done using this method for different locations and even for a particular variable with respect to the road collisions and severity during night time.

- A database is created with lighting parameters that are both weather dependent and independent variables along with accident severity index and other values that can be used for further lighting research.

1.6 Organization of the Thesis

This research is presented in 6 chapters as follows.

- Chapter 1 explains the problem statement and presents the objective and structure of the thesis.
- Chapter 2 consists of a review of many concepts related to weather characterization in Canada, Road collisions and Role of Illumination and weather on night time road collisions.
- Chapter 3 contains the methodology of the two different methods and the process employed in collecting, analyzing and processing the data.
- Chapter 4 presents the pre-analysis where initial analysis exploration of the effect of lighting for various weather conditions were measured and very preliminary safety performance is explored. The results of this chapter has been submitted as a conference paper for the 7th annual International Conference on sustainable Energy and Environmental Sciences.
- Chapter 5 presents the two traditional methods to analyze safety performance and the effect of weather on nighttime collisions for a case study of the Arthabaska region. This chapter is being formatted and will be submitted for a conference.
- Chapter 6 contains the conclusions and recommendations part that can be used for future research work.

2. Literature Review

2.1 Introduction

Identifying an individual or an object (target) at night time or during circumstances with difficult visibility is key for the understanding the road safety (Bozorg Chenani et al. 2016). Road lighting, in general should be of a sufficient level that satisfy the necessity of road users (Bremond et al. 2013). This chapter explains the major concepts on which lighting and safety are based upon, but also extends to other non-traditional necessary topics from within the scope of this research. They are as follows:-

- Weather characterization in Canada
- Road collisions in general
- Role of Illumination on road collisions
- Role of Weather on nighttime road collisions

The first section explains the different weather and climatic conditions in Canada. The second section explains road collisions in Canada and the major causes for it. The third section explains the impact of illumination and road collisions. The final section explains the role of weather on nighttime collisions.

2.2 Weather characterization in Canada

Weather represents short-term circumstances of the atmosphere and climate is the numerical mean of the weather over an elongated period of time (National Ocean Service 2018). Weather and Climate are inevitably important factors considered while planning or designing roadways. Weather variability plays a crucial part in road traffic injuries (Golob et al. 2018). In the U.S, it is estimated that weather-related automobile accidents causes more fatality than massive weather disasters(US Department of Transportation 2017). It is important to properly characterize the different climatic conditions and weather changes in Canada to acquired a better understanding of safety performance.

2.2.1 Climate in Canada

In short, Climate is the average of daily weather. Records in climate represents high values such as extreme temperatures that are taken as an average for a day or a period of time(National Oceanic and Atmospheric Administration 2017). Climate change refers to long term changes in perpetual mean of daily weather.

Diversity of landscapes represent the different kinds of climatic conditions in Canada (Natural Resources Canada 2009). The variation in climatic conditions of Canada is given by Natural Resources Canada (NRCan) as shown in 2.1.

The table 2.1 clearly shows the difference in climatic conditions from place to place in Canada and the necessity to consider climate as an important factor while designing roads. Environment Canada uses certain weather terms to identify the climatic conditions. Frequently used weather terms that refer the atmospheric condition and we use in this thesis are clear, snowy, cloudy, rainy windy and foggy. But little is known about the impact of specific weather circumstances on the visibility of the driver and in turn on the road collisions.

Table 2.1 **Climate in Canada**

Geography	**Climate Characterization**
Northern parts	Low precipitation, Permafrost, Treeless Tundra
South of the tundra	Short and warm summers and long and cold winters, Abundant annual precipitation
Pacific coast	Heavy rainfall, Mild temperatures
Prairies	Abundant number of days with sunshine
Atlantic coast	Long and mild winters, Short and cool summers
Great Lakes and St. Lawrence river coast	Warm summers, Cool winters

It is estimated that 60% of all weather related accidents occur due to either form of precipitation (i.e., Rain or Snow) (US DOT 2017). The majority of remaining weather-related accidents occur due to wet or icy pavements caused by some form of precipitation (US DOT 2017).

Precipitation in Canada

In Canada, the coast of British Columbia(BC) receives the heaviest rainfall and with annual precipitation in the order of about 2500 mm/year (Environment Canada 2018). Ocean Falls, in the province of BC recorded an annual precipitation of about 4145.1 mm/year (Environment Canada 2018). A place called Ucluelet on the islands of Vancouver recorded the highest rainfall for one day with about 489 mm on 6^{th} of October, 1967 (Environment Canada 2017). The region surrounding the Atlantic coast receives the second highest rainfall in Canada (Environment Canada 2017). Hurricanes bring out rainfall in other parts of the country (Environment Canada 2017).

The data for the Figure 2.1 is obtained from The world bank group shows the average temperature and rainfall of Canada for all the months of a year from 1991 to 2005.

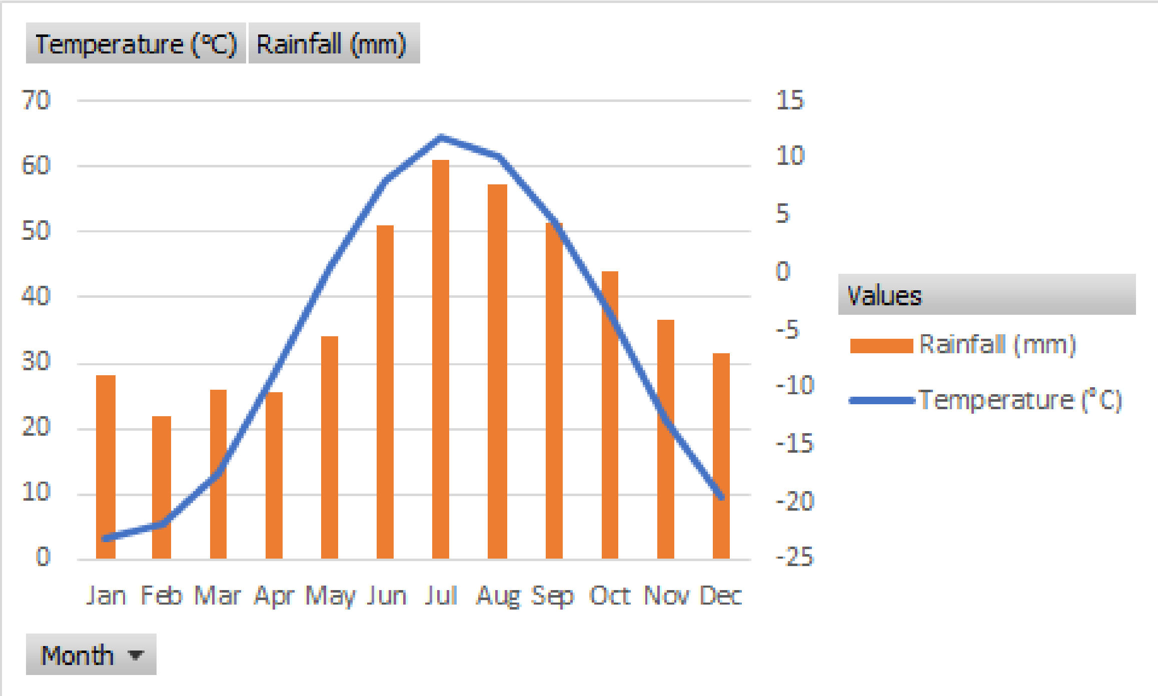


Fig. 2.1 **Average Temperature and Rainfall in Canada from 1991 to 2005**

Canada is a country with snowfall, with various regions of the country encountering snowfall for nearly six months a year. Hills and mountains in BC receives about 1000 cm of average snowfall per year (Environment Canada). The city of Corner Brook in the province of Newfoundland receives an average annual snowfall of around 420 cm and it is the snowiest city center (Environment Canada). Table 2.2 created from the data obtained from Environment Canada shows the amount of snowfall in major cities of Canada.

Many of the research papers focus on wet pavements from rainfall. Snowfall increases the crash rate by 84% and injury rate by 75% (Qiu et al., 2008). Rainfall increases the injury crash rate by 52% (Qiu et al., 2008). Rainfall related collisions have a lesser effect than the collisions occurring due to snowfall in Canada (Andrey et al., 2001). Risk of collisions are found to be higher for sleet or freezing rain in Canada (Andrey et al., 2001). The impact of snow on road collision rates is on the decrease, while the impact rainfall on crash rates does not follow the same pattern (Qiu et al., 2008).

Table 2.2 **Snowfall in major cities of Canada**

Cities	**Average Annual Snowfall (cm)**	**Snow on the ground annually (days)**
Montreal, Quebec	209.50	104
Quebec City, Quebec	303.40	141
Edmonton, Alberta	123.50	133
Calgary, Alberta	128.80	86
Halifax, Nova Scotia	154.20	69
Ottawa, Ontario	175.40	115
Regina, Saskatchewan	100.20	125
Toronto, Ontario	121.50	65
Vancouver, British Columbia	44.60	9

2.2.2 Climate in Quebec

Quebec is the second largest province in Canada. According to Koppen climate classification (2011) Quebec has three distinct climatic regions ranging from humid continental climate in southern Quebec to subarctic and tundra climate in central and northern parts of Quebec respectively. Dominated by the storm from Atlantic and North American systems, Quebec receives copious rainfall throughout the year (Environment Canada). Winters are cold and snowy for an extended period of time (Environment Canada).

2.2.3 Extreme weather in Canada

Weather extremes in Canada are common as temperature ranges from extreme cold during winter in 1947 to worst heat wave during summer in 1936 (Environment Canada). Global warming and climate change are likely to fuel the extreme climate resulting in worst weather conditions (Environment Canada). Due to extreme climates, it is likely that highway traffic will be disturbed causing more collisions (National Climate Assessment 2014). It has been estimated that risk of accidents increase by 23% for each and every day increase in precipitation (Liu et al., 2017). Another study states that due to climate change, warmer temperatures will result in fewer accidents but more fatalities, whereas increase in rainfall reduces fatalities but increases the number of accidents (Leard 2016). As Canada is caught in between these extremities, it is important to do further research to reduce road collisions.

2.3 Road Collisions

Road collisions are calculated in terms of the number of fatalities (deaths) and injuries suffered by individuals due to accidents on the road and it does not account for the suicidal accidents(Organization for Economic Cooperation and Development 2018). Road accidents are a major contributor to the hindrance in the development of a country (WHO 2014). The World bank encourages its member countries to include components for road safety in their national strategies(WHO 2014).

2.3.1 Reality around the world

It is estimated that each day around 3400 people are killed in road accidents (Center for Disease Control and Prevention 2016). Globally, it is estimated that traffic injuries will be the seventh leading cause of death (Center for Disease Control and Prevention 2016). Each year road injuries costs around 520 billion dollars worldwide (CDC 2016). Chart 2.2 shows the number of deaths per 1,000,000 people in different countries. This data was obtained from the Organization for Economic Cooperation and Development(OECD). The chart 2.2 shows the accidents caused only by road accidents and not the accidents happening due to other type of accidents. The injury rate is at an alarming rate and safety components should be installed by all the countries around the world. Chart 2.2 shows that Canada performs better and work needs to be done to reduce the number of accidents.

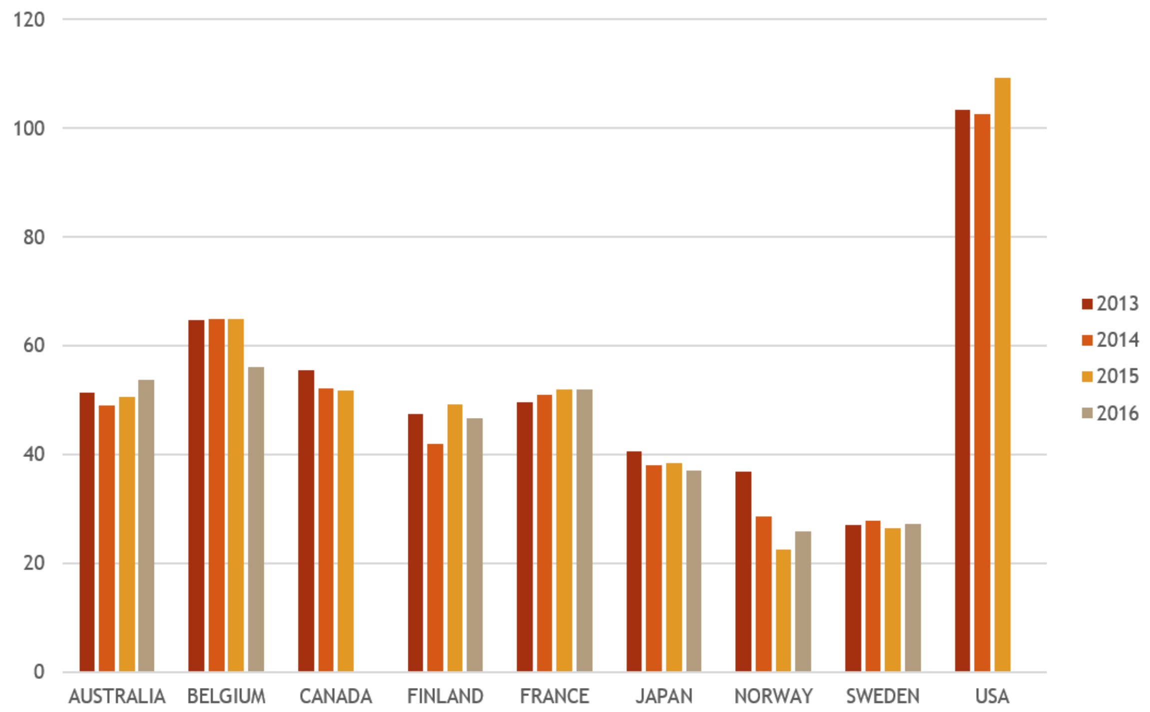


Fig. 2.2 **Deaths per 1,000,000 in countries around the world**

WHO data in 2002 suggests that 3242 persons are dying each day globally due to motor vehicle accidents. Table 2.3 is about the global road traffic related deaths and it shows the percentage of traffic related deaths. For the year 2002, 23% of all deaths globally are due to road accidents(WHO 2002).

Table 2.3 **Global traffic related mortality**

	Number	**Rate per 100 000 population**	**Proportion of total(%)**
Low-income and middle-income countries	**1 065 988**	**20.20**	**90**
High-income countries	**117 504**	**12.60**	**10**
Total	**1 183 492**	**19.00**	**100**

Source: WHO Global Burden of Disease project, 2002.

Table 2.4 **Global research and development funding**

Disease or Accidents	US$ millions	1990 DALYs ranking)	2020 DALYs ranking
HIV/AIDS	919-985	2	10
Malaria	60	8	_
Diarrhoeal diseases	32	4	9
Road Traffic crashes	24-33	9	3
Tuberculosis	19-33	_	7

DALYs: Disability-adjusted life years. (source : WHO 1996)

2.3.2 Social and Economic costs

In high income countries, the cost of expenditure on accidents are around 2% of the GDP of that country. The estimated economic costs of crashes around the world is 18 billion dollars (Jacobs 2000). Comprehensive data are not available for some middle and low income economies. It is estimated that capital costs of road accidents in 2000 were 230 billion dollars (Blincoe 2002). In countries like Kenya, around 75% of all the road casualties accounts for productive adults who are economically strong. This results in huge economic and social costs (Odero 2003).

Despite these costs, the investment done on road accidents are very low globally. Table 2.4 shows the lack in investment for road safety. Road journey brings more benefits but at the same time the price that is paid for these benefits are very high due to the lack of safety (WHO 1996).

2.3.3 Distribution of accident rates among road users

There are various studies suggesting different mortality rates in road accidents. The combination of Pedestrians and passengers accounts for around 80% of all road fatalities in Kenya (Odero 1997). In low and middle income economies pedestrians and passengers in any mass transportation constitutes for the major percentage of traffic fatalities (WHO 2011). In contradiction, in high-income economies, more than 60% of all road fatalities represents the occupants of a car, suggesting a huge number of cars in use (WHO 2012).

It is estimated that more than 50% of fatalities globally, occurs amid the young people aged between 15 and 44 years (Peden 2002). Males form the highest rate of traffic mortality at around 73% globally (WHO 2012). Studies have found that the difference in mortality rates is due to exposure and the behavior of taking risks (WHO 2012).

Socioeconomic factors are considered to be a liability for general and traffic injuries (Nantulya 2001). Several studies suggests that people who comes from a poor background are at a greater exposure to the risk of being injured or killed in a road crash (LaFlamme 1996). In many of the middle income economies, more that 60% of the people are found to travel in buses (WHO 2012). It is found that the number of road accidents are higher in urban areas due to urbanization and the severity of the accidents are higher in rural areas where there is a provision of traveling in greater speeds (WHO 2012).

2.3.4 The risk factors of road accidents

Traffic risk is defined as a function of four parameters (WHO 2012). They are,

- The amount of travel or Annual Average Daily Traffic
- Probability of a crash for a particular lighting exposure.
- Probability of the injury.
- Outcome of the accident or injury.

In addition to the parameters, there are many other errors that are responsible for the risk of accidents (Tingvall 1995). They are human error , kinetic energy during an impact, an individual's tolerance to the impact and the availability of trauma care and emergency services. In addition to these human errors there are certain important natural factors (Rumar 1999) such as,

- Night vision during night time accidents.
- Processing of information by the brain.
- Psychological factors with age.

All the above mentioned factors should be considered in creating quality-assured and sophisticated systems.

2.3.5 Road collisions in Canada

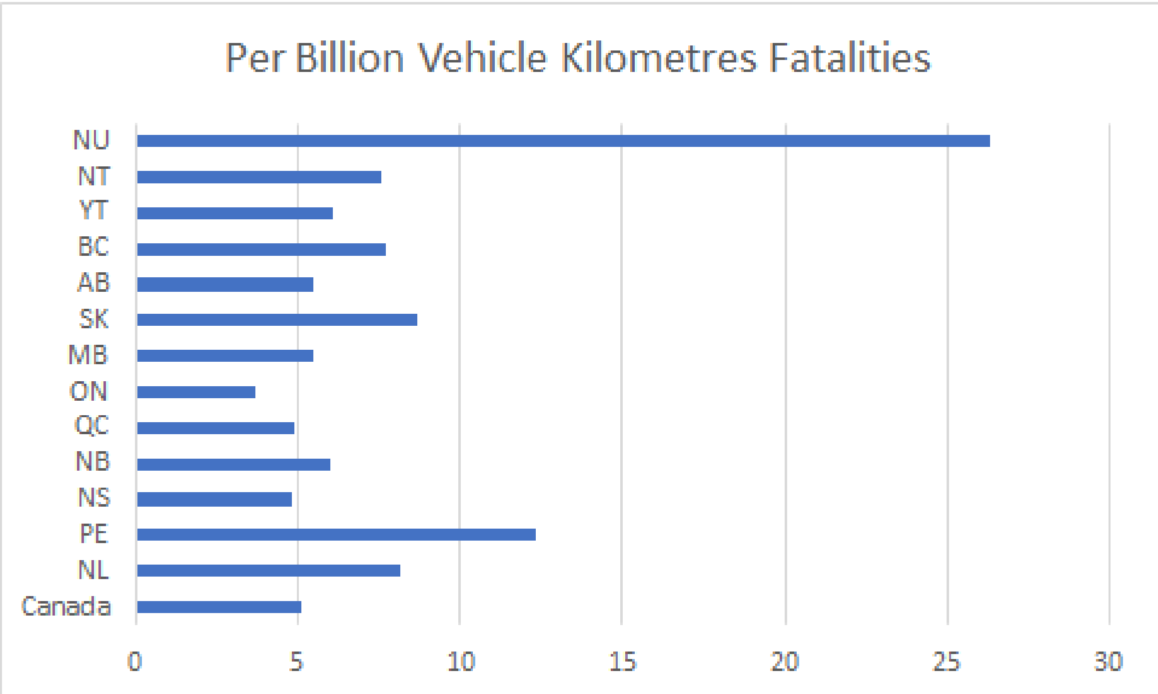


Fig. 2.3 **Canadian mortalities per Billion vehicle-km by province**

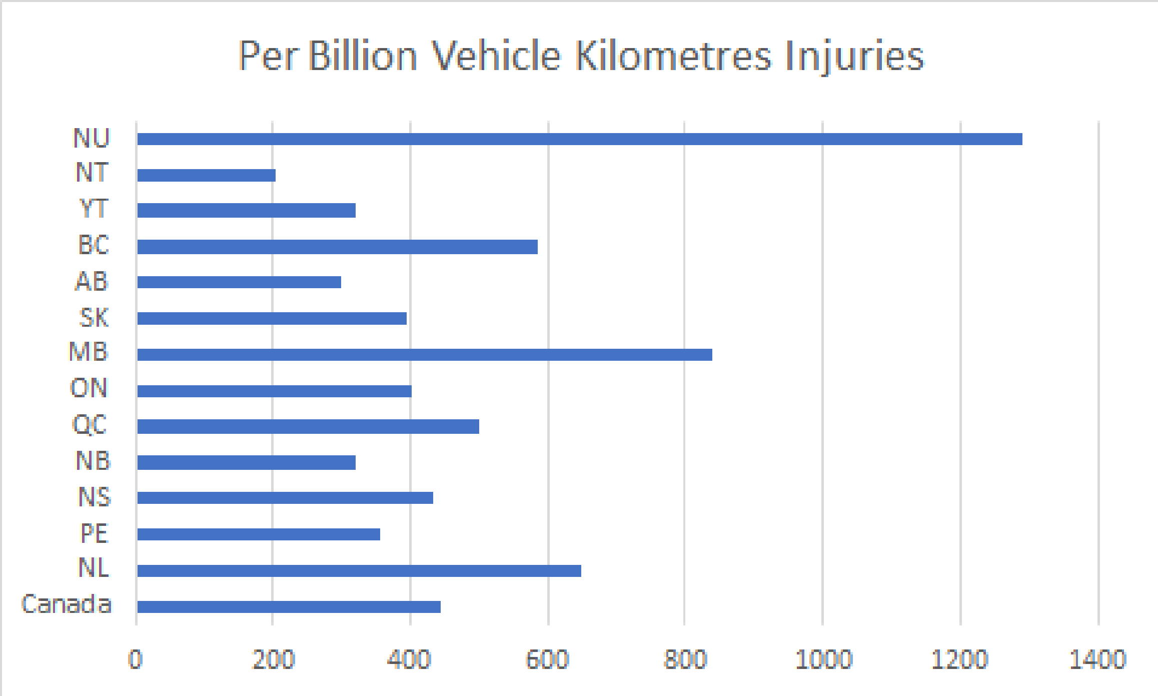


Fig. 2.4 **Canadian injuries per Billion vehicle-km by province**

Among the OECD countries Canada was ranked 10 in terms of deaths per billion kilometers in 2008. During the years 2004 to 2008, around 75% of all deaths and serious injuries have been passengers or drivers of vehicles (Road Safety Canada 2011). It is estimated that more than 40% of all deaths and serious injuries are distributed among young people in Canada (Road safety Canada 2011). The social and economic costs due to deaths, treatment, productive losses, property damages accounts for many million dollars.

Figure 2.3 and 2.4 shows the casualty rates and injury rates of various provinces in Canada for the year 2015. In Canada, results indicate that reduction in speed by 1% have resulted in the reduction of the possibility of serious collisions by 5% (OECD 2008). It is estimated that around 40% of accidents occur at intersections (OECD 2008). It is calculated that around 20% of fatal collisions occur due to the fatigue of the diver (Road safety Canada 2015). Heavy vehicles contribute around 20% of vehicle collisions (Road safety Canada 2015).

Rss's vision is to make Canada the safest place in the world from road accidents (Road safety Canada 2011). Canada has made a significant reduction in the fatality rates by employing various safety measures. Canada has made a significant improvement towards road safety over the past 40 years. Still, a person dies every four hours and a person is admitted to the hospital because of serious injuries due to road collisions (Road Safety Canada 2015).

2.3.6 Road collisions in Quebec

Compared to 2016, there is an increase in 13 deaths, 28 serious injuries, and 512 less minor injuries in the year 2017 (SAAQ) but road collisions numbers need to be seen in groups of 3 to 5 years, as there is unavoidable random variability associated. The capital cost spent during the year 2017 has increased by 6% compared to the year 2016 (SAAQ) . The number of mortalities of pedestrians, the cyclists, and heavy tractor from 2016 has increased by 10% in 2017 (SAAQ). During the year 2017, the passengers in the car accounted for the most number of deaths at around 58% (SAAQ). In the same year, adults aged in the range of 15 to 24 years constitute about 21% of the total casualties (SAAQ).

At night, urban roads are the major locations for some fatal collisions (Road safety Canada). To reduce the number of accidents, Quebec has conducted a pilot study using cameras for speed detection in the areas of Montreal and the results indicate that the extreme speeding has been reduced by 90% (Road safety Canada). Quebec has introduced anti-racing laws for safety measures (Road safety Canada). In addition to that, legislation for the speeding of heavy trucks has been implemented (Road safety Canada).

2.4 Role of illumination in road collisions

The main importance of street lighting is to increase the quality of life and to extend the activity that will usually be carried out in daylight (Royal Society for the Prevention of Accidents 2017). A study in 2003 found that 65% of the respondents perceived that better street lighting would reduce the number of accidents (RSPA 1978). A study indicated that the rate of collisions is 1.6 times higher during night time than daytime (Hasson 2002). Street lighting is an effective approach to provide visibility, to supplement the head lights, and to help the driver to gain information to complete the task of driving (Hasson 2002). Beyer(2009) questions the effectiveness of street lighting in developing and under developed countries.

2.4.1 Road Lighting levels - International

Countries like Australia and New Zealand follow system somewhat similar to the North-American countries. According to the system pavements are classified based on the type of functional characteristics and in addition to that reflectance in the pavement is also considered. Four design methods are defined by IESNA (2005) based on control mark, illuminance and luminance. In addition to luminance and illuminance, Australia and New Zealand defines rule for intersections and curve spacing chart (Al-Dulaimi 2016).

European countries follow a complex guideline according to which each pavement should be classified based on volume of the traffic, speed, geometry of the pavement, environmental influences and other influences such as the usage of land and weather type. This system offers an opportunity to transition between the various lighting situations. They provide particular instructions to move between them. IESNA (2005) provides a straight-forward approach while the European systems follow a conservative approach (Al-Dulaimi 2016).

2.4.2 Roadway lighting levels - North America

Two guidelines are usually followed in North America. AASHTO (2005) is used for lighting warrants and IESNA (2005) is used for lighting allocation in terms of the recommended levels. Table 2.5 shows the norm for the recommended use of the Illumination values (IESNA 2005). These values can be used for the intersections where the rate of accidents will be too high.

Important factors such as night-to-day ratio, lighting, AADT and curvature are considered. Other factors such as frequency, slope of the pavement and others are also considered (AL-Dulaimi 2016). Walton in 1974 is the first person in North America to propose a lighting warrant. This is done through national research program and it established a regulated method for lighting warrants. In 2005, AASHTO released a version of the guidelines for lighting. In the following year, TAC followed the guidelines framed by AASHTO (2005) and created its own system without much changes. There is a need to calibrate the lighting warrant guidelines published by various states as they have made some modifications to the guidelines published by AASHTO (Al-Dulaimi 2016).

Table 2.5 **Illuminance criteria for types of roads**

Road and pedestrian conflict area		**Pavement classification (Average values)**			**Uniformity ratio (Eavg/Emin)**	**Veiling Luminance ratio (Lvmax/ Lavg)**
Road	**Pedestrian conflict area**	**R1 (lux/fc)**	**R2 & R3 (lux/fc)**	**R4 (lux/fc)**		
Freeway class A		6.0/0.6	9.0/0.9	8.0/0.8	3	0.3
Freeway class B		4.0/0.4	6.0/0.6	5.0/0.5	3	0.3
Expressway	High	10.0/1.0	14.0/1.4	13.0/1.3	3	0.3
	Medium	8.0/0.8	12.0/1.2	10.0/1.0	3	0.3
	Low	6.0/0.6	9.0/0.9	8.0/0.8	3	0.3
Major	High	12.0/1.2	17.0/1.7	15.0/1.5	3	0.3
	Medium	9.0/0.9	13.0/1.3	11.0/1.1	3	0.3
	Low	6.0/0.6	9.0/0.9	8.0/0.8	3	0.3
Collector	High	8.0/0.8	12.0/1.2	10.0/1.0	4	0.4
	Medium	6.0/0.6	9.0/0.9	8.0/0.8	4	0.4
	Low	4.0/0.4	6.0/0.6	5.0/0.5	4	0.4
Local	High	6.0/0.6	9.0/0.9	8.0/0.8	4	0.
	Medium	5.0/0.5	7.0/0.7	6.0/0.6	4	0.4
	Low	3.0/0.3	4.0/0.4	4.0/0.4	4	0.4

2.4.3 Demand Responsive lighting systems

It is found that nearly 40% of the energy budget of a city are being spent on artificial lighting (Cho 2008). It is estimated that one street light can emit about 200 kg of greenhouse gases every year (Cho 2008). There is a need to reduce the greenhouse gas emissions, the cost for operating and maintaining the infrastructure. The smart artificial lighting infrastructure, comprises of motion sensors that activates only when there is a need and it can prompt when something needs to be replaced (Atkinson 2012).

The expectation on outdoor lighting are more in addition to providing lighting (Cho 2008). In addition to satisfying their basic role of emitting light onto dim roadways, parking spaces etc., a street lighting infrastructure is progressively evaluated base don the consumption of energy, enhancing the safety of the road users and provides a scope for smart technologies (Cho 2008). Richmond hill in Ontario began installing new street lighting infrastructure including additional chips and sensors to support future requirements for a smart city (Atkinson 2012).

2.4.4 Light warrant calibration

Al-Dulaimi (2016) created a database for 2500km stretch of roads to measure the illuminance using a Spectrosense 2+GPSand the Photolux software for luminance. (Al-Dulaimi 2016). The database is merged with certain parameters including road collisions, geometrical characteristics and other accident related characteristics (Al-Dulaimi 2016). A portion of such database is used in the analyses of this research, but expanded to include a weather-dependent correction to the artificial lighting characteristics being tested at each particular analysis.

Al-Dulaimi (2016) runned a zero-inflated negative binomial distribution using the Stata software before the calibration of the lighting warrants (Al-Dulaimi 2016). The analysis was used to identify the significance of various parameters for specific segments based on the characteristics observed (Al-Dulaimi 2016). The results show that at higher values of illuminance with 80% confidence levels, the accidents tend to decrease in numbers. In addition to that higher values of glare resulted in more collisions.

The calibration of the lighting warrant is done using the scores obtained by re-escalation and normalization of the coefficients acquired after the analysis of the database (Al-Dulaimi 2016). The proposed grid score is obtained using the equation 2.1 (Al-Dulaimi 2016).

$$PT_{\mathrm{i}} = \left(\frac{P_{\mathrm{i}}}{\sum_{i=1}^{N} P_{\mathrm{i}}} \right) 20 \tag{2.1}$$

Where,

PT_i = Proposed score value for the variable $_i$

P_i = Value of the parameter obtained from the analysis

The results show that illuminance should be increased to a very high level and luminance should be decreased to a low level to reduce the severity and the number accidents (Al-Dulaimi 2016). No exploration of the role of weather was done, and the characteristics of road collisions were averaged over segments of 500 meters. No exploration was done as to the impact of the segment size on the results, nor on the possibility of preserving the accidents as point features.

2.5 Role of weather on nighttime collisions

Driving is one of the most complex tasks that is further made complex by the changing environmental condition around the driving area (Plainis 2016).This is further complicated by the absence of lighting (nighttime) or during improper lighting conditions (Plainis 2016).

Weather forecast is an important factor to be considered to reduce the number of road accidents (Andrey 2001).

2.5.1 Impact of weather on road crashes

In USA, nearly 1,300,000 of road accidents are due to weather related (US DOT 2017). This includes 6000 people who are killed because of this weather related reasons (US DOT 2017). A majority of the accidents occur during wet pavement (US DOT 2017). On average, 15% and 19% of all fatal and major injury crashes occur during adverse weather conditions (US DOT 2017).

Table 2.6 **Traffic parameter rate reduction due to weather**

Weather type	**Average speed reduction (%)**	**Free-flow speed reduction (%)**	**Capacity reduction (%)**	**Capacity flow rate reduction (%)**
Heavy rain	3 to 16	6 to 17	10 to 30	14
Light rain or snow	3 to 13	2 to 13	4 to 11	5 to 10
Heavy snow	5 to 40	5 to 64	12 to 27	30 to 44
Low visibility	10 to 12		12	

Table 2.6 (US DOT 2017) shows the reduction in traffic parameter values due to adverse weather conditions. It can be observed that the flow and speed of traffic is reduced drastically and proper functioning of the traffic flow is disturbed leading to accidents.

There are several factors that is to be considered while designing a model to reduce the accidents due to weather (Peden 2004). They are,

- Resistance of the pavement (due to snowfall, frost etc.).
- Visibility (due to precipitation or fog).
- Strong winds.

- Change in temperature.
- Complexity of the geometry (Distractive terrain or landscape).

A study in Ontario by Andrey (2003), states that nearly 16% and 18.5% of all fatalities and serious injuries are due to weather related accidents. This study also insists on the fact that snowfall is more adverse than rainfall in many Canadian cities. In the UK, a study found a significant relation between heavy precipitation and accident in certain metropolitan areas (Jarosweski 2014). Perrels (2015) states that adverse weather conditions can increase the number of crashes by 20%.

Theofilatos (2014) analyzed over 20 studies on weather related crashes where 15 studies represents likelihood of crashes and 5 studies focus on severity of the accidents. These studies explains the increase in number of accidents due to precipitation and the severity can be reduced by reducing the speed. There is a decrease in the demand of the traffic during bad weather conditions but the risk and number of collisions are more during such times (Cools 2010). The effect of the accident outcomes depend on the weather type or season and the time of accident (Cools 2013).

2.5.2 Night time accidents

According to National Highway Traffic Safety Administration most fatalities due to road accidents occur during twilight condition and nighttime condition. According to the US Department of Transportation 58% of teenage road crashes occur during night time. According to National Safety council, a majority of car crashes during night time occurs due to,

- Fatigue - According to a study by NHTSA, about 60% of of the drivers involving in an accident admitted that they were tired and 37% people admitted of falling asleep while driving (National Sleep Foundation).

- Darkness - During night time, recognition of the colors, peripheral vision are very limited during dark environment (NHTSA). People aged over 50 years of age need twice as much as light compared to a 30 year old (American Optometric Association).
- Rush hour - During the peak hour traffic between 5 and 8 p.m., where there will be less lighting, most people will be eager to return home from work and they will be careless which increases the risk of accidents (NHTSA).
- Impairment - Drivers under the influence of drugs and alcohol are also a major cause for the increased in night time accidents (CDC).
- Speed - Bassani (2012) found that the operating speeds at nighttime are higher compared to daytime.

2.5.3 Impact of weather on nighttime crashes

A study by Green (1983) proves that the perception of the driver during nighttime is reduced by precipitation. Precipitation changes the visibility of by its impact on headlamps and other road markings. The process in which the rain interacts with the head light or other sources of light is,

- Rain drops filter the output of the headlight sources and the output is further reduced by the dirty water (Green 1983).
- Only a portion of light is absorbed and the rest is scattered which reduces the output (Green 1983).
- The phenomenon of backscatter reflect the light causing the reduction in the contrast of the objects in the field of view. It also creates visual annoyance which can cause poor vision (Green 1983).

- This poor visibility causes the people to concentrate on the front neglecting the view on the sides. So, it, may be dangerous for pedestrians or animals crossing the road (Green 1983).

Another important phenomenon that results in increasing the risk of accidents by reducing the visibility is fog (Green 1983). The harmful effects of fog include,

- Lowering the Contrast - Though being smaller particles, fog results in more backscattering and causing a loss of contrast of objects in the field of view. This is the reason why it is not recommended to use high beams during foggy situations (Green 1983).
- Poor perception to calculate speed and distance - Research studies states that reduction in contrast results in poor judgment of objects in motion (Green 1983). Due to this, it becomes difficult for the drivers to judge the speed of the their vehicle and the speed of the vehicle on the opposite side, making the fog more dangerous (Green 1983).
- Error of Accommodation - Accommodation process is a psychological phenomenon in which our eyes focus the objects of different distance sharply and this is drastically reduced by fog (Green 1983).

A study by Annika (2016) investigated the effect of weather, lighting conditions and road lighting on the speed of the vehicle. Three important results were inferred. They are,

- The speed of the vehicle is observed to be higher in bright conditions than in dark conditions.
- The outcome of the lighting condition depends upon the posted limit of the speed.
- The outcome of the lighting condition depends upon the weather or environmental conditions.

2.6 Summary and Drawbacks

- Most of the studies concentrated on road crashes during daytime and it is not possible to find more studies that gives a complete analysis of nighttime accidents.
- Most of the studies considered accidents without separating them on the basis of time of occurrence.
- Certain studies deal with specific factors like weather and lighting as separate entities and no study has found the impact of weather on lighting in nighttime accidents.
- Many studies have considered the presence of street lighting as a part of several factors but not as a separate entity in understanding their impact.
- Majority of previous experiments deal only with logging the illuminance data manually but there is a lack of research with the use of new Geo-referenced technologies in measuring the illuminance data.
- Few studies research about the impact of weather on nighttime accidents. There is a lack of research in analyzing weather in relation to other factors and their impact on nighttime accidents.
- Majority of the studies does not classify the impact on accidents based on the type of roads.

3. Methodology

3.1 Introduction

This chapter deals with the methods used to measure the lighting data, methods for database creation and analyzing the database to evaluate the correlation of weather on lighting on night time road accidents. The flow of this chapter is given in the form of a process tree in figure 3.1. Collection of Data is explained in Section 3.2, Cleaning and creation of database is explained in 3.3 and the methods in which the data is analyzed is explained in section 3.4.

3.2 Data Collection

Collection of factual data is the most critical stage of a research. For this research, certain variables related to road collisions are obtained from the government of Quebec and illumination (weather independent) values are obtained from the previous study by Al-Dulaimi (2015), who proposed a novel method to measure the lighting warrants and to statistically analyze the road collisions to alter the lighting warrant scores and to lower the number of accidents during night time. Important data such as weather related illumination data values are being collected in the field for different climatic conditions during this research.

Three datasets are created for this research. They are,

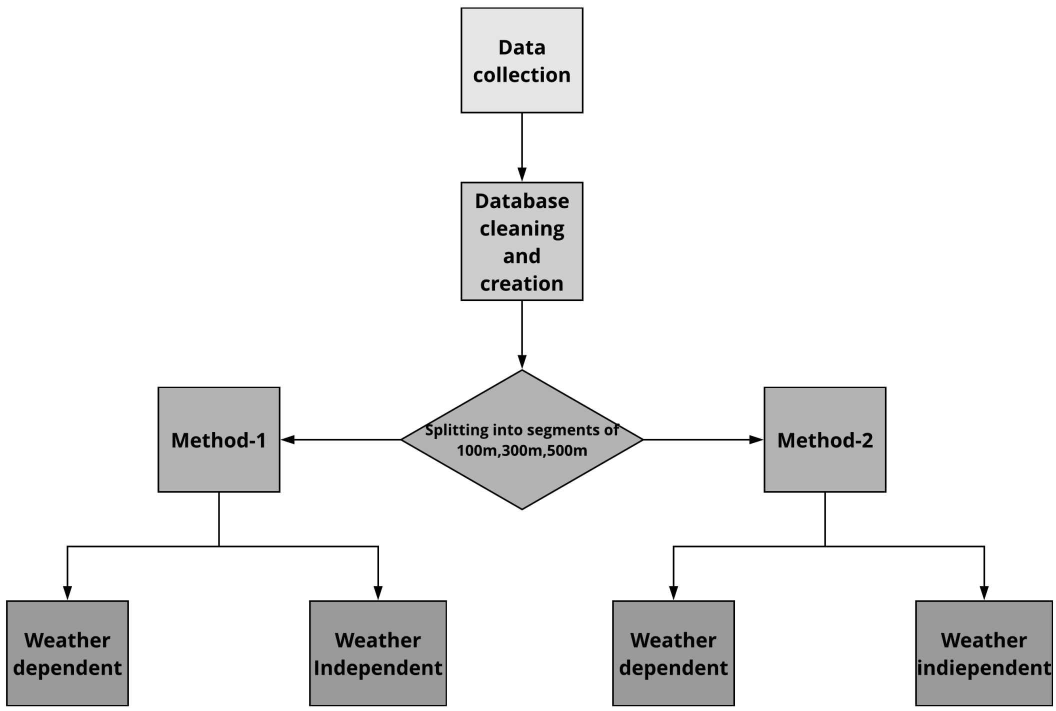


Fig. 3.1 **Process tree to explain the methodology**

- Dataset A - Road collisions data from the government of Quebec.
- Dataset B - Data from previous study by Al-Dulaimi (2016).
- Dataset C - New weather related data obtained during this research.

From the Dataset A, nighttime collisions are separated and it is observed that most of the accidents occur during four major weather conditions: Rainy, cloudy, snowy and clear as defined by Environment Canada. So, it is necessary to collect the data for these weather types so that it can be incorporated into each nighttime road collision. this is done on Dataset C. Dataset B provide previously measured lighting and it does not reflect the weather at the time of the collision, but rather at the time of the data collection, called weather-independent lighting characteristics.

Three weather dependent lighting parameters include: Luminance, measured in cd/m^2; Illuminance, measured in lux; and UGI. Luminance and Illuminance are the two dominant metrics for lighting road during night time (IESNA 2005). Assessing glare is also equally important as it affects driver's visions (Vos 2003). For this research, the data is collected using a canon camera and a special lens with the calibrated settings so that it can be processed using the photolux software.

Photolux is a software to measure different lighting parameters. The data is collected by taking pictures of the road in the direction of the vehicle movement to avoid headlight glare. The sole objective is to measure the lighting parameters of the street with the movement of the vehicle such that headlight of the vehicle does not disrupt the values of street lighting. The values were taken for the four weather conditions and for different types of roads such as street, collector and arterial as the dataset from Arthabaska region consists of these type of roads.

Pictures are taken for different weather conditions and many pictures are taken for the same weather condition to use the average as the value to be imputed within the database and test if the weather-dependent lighting explains road collisions. Pictures on the same day and different days for the same condition are taken to validate the quality of the database. The Figure 3.2 shows the camera used for taking the pictures. The settings for the camera required for the optimal analysis is presented in the table 3.1. These settings were provided by the manufacturer of the software photolux and are the ones previously calibrated and tested to produce values close to a colorimeter.

The pictures are then transferred to the computer to be used in the photolux software to find the lighting parameters. The image format used in this software is .CR2 and when the image is loaded in the software, it calculates the lighting parameters. Figures 3.3, 3.5, and 3.7 show some of the pictures taken using the camera for different climatic conditions and for different roads. Figures 3.4, 3.6, and 3.8 display the processed results for the pictures

Fig. 3.2 **Camera used for data collection**

Table 3.1 **Settings used in the Camera**

Parameter	Settings
Image Quality	M
Picture Style	Neutral
White balance correction	0.0
Color space	sRGB
Bracketing	0
ISO	400

taken with the camera, using Photolux software. Compute Statistics and compute indices are the two options in this software to estimate the lighting parameters. The average weather dependent values as represented in the software is used in this research. A separate database is created for a number of observations so that the overall validity of the data is verified and the average of all values are used.

The rest of the data is obtained from road collisions data or derived from certain values which will be explained in database cleaning and creation process.

Fig. 3.3 **Collector road- Cloudy condition**

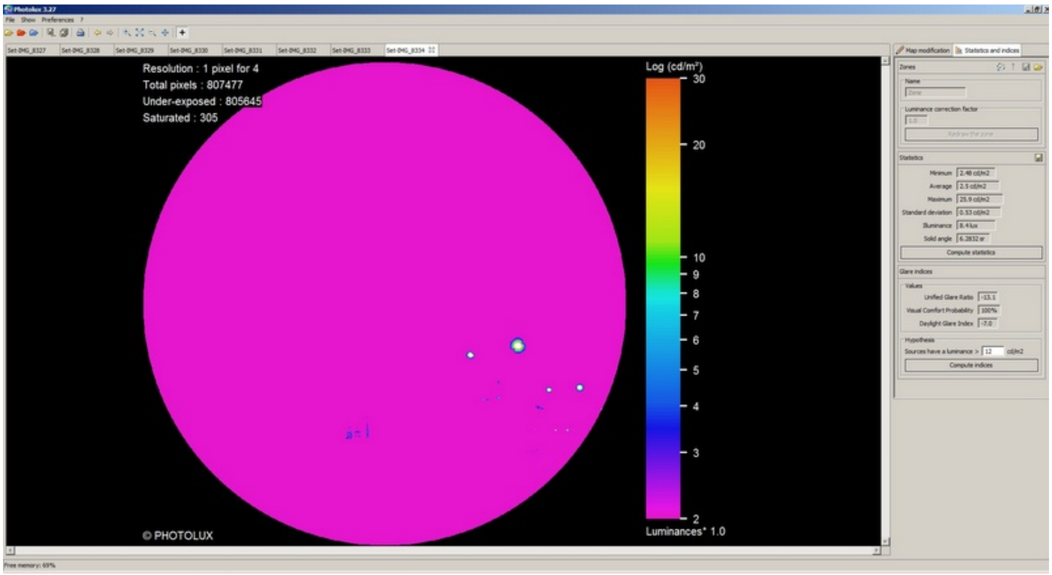


Fig. 3.4 **Processed Collector road- Cloudy condition**

Fig. 3.5 **Street road- Clear condition**

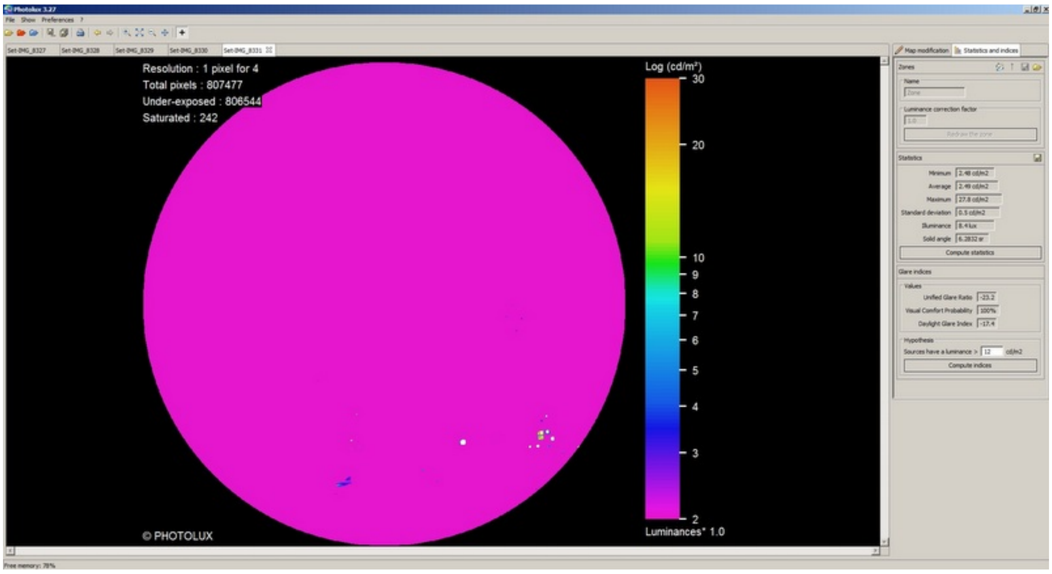


Fig. 3.6 **Processed street road- Clear condition**

Fig. 3.7 **Street road- Rainy condition**

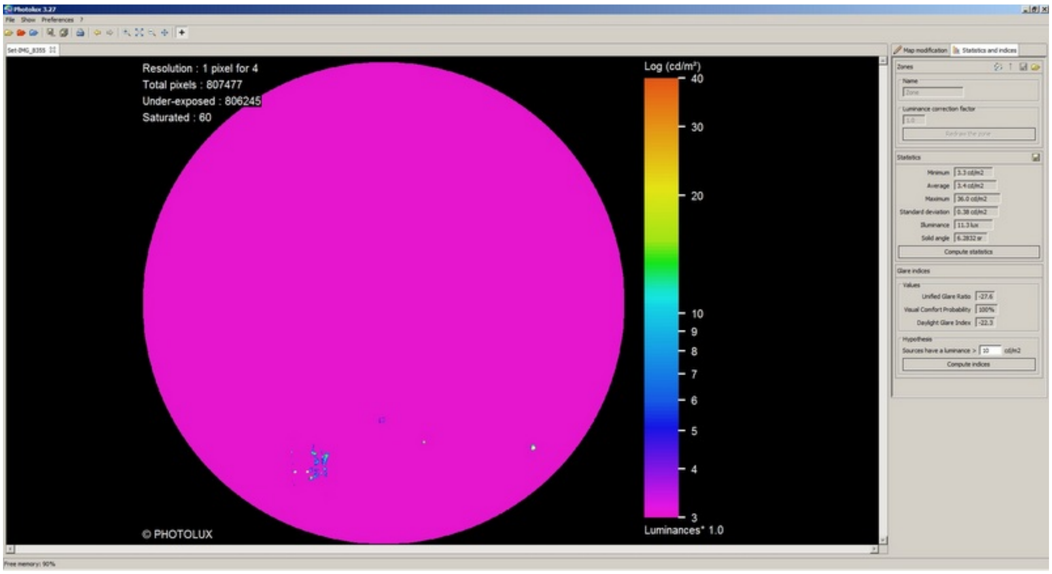


Fig. 3.8 **Processed street road- Rainy condition**

3.3 Database Creation

3.3.1 Weather dependent data

Weather dependent variables are obtained from the previous procedure and stored on Dataset C. Average values of illumination characteristics are entered in the database. They come from repeated measurements of each weather type for different type of roads. These values represent the lighting values for a particular accident occurring during a specific weather condition. There were prior expectations in the data observed. For snowy (snow on the ground) condition, there was an expectation that luminance will increase and the glare will decrease due to a bright background. The expectation for the rainy condition is that, it will produce a wet surface, creating a mirror like reflection of the light, causing the glare to increase.

Table 3.2 illustrates the values entered in the database created from the weather dependent lighting data. The results show that the prior expectations for rainy and snowy conditions stand true. The negative values of the UGI are just the representations obtained from the software and the corresponding positive values are to be used for the analysis as the value of UGI tends to be positive. The data base is saved in the form of open XML format spreadsheet file (.xlsx). The file is opened in Microsoft Excel 2016 software.

Table 3.2 **Weather dependent lighting data**

Road	**Weather**	**Range**	**Luminance (cd/m^2)**	**Illuminance (lux)**	**UGI**
Street	Clear	Max	2.50	8.40	-17.40
		Min	2.49	8.40	-21.90
		Average	**2.49**	**8.40**	**-19.65**
	Cloudy	Max	2.49	8.40	-15.60
		Min	2.50	8.40	-22.00
		Average	**2.49**	**8.40**	**-18.80**
	Snowy	Max	2.64	8.90	-17.20
		Min	2.50	8.40	-18.20
		Average	**2.54**	**8.54**	**-18.12**
	Rainy	Max	3.90	13.20	-29.20
		Min	3.30	11.10	-31.70
		Average	**3.55**	**11.90**	**-30.43**
Arterial and Collector	Clear	Max	2.53	8.50	-8.60
		Min	2.49	8.40	-15.40
		Average	**2.50**	**8.42**	**-11.37**
	Cloudy	Max	2.50	8.40	-12.20
		Min	2.49	8.40	-15.40
		Average	**2.49**	**8.40**	**-13.56**
	Snowy	Max	3.50	11.50	-9.80
		Min	3.40	11.40	-12.60
		Average	**3.45**	**11.40**	**-10.86**
	Rainy	Max	3.60	12.10	-29.20
		Min	3.40	11.50	-33.80
		Average	**3.50**	**11.80**	**-31.50**

The weather dependent values from the database must be formed into a new database with the average values for each road and weather type. Table 3.2 shows the maximum, minimum and and final average values that are used as the weather dependent data for each collision of a particular weather type and a specific type of road. The lighting parameters are found to be approximately equal for arterial and collector roads, so the same value for both the arterial and collector road types are used.

3.3.2 Road collisions

The dataset A, containing the dataset of all the road accidents in the Arthabaska region for a period of 5 years from the year 2007 to 2011 provided by the government of Quebec is used for getting certain variables such as road collision data for a particular location and severity of the accidents. The data base is available in the form of shape file format (.shp). This shape file is opened in ArcMap 10.5 software which is a product of ArcGIS. The database contains accidents during day and night. As the time of the accident is mentioned in the database, it is easier to separate the night time accidents with the location of the accident in a particular stretch. In addition to that, AADT values are also extracted from the database which will be useful in finding the correlation during the analysis. Table 3.3 shows the subjective variables that are used to identify and isolate night time collisions.

Table 3.3 **Sample database to identify night time road collisions**

Year	Time	Vehicle count	Lighting	Accident severity
2009	19:40	1	Not-illuminated night path	*Major material*
2008	02:30	1	Not illuminated night path	*Major material*
2010	19:45	1	Day light	*Major material*
2010		1	Non precise	*Minor material*
2008	02:30	1	Not-illuminated night path	*Minor material*
2008	11:00	1	daylight	*Light injuries*
2007	20:58	2	Not illuminated night path	*Light injuries*
2007	17:20	1	Not illuminated night path	*Light injuries*

The time of the setting of the Sun varies relative to seasons and climate.According to the United States Naval Observatory the time of both dawn and dusk are considered to be night time and the accidents observed are termed as night time accidents. For the location of Victoriaville in the Arthabaska region, the time during the usage of artificial lighting is given by National research Council of Canada from which the database is compared to the values of civil dawn and civil dusk. For data without proper timing, additional criteria in the database with 5 parameters such as,

- Daytime
- Night time without street lighting
- Night time with street lighting
- Amidst day and night time
- Not precise

are provided in the database. Using the above criteria, data for night time accidents are separated. There were 3099 accidents in the database out of which 912 accidents occurred during night time. As the data provided for each accident is subjected to the police officer present at the accident collision site, there were some disparity between the two above mentioned criteria and such values of the accidents were removed from the resulting database.

The resulting values along with AADT and other parameters to find the severity of the accident are consolidated into a new database and exported as a new layer into ArcGIS software. Along with this, the locations of the accidents along with the weather condition during which it happened is also isolated and saved as a separate shape file.

3.3.3 Severity Index

The severity of the accident for a particular location from the government database is divided into five different categories namely,

- Fatal accident
- Major human injury
- Light human injury
- Major vehicle damage
- Minor vehicle damage

A count of the number of collisions per severity type is available in the database prepared by Al-Dulaimi (2016) and used in this research. The original database contained variables reflecting the count per severity level. For example, In a collision if there is a major human injury, that category is assigned a value of 1 and the rest categories are assigned a value of 0. The next step is to assign a monetary value to each collision as shown in table 3.4 and the calculation is shown in table 3.5).

These values are saved as a separate database, as these values will be incorporated into separate databases of 100m,300m and 500m respectively that will be explained in the later sections.

Table 3.4 **Categories of severity of road collisions**

Category	Severity (CAD)	Weighting factor
Fatality	5,000,000	5
Major human Injury	500,000	0.5
Light human Injury	100,000	0.1
Major Vehicle damage	10,000	0.01
Minor Vehicle damage	1000	0.001

To find the accident severity index different categories of the type of collisions are assigned a value in terms of Canadian dollars (CAD). Table 3.4 (Al-Dulaimi 2016) shows the the values assigned for each category. The value in this table for each criteria is divided by 1,000,000 for easier calculation and to obtain the weighting factor of the values in regards to

Table 3.5 **Example of severity index calculation**

Number of Accidents	Fatality	Major Human Injury	Light Human Injury	Major Vehicle damage	Minor Vehicle damage	Severity Index
1	0	0	0	1	0	0.01
0	0	0	0	0	0	0
1	0	0	1	0	0	0.1
7	0	0	2	5	0	0.25
4	0	0	0	3	1	0.031

the severity index. From these values, accident severity index can be obtained by multiplying the number of accidents of each category to their respective weighting factors and adding them together.

Table 3.5 shows a sample data with the calculated accident severity index values. For example, from the table 3.5 lets take the 5th row, where the total number of accidents are found to be 4 for a 100m segment and the creation of segments will be explained in later sections. Out of these 4 accidents, 3 are major vehicle damage accidents and one is minor vehicle damage accident. The severity index in 3.1 is calculated as,

$$\begin{aligned} SeverityIndex &= 0*5+0*0.5+0*0.1+3*0.01+1*0.001 \\ &= 0.0310 \end{aligned} \tag{3.1}$$

3.3.4 Weather independent data

The dataset B from the previous study of Dr. Al-Dulami (2016) consisting of night time road accidents for a period of five years in the Arthabaska region from 2007 to 2011 is used. The database is available in the form of a shape file format(.shp). This shape file is opened in ArcMap 10.5. The database consists of various values related to lighting warrants for nighttime road accidents. From that, Illuminance value for particular locations along a stretch of the road with the posted speed while measuring the lighting data is isolated and exported into a separate shape file.

3.3.5 Creating linear segments

The final step in creating a database is by splitting a route into segments of 100m, 300m and 500m. This is done to find the correlation between the parameters from smaller to wider range segments. This helps to get a broader perspective of the study. The shape file from the previous study by Dr. Al-Dulami (2016) and Matout(2013) consisting of the light parameters along with the posted speed of the vehicle is used to create segments. The shape file is loaded into ArcGIS software. The entire stretch is converted to a single route so that it will be easier to separate them in terms of 100m, 300m and 500m linear segments.

To create a single route in ArcGIS, Create route option under Linear referencing tools category in Arc toolbox is used. A dialog box appears as shown in figure 3.9. In that dialog box the layer of the stretch of the road is loaded and any unique identifier is entered in route identifier field. The default measure source of the route is length and it is selected. The output feature class is saved.

A layer is formed with few fields merging the stretch to an extent and the rest of the data is erased. The next step is to merge these remaining list of routes into a single stretch. For this, the layer is edited using editor tool. The option merge under editor tool is used to merge, by selecting all the fields in this new layer. Figure 3.11 shows the resulting single route formed after this process. This route needs to be split into 100m, 300m, 500m linear segments. Under the editor tool an option called split is used. Split dialog box appears as shown in figure 3.10.

The stretch of the route is about 97.5 kilometers which is to be split into linear segments. In split options, equal parts option is selected. The number of equal parts is obtained by

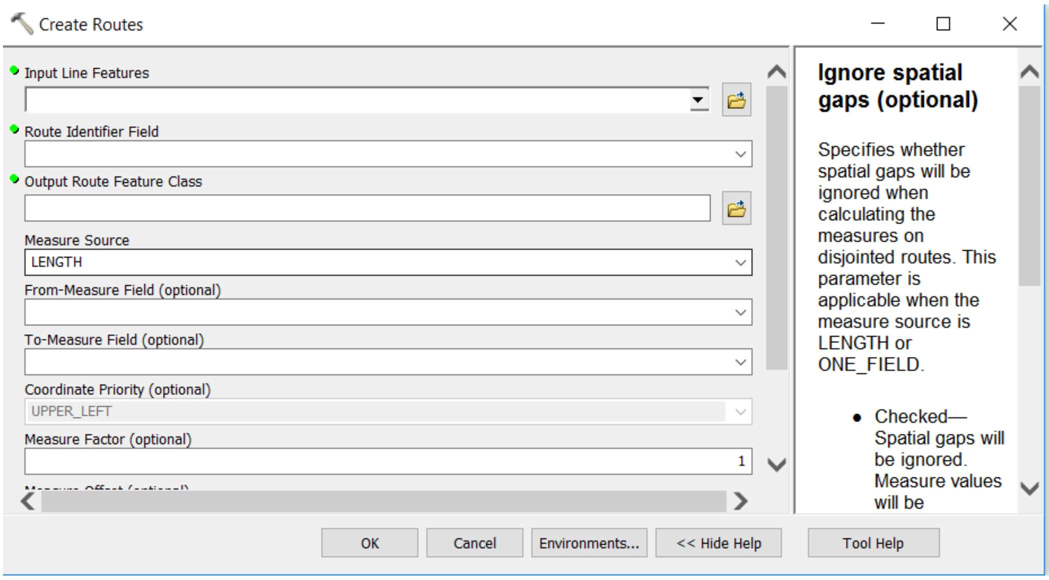


Fig. 3.9 **Dialog box for creating route**

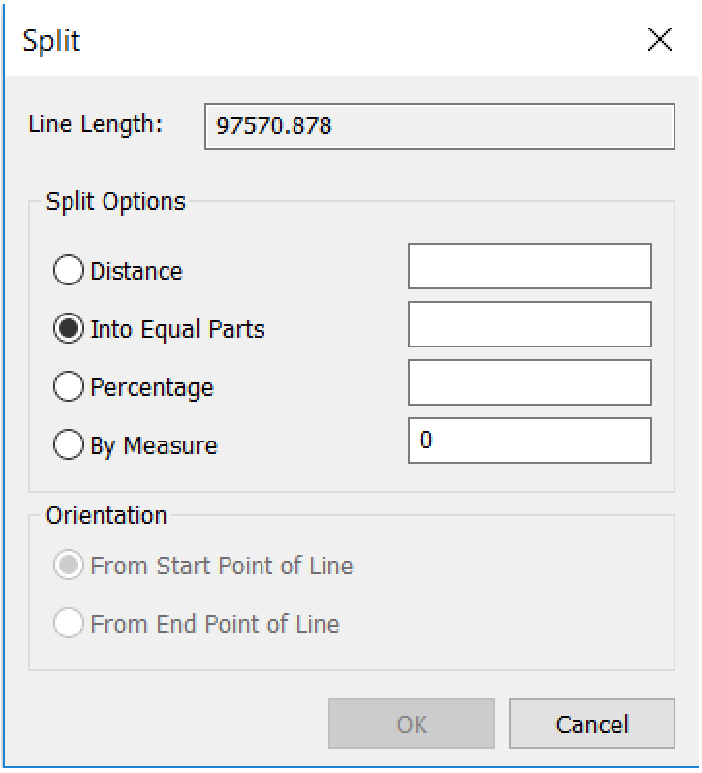


Fig. 3.10 **Dialog boxes for creating and splitting the routes**

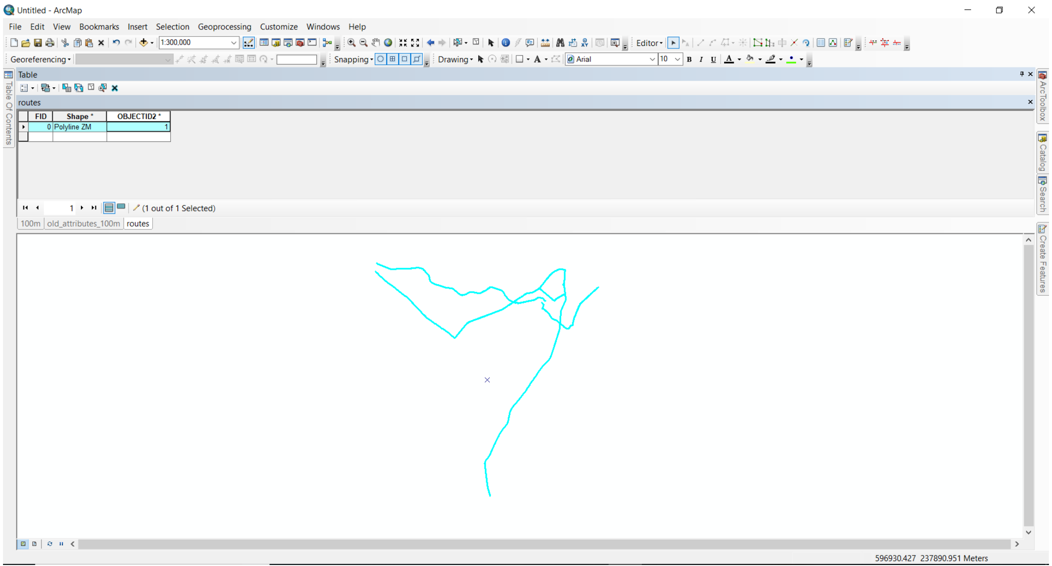


Fig. 3.11 **Screen shot of the single stretch of the road**

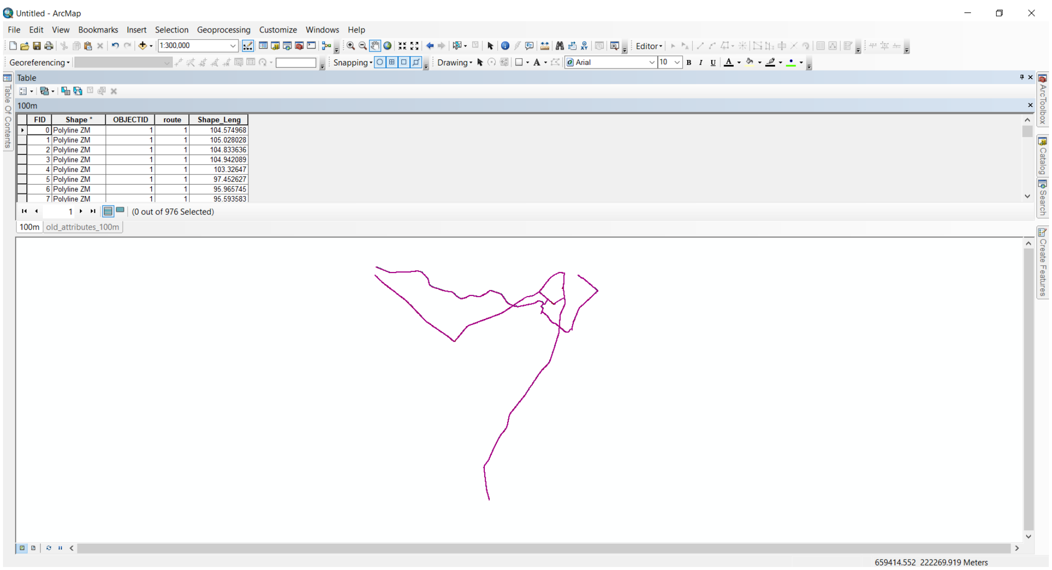


Fig. 3.12 **Screen shot of 100m split linear segments**

dividing the total length by 100m, 300m or 500m segments. For example, for obtaining 100m segments, dividing the length of 97570m by 100 gives us an approximation of parts of 976. Similar method is followed for the 300m and 500m segments which will be in equal parts of 325 and 195 respectively. The resulting split 100m segments are shown in the figure 3.12.

3.4 Methods for creating a database

A final database is created by merging all the above mentioned data into a single database. Two methods are tested for the analysis. The methods are not confined to a particular location and can be used for any case study. The methods focus on the analysis of both the average lighting parameter values for all weather types and the lighting parameter values for each and every weather type as a separate entity.

3.4.1 Method 1

In this first method, values are aggregated through their average into segments of 100m, 300m and 500m respectively. The procedure to create a database using this method is same for all the above mentioned length of the segments. Appendix A contains the steps for this approach for a 100 meter segment and applicable for any segment size. There are 848 accidents observed.

3.4.2 Method 2

In this second method, each individual collision for different type of roads (Arterial or collector, and street) along with observed characteristics, is stored as a separate observation. Further each collision is classified based on climatic conditions into clear, cloudy, rainy and snowy and the corresponding values of lighting measured for such weather condition are attached. Weather independent lighting value for illuminance is also attached. This method is divided into segments of 100m, 300m and 500m respectively. The procedure for this method is in Appendix B.

There are about 848 accidents observed out of which 835 accidents alone account for arterial and collector road accidents, rest of which occur in street roads. Out of those 835 accidents in arterial and collector roads: 73, 89, 300, 373 are the number of accidents that occurred at snowy, rainy, cloudy, clear weather conditions. As the sample size of accidents in street roads are less in number, street road analysis is ignored for the second method. These values are for the stretch of 97.5 kms of road and for the accidents occurring during nighttime for various climatic conditions.

3.4.3 Common changes

The overall stretch of the road segment has varied lighting. Some segments have no lighting and some segments have proper lighting. In the database, the values of weather independent data whose values are less than 1 are considered to be no lighting condition. Corresponding to the above mentioned values, the weather dependent values are changed to zero, representing the no light condition. In addition to that, for the segments where the accidents are zero, the corresponding very few weather dependent values are found to be zero which cannot be true. So, Illuminance values for weather independent values are used for corresponding weather dependent values. As there are no weather independent Luminance and UGI values in such database, the average of weather dependent values are calculated and replaced for those zero values. Only a very few values needs this type of replacement.

The analysis of the above database along with the discussion of the results are presented in the following chapter using a case study of the Arthabaska region.

4. Pilot study

4.1 Analysis and Results

A pre-analysis is carried out to verify if the change in conditions of the lighting for the given stretch of the road with respect to the weather, impacts the number of collisions without considering the presence or absence of artificial lighting. For this, the stretch of the road with the non standard lighting or the Illuminance values less than one were ignored and corresponding weather related lighting values are entered in the database. The rest of the process of the analysis is the same and even this dataset is analyzed using the two methods as explained above.

Equation 4.1 shows the functional form for this case study.The length was ignored given all segments were of the same size.

$$Y = AADT^{\alpha} e^{\beta \mathrm{x}} \tag{4.1}$$

Where a and b are estimators of the true parameters, and x is a vector of observed independent variables. AADT refers to Annual Average Daily Traffic. The value of zero was implanted for observations with zero collisions. A few road segments missing their AADT value were given an average value in order not to bias the analysis.

A correlation analysis revealed very high dependency of UGI(Unified Glare Index) and luminance (cd/m^2). For this reason, glare was dropped from the analysis (Table 4.1).

Table 4.1 **Correlation Analysis**

	Posted Speed	**AADT**	**Luminance (cd/m^2)**	**Illuminance (lux)**	**Avg. UGI**
Posted Speed	**1**				
AADT	**0.07**	**1**			
Luminance (cd/m^2)	**-0.12**	**0.05**	**1**		
Illuminance (lux)	**-0.12**	**0.13**	**0.02**	**1**	
Glare UGI	**0.12**	**-0.05**	**-0.93**	**-0.02**	**1**

Both analyses were made for segments of 500 meters, which include 33 observations with zero collisions and 162 observations with various values for the count of collisions.

Table 4.2 **Frequency analysis for weather dependent collisions-500m segments-Method 2**

ln_count	**Coef.**	**Std. Err.**	**z**	**P>z**	**95% Conf. Interval**
Posted Speed	**−0.01**	0.00	−4.81	**0.00**	-0.02 to -0.01
ln(AADT)	**0.16**	0.10	1.65	**0.10**	-0.03 to 0.35
Illuminance (lux)	**0.21**	0.02	12.38	**0.00**	0.18 to 0.25
_cons	−2.14	0.83	−2.58	0.01	−3.76 to −0.51

The two previous methods were used to test the effect of aggregation of the accidents and their corresponding lighting characteristics either true their mean value or by keeping the collisions separate. Results from segments of 500 meters shown in Tables 4.2 and 4.3 show

Table 4.3 **Frequency analysis for non-weather dependent collisions-500m segments-Method 2**

ln_count	Coef.	Std. Err.	z	P>z	95% Conf. Interval
Posted Speed	**−0.02**	0.00	−9.61	**0.00**	−0.03 to −0.02
ln(AADT)	**0.35**	0.08	4.06	**0.00**	0.18 to 0.51
Illuminance (lux)*	**0.00**	0.00	1.87	**0.06**	0.00 to 0.07
_cons	−1.39	0.75	−1.85	0.06	−2.86 to 0.08

Note*: Weather independent illuminance measured the same day for all segments.

Table 4.4 **Frequency analysis for weather dependent collisions-500m segments-Method 1**

ln_count	Coef.	Std. Err.	z	P>z	95% Conf. Interval
Posted Speed	**−0.02**	0.00	−5.28	**0.00**	−0.02 to −0.01
ln(AADT)	**0.23**	0.11	2.11	**0.04**	0.02 to 0.44
Illuminance (lux)	**0.20**	0.03	5.93	**0.00**	0.13 to 0.26
_cons	−1.72	0.97	−1.78	0.08	−3.61 to 0.17

Table 4.5 **Frequency analysis for non-weather dependent collisions-500m segments-Method 1**

ln_count	Coef.	Std. Err.	z	P>z	95% Conf. Interval
Posted Speed	**−0.01**	0.00	−5.25	**0.00**	−0.02 to −0.01
ln(AADT)	**0.32**	0.10	3.06	**0.00**	0.11 to 0.53
Illuminance (lux)*	**0.00**	0.00	1.410	**0.15**	−0.001 to 0.01
_cons	−0.93	0.94	−0.99	0.32	−2.76 to 0.90

Note*: Weather independent illuminance measured the same day for all segments.

that under aggregation following method 2, weather at the time of the collisions did not play a significant role. Values of explanatory variables for the weather dependent analysis showed large coefficients but same signs which are associated with the sense of contribution to the response.

A similar analysis conducted under method 1 (Table 4.4 and 4.5 showed similar results, having weather dependent collisions to result in stronger values of the coefficient for illuminance explaining more collisions at those sites with higher illuminance which suggest the fact that illumination is not playing a role and that other factors (impairment, etc.) could be contributing to road collisions more than visibility.

Table 4.6 **Frequency analysis for weather dependent collisions-300m segments-Method 2**

ln_count	**Coef.**	**Std. Err.**	**z**	**P>z**	**95% Conf. Interval**
Posted Speed	−**0.01**	0.00	−4.71	**0.00**	−0.02 to −0.01
ln(AADT)	**0.13**	0.08	1.60	**0.11**	−0.03 to 0.30
Illuminance (lux)	**0.26**	0.01	17.22	**0.00**	−0.23 to 0.29
_cons	−2.69	0.75	−3.57	0.00	−4.16 to −1.21

A similar analysis was conducted for 300m (Table 4.6 and 4.7). There were 869 observations with zero collisions out of 1260 observations. The aim was to test if segment size had an impact on the results. As seen: the contribution of illuminance for non-weather dependent collisions is very small, almost neglected just as in the previous analysis, but for the weather dependent collisions it does show a much higher value, same as before, reinforcing the theory that more collisions are being observed at illuminated sites and that possibly the factors producing them were not related to lighting but to other issues related to the driver or the vehicles.

Table 4.7 **Frequency analysis for non-weather dependent collisions-300m segments-Method 2**

ln_count	Coef.	Std. Err.	z	P>z	95% Conf. Interval
Posted Speed	**−0.02**	0.00	−7.32	**0.00**	−0.03 to −0.01
ln(AADT)	**0.37**	0.09	4.09	**0.00**	0.19 to 0.55
Illuminance (lux)*	**0.00**	0.00	1.490	**0.13**	−0.001 to 0.01
_cons	−1.63	0.79	−2.06	0.04	−3.19 to −0.07

Note*: Weather independent illuminance measured the same day for all segments.

4.2 Conclusion

Weather conditions for the case study of Arthabasca were not found to impact road collisions during night time for the region analyzed. For all segment size analyses, it was found that higher values of traffic volume and illuminance explained more frequent collisions.Higher posted speed was associated with less frequent collisions. This should be further analyzed without changing the actual conditions of the road in the analysis and the results are presented in the following chapter.

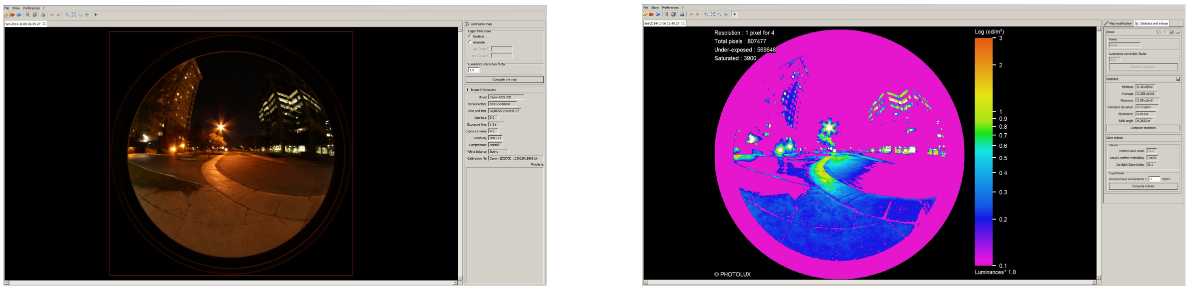
5. Case Study of Arthabaska region

5.1 Introduction

Road collisions will impact adversely thousands of person's lives. Road accidents were ranked 8^{th} among the top ten leading causes of death in 2011 (WHO). Majority of the existing research focuses on intersections and interchanges (Abdel-Aty et al. 2005, Santiago-Chaparro et al. 2010, Lord and Persuad 2000, Lovegrove and Sayed 2006). Few researchers had concentrated in road segments (Jonsson, Ivan and Zhang 2007). This difference in research importance given to intersections is because more road accidents are observed at intersections (Barua, Azad and Tay 2010). Collision frequency typically responds to higher volumes of traffic(El-Basyouny et al. 2006 and Hadayeghi et al.2006), the presence of complex geometries in particular combinations of horizontal and vertical curves (Eassa et al. 2009 and Hummer et al. 2010).

Wet slippery surfaces also contribute to explain a larger number of road collisions (Bullas et al. 2013 and Gilfillan et al. 2000). Urban sites seem to receive more attention than rural ones (Karlaftis et al. 2002 and El-Basyouny et al. 2010) with constant efforts on improving safety at either urban sites or intersections (Feldman et al. 2010), some of them had to look into traffic calming (Zein et al. 1997). Typical studies focus on motorized vehicles particularly cars, although other research had focused on motorcycles (Haque et al. 2010) or pedestrians (Lyon et al. 2002) highlighting the need to count with pedestrian counts to be able to estimate the presence of nonmotorized users and therefore incorporate safety requirements of this type of users. This is especially true for night time road collisions in which current guidelines (IESNA 2005) and TAC (TAC 2006) establish decision criteria for illumination warrant and levels (G3, G5) on the basis of the presence of pedestrians.

Research has proven that many severe accidents occur at night time (Isebrands et al. 2010) particularly involving pedestrians (Zhou et al. 2009). The typical countermeasure for night time collisions is roadway lighting (Rea et al. 2009). (TAC 2004) acknowledges a reduction of collisions at road segments to which lighting is provided as a countermeasure, in particular with effectiveness between 10 to 40% of all crashes observed and up to 65% of fatal crashes. Isebrands et al. 2010 found 37% reduction in crash rate. This is also supported by (International Commission on Illumination 1992) that found a lot of studies before 1992 revealing that nighttime accidents result in more severe accidents and that lighting did help reduce their frequency. Several studies have been conducted for examining the relationship between roadway lighting levels and safety. (Zhou et al. 2009) investigated how maintained illuminance levels impact the safety of pedestrians, finding a higher frequency of pedestrian crashes at sites with a low level of lighting. Similar findings got (Isebrands et al. 2010) for Minnesota. (Yannis et al. 2013) found that road lighting contributes to reduce accident frequency and especially reduce the number of persons killed and seriously injured in a study conducted with data from urban and rural roads in Greece. One of the main issues is the lack of understanding of the role of different weather circumstances on road collisions at night time.



(a) **Image analysis using Photolux software** (b) **Statistical analysis using Photolux software**

Fig. 5.1 **Photolux Software**

5.2 Objective

This chapter investigates if levels of lighting under various weather conditions do impact collisions rates and severity during night time.

5.3 Methodology

A case study of the Arthabaska region in Quebec is presented. Tests are conducted to verify if lighting measurements taken during the same day, bias the results in comparison to lighting levels considering the type of weather during the time of the accident. To do this, various measurements of lighting are conducted during different weather conditions, and those values are attached to each historical collision following the weather reported by the police report. Lighting values were collected for luminance in candela per square meter (cd/m^2) and illuminance in lux. These values were estimated by professional software photolux as illustrated in Figure 5.1

5.3.1 Safety Regression Model

Road collisions are count data and as such follow unique types of regression models. Poisson regression is one of such special cases; it is applicable when the mean of the observed response is close to the variance. Negative binomial is the other common choice, which does not require to satisfy the previous assumption. Another interesting consideration is the fact that in safety analysis often the dependent variable encounters many observations with zero value. Under such situation, one must use inflated approaches for the analysis.

Negative Binomial and Zero inflated negative binomial were used in this study. The functional form used for this analysis was traditional which considers traffic volume as the primary predictor in conjunction with a vector of independent variables and associated parameters to be estimated and interpreted on the analysis. Equation 5.1 shows the functional form for this case study.The length was ignored given all segments were of the same size.

$$Y = AADT^{\alpha} e^{\beta \mathrm{x}} \tag{5.1}$$

Where α and β are estimators of the true parameters, and x is a vector of observed independent variables. AADT refers to Annual Average Daily Traffic.

5.3.2 Data Aggregation

Two methods were used to aggregate collisions. Method 1 aggregated the values of weather dependent illuminance over the same segment. Method 2 aggregated all collisions occurring under the same weather condition over the corresponding road segment (sizes 100m, 300m, 500m). This means that the same segment may appear on the database various times if it observed collisions during different weather conditions. The following is a sample of the database used for the analysis (Table 5.1).

Table 5.1 **Sample from the database used for Method 2**

Posted Speed (km/hr)	**AADT**	**Collision Count**	**Luminance (cd/m^2)**	**Illuminance (lux)**	**Avg. UGI**
50	2800	9	2.50	8.42	−11.37
50	5032	8	3.50	11.80	−31.50
50	5032	8	2.49	8.40	−13.56
90	12300	8	2.49	8.40	−13.56
90	12300	8	2.49	8.40	−13.56
60	2166	7	2.49	8.40	−13.56
50	5032	7	2.50	8.42	−11.37
90	3900	6	2.49	8.40	−13.56
90	12300	6	2.50	8.42	−11.37
50	5032	4	3.45	11.40	−10.87
60	2166	4	3.50	11.80	−31.50
70	16600	4	2.49	8.40	−13.56
70	12300	4	2.49	8.40	−13.56

5.4 Analysis

The database created in the previous chapter is used for the analysis.The analysis is done for segments of 100m, 300m and 500m respectively for the two above mentioned methods. A correlation analysis revealed very high dependency of UGI(Unified Glare Index) and luminance (cd/m^2) (Table 5.2, 5.3,5.4).

Two analysis were prepared one for weather dependent and another one for non-dependent. Values of illuminance (in lux) taken on the same day with winter conditions, under a clear sky, with no snow on the ground were used as a non-weather dependent benchmark. Specific values of various weather conditions collected during different seasons of the year were attached to the database to reflect the effect of the weather on the amount of illuminance (lux) during the time of the collision. Data was collected with the aid of a specialized software Photolux and a professional camera with a fish-eye lens. ZINB regression is used here as the data contains a significant number of zero observations. Posted speed is used to inflate

Table 5.2 **Correlation Analysis (100m)**

	Posted Speed	**AADT**	**Luminance (cd/m^2)**	**Illuminance (lux)**	**Avg. UGI**
Posted Speed	**1**				
AADT	**0.07**	**1**			
Luminance (cd/m^2)	**-0.46**	**0.20**	**1**		
Illuminance (lux)	**-0.12**	**0.13**	**0.33**	**1**	
Glare UGI	**0.44**	**-0.19**	**-0.98**	**-0.32**	**1**

Table 5.3 **Correlation Analysis (300m)**

	Posted Speed	**AADT**	**Luminance (cd/m^2)**	**Illuminance (lux)**	**Avg. UGI**
Posted Speed	**1**				
AADT	**0.06**	**1**			
Luminance (cd/m^2)	**-0.61**	**0.19**	**1**		
Illuminance (lux)	**-0.23**	**0.14**	**0.44**	**1**	
Glare UGI	**0.58**	**-0.18**	**-0.95**	**-0.41**	**1**

Table 5.4 **Correlation Analysis (500m)**

	Posted Speed	AADT	Luminance (cd/m^2)	Illuminance (lux)	Avg. UGI
Posted Speed	**1**				
AADT	**0.07**	**1**			
Luminance (cd/m^2)	**-0.63**	**0.19**	**1**		
Illuminance (lux)	**-0.28**	**0.05**	**0.46**	**1**	
Glare UGI	**0.58**	**-0.17**	**-0.94**	**-0.43**	**1**

the as the number of accidents vary according to the speed to a great extent. In addition to that as the variance is much larger than the mean, ZINB is preferred. Table 5.5 shows the observation count for the database created.

Table 5.5 **Number of Observations**

Segments	METHOD 1 (Observations)			METHOD 2 (observations)		
	Total	**Zero**	**Non-Zero**	**Total**	**Zero**	**Non-Zero**
100 m	976	656	320	3780	3295	485
300 m	325	103	222	1260	869	391
500 m	195	33	162	765	429	336

5.4.1 100m

Analysis for the weather dependent and independent data were made for segments of 100 meters that includes 976 total observations along with 656 zero observations for method 1 and 3780 total observations along with 3295 zero observations for method 2.

Tables 5.6 and 5.7 shows the results of the first two methods. In the first method with regards to the frequency of the accidents, both values of Illuminance (weather dependent and weather independent) are insignificant. On the other hand Luminance and UGI values are significant and they are directly and indirectly proportional to the frequency of the collisions respectively. But in regards to severity, both weather dependent and independent values become insignificant.

For the second method, in relation to frequency all weather dependent values are significant whereas weather independent value proves to be insignificant. Both Illuminance and UGI values are indirectly proportional to the count of the accidents while Luminance is directly proportional to the number of accidents. In terms of severity, all values prove to be insignificant.

5.4.2 300m

The same analysis is done for the 300m segments. This database includes 325 total observations along with 103 zero observations for method 1 and 1260 total observations along with 869 zero observations for method 2.

Tables 5.6 and 5.7 shows the results of the first two methods. In the first method with regards to the frequency of the accidents, values of Illuminance (weather independent) are insignificant. On the other hand, weather dependent values (Illuminance, Luminance and UGI) are significant. Both Illuminance and Luminance values are directly proportional to the number accidents. While, UGI is indirectly proportional. With regards to severity, both weather dependent and independent values become insignificant.

For the second method, in relation to frequency, both Luminance and Illuminance (Weather dependent) vales are significant whereas weather independent value and UGI (weather dependent) proves to be insignificant. Illuminance values are indirectly proportional to the count of the accidents while Luminance is directly proportional to the number of accidents. In terms of severity, all weather dependent values are significant. Both Luminance and Illuminance values are indirectly proportional to the severity of the accidents. While, UGI value is directly proportional to the severity of the accidents.

5.4.3 500m

The same analysis is done for 500m. The database includes 195 total observations with 33 zero observations for the first method and 756 total observations with 429 zero observations for the second method.

Tables 5.6 and 5.7 shows the results of the first two methods. In the first method with regards to the frequency of the accidents, values of Illuminance (weather independent) are insignificant. On the other hand, weather dependent values (Illuminance, Luminance and UGI) are significant. Both Illuminance and Luminance values are directly proportional to the number accidents. While, UGI is indirectly proportional. With regards to severity, both weather dependent and independent values become insignificant.

For the second method, in relation to frequency, Illuminance (Weather dependent) vales are significant whereas weather independent value, Luminance and UGI (weather dependent) proves to be insignificant. Illuminance values are indirectly proportional to the count of the accidents. In terms of severity, all weather dependent values are significant. Both Luminance and Illuminance values are indirectly proportional to the severity of the accidents. While, UGI value is directly proportional to the severity of the accidents.

Table 5.6 **Regression Analysis results**

Method-1

Frequency	**100 m**		**300 m**		**500 m**	
	Coeff	**P-value**	**Coeff**	**P-value**	**Coeff**	**P-value**
Illuminance*	0.0026	0.4170	-0.0010	0.7380	0.0061	0.1450
Illuminance	-0.1400	0.1030	**0.3652**	**0.0580**	**0.0604**	**0.0030**
Luminance	**0.3531**	**0.0000**	**0.2146**	**0.0020**	**0.2773**	**0.0000**
UGI	**-0.0634**	**0.0000**	**-0.0362**	**0.0050**	**-0.0510**	**0.0000**
Severity	**100 m**		**300 m**		**500 m**	
	Coeff	**P-value**	**Coeff**	**P-value**	**Coeff**	**P-value**
Illuminance*	-0.0019	0.7450	-0.0063	0.4860	0.0360	0.3360
Illuminance	-0.0225	0.2910	0.0093	0.7790	-0.0070	0.5620
Luminance	0.0537	0.6700	0.1050	0.4720	0.2404	0.1040
UGI	-0.0184	0.4140	-0.0173	0.5180	-0.0400	0.1620

Note*: Weather independent illuminance measured the same day for all segments.

Table 5.7 **Regression Analysis results**

Method-2

Frequency	**100 m**		**300 m**		**500 m**	
	Coeff	**P-value**	**Coeff**	**P-value**	**Coeff**	**P-value**
Illuminance*	0.0027	0.2030	0.0022	0.3860	0.0035	0.2650
Illuminance	**-0.0186**	**0.0050**	**-0.0248**	**0.0090**	**-0.0267**	**0.0270**
Luminance	**0.3551**	**0.0000**	**0.1303**	**0.0230**	0.0429	0.4760
UGI	**-0.0514**	**0.0000**	-0.0143	0.1190	-0.0043	0.6470
Severity	**100 m**		**300 m**		**500 m**	
	Coeff	**P-value**	**Coeff**	**P-value**	**Coeff**	**P-value**
Illuminance*	-0.0050	0.5550	-0.0038	0.6120	-0.0090	0.4750
Illuminance	-0.0450	0.1330	**-0.0623**	**0.0530**	**-0.0983**	**0.0140**
Luminance	-0.1668	0.2470	**-0.2555**	**0.0550**	**-0.4125**	**0.0070**
UGI	0.0373	0.1710	**0.0491**	**0.0470**	**0.0724**	**0.0100**

Note*: Weather independent illuminance measured the same day for all segments.

5.4.4 Results and Discussion

- It is evident from the above results, in regards to the case study, weather does have an impact on the severity and frequency of collisions for the given stretch of the road.

- Second method should be preferred to first method since second method is consistent and it shows the significance of the values. It is important to note that the second method proves the significance of the severity of the accidents of all weather dependent values for the segments of 300m and 500m. First method can be used for initial analysis depending on the availability of the information but for a detailed analysis and for an in-depth result, second method is recommended. This is evident from the tables 5.6 and 5.7.

- In terms of the size of the segments, it is evident that 300m and 500m are the best in explaining the impact of the weather since some of the weather dependent values in relation to frequency and all of the weather dependent values in relation to severity is significant and explains the impact of weather on night time accidents. It is evident from the table 5.7. In addition to this, hausman test is conducted for the above segments for both frequency and severity. The results shows that, it is optimal to rely on severity to understand the impact of weather. The results of the test are given in the table 5.8

Table 5.8 **Hausman test method 2**

Frequency	**300m**	**500m**
Chi sq	12.27	2.15
P value	**0.00**	0.34
Severity	**300m**	**500m**
Chi sq	5.07	6.76
P value	**0.08**	**0.03**

- It is also evident from table 5.7 that severity explains the impact in 300m and 500m segments for method 2 while the frequency explains the impact in 100m segments.

- Posted speed values are indirectly proportional to the severity of collisions. i.e., The severity of collisions decrease with the increase in the values. This explains that the standard values must be changed for reducing the severity of accidents in the stretch of the road. These results are evident from the tables 5.9 to 5.16.

- AADT values are significant but they fail to represent the proportionality. This is evident from the tables 5.9 to 5.16.

- Weather independent values seem to not explain the impact on collisions for both the frequency and the severity.

- Weather dependent values such as Luminance and Illuminance of 300m and 500m are indirectly proportional to the severity of the accidents. It is evident from the tables 5.6 and 5.7.

- UGI values are directly proportional, stating that for the higher values of glare, severity of accidents is greater. It is evident from the tables 5.6 and 5.7.

Table 5.9 **Severity analysis - 500m segments- Method 2 (weather independent)**

Accident Severity	**Coef.**	**Std. Err.**	**z**	**P>z**	**95% Conf. Interval**
Posted Speed	-0.02	0.01	-1.45	0.15	-0.03 to -0.01
AADT	**0.00**	0.00	2.50	**0.01**	0.0000 to 0.0002
Illuminance (lux)*	-0.01	0.01	-0.71	0.48	-0.03 to 0.02
_cons	-2.06	0.86	-2.38	0.02	-3.75 to -0.36

Note*: Weather independent illuminance measured the same day for all segments.

Table 5.10 **Severity analysis - 500m segments-Method 2 (weather dependent)**

Accident Severity	**Coef.**	**Std. Err.**	**z**	**P>z**	**95% Conf. Interval**
Posted Speed	**-0.03**	0.01	-2.58	**0.01**	-0.06 to -0.01
AADT	**0.00**	0.00	3.10	**0.00**	0.0001 to 0.0002
Illuminance (lux)	**-0.10**	0.04	-2.46	**0.01**	-0.18 to -0.02
_cons	-0.59	1.04	-0.57	0.57	-2.63 to 1.45

Table 5.11 **Severity analysis-500m segments-Method 2 (weather dependent)**

Accident Severity	**Coef.**	**Std. Err.**	**z**	**P>z**	**95% Conf. Interval**
Posted Speed	**-0.03**	0.01	-2.73	**0.01**	-0.06 to -0.01
AADT	**0.00**	0.00	3.14	**0.00**	0.0001 to 0.0002
Luminance	**-0.41**	0.15	-2.72	**0.01**	-0.71 to -0.12
_cons	-0.31	1.08	-0.29	0.77	-2.44 to 1.81

Table 5.12 **Severity analysis-500m segments-Method 2 (weather dependent)**

Accident Severity	**Coef.**	**Std. Err.**	**z**	**P>z**	**95% Conf. Interval**
Posted Speed	**-0.03**	0.01	-2.64	**0.01**	-0.06 to -0.01
AADT	**0.00**	0.00	3.07	**0.00**	0.0001 to 0.0002
UGI	**0.07**	0.03	2.57	**0.01**	0.02 to 0.13
_cons	-0.54	1.04	-0.52	0.61	-2.57 to 1.50

Table 5.13 **Severity analysis-300m segments-Method 2** (weather independent)

Accident Severity	Coef.	Std. Err.	z	P>z	95% Conf. Interval
Posted Speed	-0.01	0.01	-1.22	0.22	-0.03 to 0.01
AADT	**0.00**	0.00	2.51	**0.01**	0.00002 to 0.0002
Illuminance (lux)*	-0.004	0.01	-0.51	0.61	-0.02 to 0.01
_cons	-2.94	0.71	-4.12	0.00	-4.34 to -1.54

Note*: Weather independent illuminance measured the same day for all segments.

Table 5.14 **Severity analysis-300m segments-Method 2 (weather dependent)**

Accident Severity	Coef.	Std. Err.	z	P>z	95% Conf. Interval
Posted Speed	**-0.02**	0.01	-2.11	**0.04**	-0.04 to -0.001
AADT	**0.00**	0.00	2.93	**0.00**	0.00004 to 0.0002
Illuminance (lux)	**-0.06**	0.03	-1.94	**0.05**	-0.13 to 0.00
_cons	-2.04	0.84	-2.43	0.02	-3.68 to -0.40

Table 5.15 **Severity analysis-300m segments-Method 2 (weather dependent)**

Accident Severity	Coef.	Std. Err.	z	P>z	95% Conf. Interval
Posted Speed	**-0.02**	0.01	-2.10	**0.04**	-0.04 to -0.001
AADT	**0.00**	0.00	2.91	**0.00**	0.00004 to 0.0002
Luminance	**-0.26**	0.13	-1.92	**0.06**	-0.52 to 0.01
_cons	-1.97	0.87	-2.27	0.02	-3.68 to -0.27

Table 5.16 **Severity analysis of collisions-300m segments-Method 2 (weather dependent)**

Accident Severity	**Coef.**	**Std. Err.**	**z**	**P>z**	**95% Conf. Interval**
Posted Speed	**-0.02**	0.01	-2.14	**0.03**	-0.04 to -0.002
AADT	**0.00**	0.00	2.91	**0.00**	0.00004 to 0.0002
UGI	**0.05**	0.03	1.99	**0.05**	0.01 to 0.10
_cons	-1.97	0.85	-2.31	0.02	-3.64 to -0.30

5.5 Conclusion

Weather conditions for the case study of this exploratory study were found to impact road collisions during night time for the region analyzed. For all segment size analysis, it was found that higher values of UGI explained more severe collisions. Higher posted speed, luminance and illuminance (weather dependent) were associated with less frequent severe collisions. The effect of other factors such as crashes with animals, driving while impaired, etcetera, should be further investigated.

Comparing this to the previous analysis, it can be proved that, the presence or absence of non-lit conditions should be considered in order to obtain a clear result on the impact of weather on lighting. This proves the fact that, as opposed to the previous results that weather dependent illuminance contribute to the severity and collision rate when associated with the weather.

6. Conclusion and Future research

6.1 Conclusion

6.1.1 From the literature review

A comprehensive review of the literature on the role of lighting on nighttime accidents found that artificial lighting plays a vital role in reducing accidents. Yet, presence of various other factors can impact the rate of collisions. The literature identified that both severity and frequency of the accidents should be considered as both these factors can help to serve different schemes. Most studies follow the traditional method of integrating the complete length of the road segment into safety functions.

In conclusion, it was found that lighting and the weather were considered as a separate entity and so it is necessary to investigate the impact of weather on lighting on nighttime collisions. It was also found that, as opposed to the conventional methods, it is necessary to separate the length of the road into segments in order to incorporate the point data of the lighting parameters. It was also concluded that the method to be devised should be based on the crash history.

6.1.2 From Pre-analysis

It is important to consider the fact of the presence of artificial lighting. It is necessary to split the road into linear segments as the lighting parameters are in the form of points. The splitting of segments gives us a detailed analysis of the extent in which the parameters are impacting the accidents. Road segments are used in the analysis as opposed to the conventional methods as the variations in the data can be analyzed better using this method. This model consists of operational and lighting parameters to find the impact of the weather on nighttime accidents.

Weather does not seem to have an impact on the collisions rate and higher values of illuminance (both weather dependent and independent) explained more collisions. Higher posted speed explains less collisions for this case study. This study reinforces the fact from previous studies that illuminance have a smaller impact on the number of accidents and more collisions are observed and possibly they are related to other factors.

6.1.3 From the case study analysis

This case study proposes two different methods to analyze the impact of weather on nighttime accidents. A zero-inflated negative binomial model is used due to the dispersion of count data and more number of zero collisions. Here, it is proved that weather is one of the factor affecting the lighting during night time accidents and it is important to work on other factors in the future investigation.

Weather conditions were found to impact road collisions considering weather for the given stretch of the road. Higher values of Posted speed, weather dependent illuminance and luminance are found to reduce the severity of accidents. In contrast, higher values of weather dependent glare increase the severity of accidents. Second method should be preferred to first method since second method is consistent and it shows that the weather dependent values are significant. In terms of the size of the segments, it is evident that 300m and 500m are the best in explaining the impact of the weather

6.1.4 Novelty of the thesis

This research explores the impact of weather on lighting during nighttime accidents. It provide the results with evidences statistically. Two new methods are proposed to analyze the data. The methods provide a justifiable way for the people to support their recommendations using statistical analysis that link lighting parameters to reduce the number and severity of accidents or other parameters.

The methods recommended here can be used by any transportation department in the world, not only just those in North America because they are universal and simpler to follow. For researchers and analysts, the methods proposed in this research that are evidence-based create a new structure that could be used in identical problems and applications. Few such applications include designing of engineering facilities and infrastructure to support from the perspective of policy decision making. In addition to that, researchers will have the access to a very large database that can be used for future analysis involving road lighting and safety.

6.2 Future research

The methods devised in this thesis are not confined only to this case study and it can be applicable to any case study. Further research should be carried out to find the impact of weather on lighting that affects the rate of severity with other parameters of nighttime accidents. The database prepared for this research can be used to find the result. Further, research should be done on roads with and without artificial lighting to understand their impact separately. This study is limited to nighttime accident frequency and severity. Further study should look into expanding the time limit in understanding the impact of weather.

This research study is limited to some major environmental conditions. Future studies must expand the conditions including wind, fog and other sub-environmental conditions. The impact of other factors such as crashes with animals, driving impairment, etcetera, should be further investigated. Further, the role of other commercial lighting should be investigated.

This research should be carried out extensively for different weather conditions with different lighting parameters to understand their impact on the collisions. Future research can be done to calibrate the street lighting parameters during different weather conditions to reduce the number of accidents. Additional road types and color of the lighting should be investigated. Other visibility indicators can be used to deepen the analysis.

References

Abdel-Aty, M., Keller, J., and Brady, P.A (2005). Analysis of Types of Crashes at Signalized Intersections by Using Complete Crash Data and Tree-Based Regression. Transportation Research Record: Journal of the Transportation Research Board. 2005; 1908: 37-45.

Al-Dulaimi, M. (2016). A Method to Calibrate Roadway Lighting Warrants and Levels with Crash-History (Doctoral dissertation, Concordia University).

American national standard practice for roadway lighting. (2005). New York, NY: Illuminating Engineering Society of North America.

Andrey, J. C., Mills, B. E., & Vandermolen, J. (2001). Weather information and road safety.

Andrey, J.; Mills, B.; Leahy, M.; Suggett, J (2003). Weather as a chronic hazard for road transportation in Canadian cities. Nat. Hazards 2003, 28, 319–343.

Aultman-Hall, L., Safety Issues concerning Sidewalk Bicycling, presented to the Canadian Multidisciplinary Road Safety Conference, Toronto June 1997

Balk, S., & Tyrrell, R. (2011). The Accuracy of Drivers' Judgments of the Effects of Headlight Glare: Are We Really Blinded by the Light?.

Barua, U., Azad, A.K., and Tay, R (2010). Fatality Risk of Intersection Crashes on Rural Undivided Highways in Alberta, Canada. Transportation Research Record: Journal of the Transportation Research Board. 2010; 2148: 107-115.

Bassani M, Mutani G (2012) Effects of environmental lighting conditions on operating speeds on urban arterials. Transp Res Rec. doi:10.3141/2298-09.

Beyer, F. R., & Ker, K. (2009). Street lighting for preventing road traffic injuries. The Cochrane Library.

Blincoe LJ (2000), The economic impact of motor vehicle crashes 2000. Washington, DC, National Highway Traffic Safety Administration, 2002 (Report No. DOT HS-809-446).

Brémond, R., Bodard, V., Dumont, E., & Nouailles-Mayeur, A. (2013). Target visibility level and detection distance on a driving simulator. Lighting Research & Technology, 45(1), 76-89.

Bullas, J. C. (2013). Tyres. Road Surfaces and Reducing Accidents: A Review: A report on Research Carried Out for the AA Foundation for Road Safety Research and the County Surveyors' Society.

Canadian Motor Vehicle Traffic Collision Statistics (2015). Canada: Transports Canada, Collected in cooperation with the Canadian Council of Motor Transport Administrators.

Chen, D., & Chen, H. W. (2013). Using the Köppen classification to quantify climate variation and change: an example for 1901–2010. Environmental Development, 6, 69-79.

Chenani, S. B., Maksimainen, M., Tetri, E., Kosonen, I., & Luttinen, T. (2016). The effects of dimmable road lighting: A comparison of measured and perceived visibility. Transportation research part F: traffic psychology and behaviour, 43, 141-156.

Cho, S., & Dhingra, V. (2008, April). Street lighting control based on LonWorks power line communication. In Power Line Communications and Its Applications, 2008. ISPLC 2008. IEEE International Symposium on (pp. 396-398). IEEE.

Climate Change Impacts in the United States: The Third National Climate Assessment, J. M. Melillo, Terese (T.C.) Richmond, and G. W. Yohe, Eds., U.S. Global Change Research Program, 130-149. doi:10.7930/J06Q1V53.

Comission de toponymie of Quebec, 2013

Cools, M.; Creemers, L. The dual role of weather forecasts on changes in activity-travel behaviour (2013). J. Transp. Geogr. 2013, 28, 167–175.

Cools, M.; Moons, E.; Wets, G (2010). Assessing the impact of weather on traffic intensity. Weather Clim. Soc. 2010, 2, 60–68.

Crabb, G. I., Crinson, L., Beaumont, R., & Walter, L. (2008). The impact of street lighting on nighttime road casualties. Transport Research Laboratory, Wokingham, Berkshire.

Deeb, G. R., Braun, S., Carrico, C., Kinser, P., Laskin, D., & Golob Deeb, J. (2018). Burnout, depression and suicidal ideation in dental and dental hygiene students. European journal of dental education, 22(1), e70-e74.

Eassa, S. M., and You, Q. C (2009). Collision Prediction Models For Three-Dimensional Two-Lane Highways: Horizontal Curves. Transportation Research Record: Journal of the Transportation Research Board. 2009; 2092: 128-136.

El-Basyouny, K. and Sayed, T (2006). Comparison of Two Negative Binomial Regression Techniques in Developing Accident Prediction Models. Transportation Research Record: Journal of the Transportation Research Board. 2006; 1950: 9-16.

El-Basyouny, K. and Sayed, T (2010). Full Bayes Approach to Before-and-After Safety Evaluation with Matched Comparisons: Case Study of Stop-Sign In-Fill Program. Transportation Research Record: Journal of the Transportation Research Board. 2010; 2148: 1-8.

Environment Canada. (2012). National climate data and information archive.

Feldman, M., Manzi, J.G (2010)., and Mitman, M.F. An Empirical Bayesian Evaluation of the Safety Effects of High-Visibility School (Yellow) Crosswalks in San Francisco. Transportation Research Record: Journal of the Transportation Research Board. 2010.

Gilfillan, G (2000). Road Safety Benefits of Liquid Anti-Icing Strategies and Agents: Kamloops, British Columbia, Canada. Transportation Research Record: Journal of the Transportation Research Board. 2000; 1700: 24-31.

Global status report on road safety 2015. (2015). Geneva, Switzerland: World Health Organization.

Golob, T. F., & Recker, W. W. (2001). Relationships among urban freeway accidents, traffic flow, weather and lighting conditions.

Gorea, R. K. (2016). Financial impact of road traffic accidents on the society. International journal of ethics, trauma and victimology, 2(1), e6494-e6494.

Green, M (1983). Contrast detection and direction discrimination of drifting gratings. Vision Research, 23, 281-289.

Habib, P. A., Edelstein, R. P., & Nwankwor, O. I. (1978). Analysis of Pedestrian Crosswalk Safety on One-way Street Networks (No. DOT/RSPA/DPB50/78/28Final Rpt.).

Hadayeghi, A., Malone, B., and De Gannes, R (2006). Development of New Crash Experience Warrants for Traffic Signals in Ontario, Canada. Transportation Research Record: Journal of the Transportation Research Board. 2006; 1953: 120-127.

Haque, M.M. and Chin, H.C (2010). A Mixed Logit Analysis on The Right-Angle Crash Vulnerability of Motorcycles at Signalized Intersections. Transportation Research Record: Journal of the Transportation Research Board. 2010.

Hasson, P. and P. Lutkevich(2002). "Roadway Lighting Revisited." Public Roads. May/June 2002.

How Do Weather Events Impact Roads? (2017). USA: U.S. Department of Transportation. Retrieved from https://ops.fhwa.dot.gov/weather/q1_roadimpact.htm

Hummer J.E., Rasdor, W, and Findley (2010), D.J. Curve Collisions: Road and Collision Characteristics and Countermeasures. Journal of Transportation Safety & Security. 2010; 2(3): 203-220.

IESNA, L. H. (2000). Reference and application volume. New York: Illuminating Engineering Society of North America.

Illuminating Engineering Society of North America (2005). Roadway Lighting: American Standard Practice for Roadway Lighting. New York: IESNA Publication; 2005. Report RP-08-00.

International Commission on Illumination. Road Lighting as an Accident Countermeasure. 1992. Austria: CIE Publications; 1992. Research Report CIE093-1992.

Isebrands, H.N., Hallmark, S.L., Li, W., McDonald, T., Storm, R., and Preston, H (2010). Roadway Lighting Shows Safety Benefits at Rural Intersections. Journal of Transportation Engineering. 2010; 36(11): 949 – 955.

Islam, M. B., & Kanitpong, K. (2008). Identification Of Factors In Road Accidents Through In-Depth Accident Analysis. IATSS Research, 32(2), 58-67. doi:10.1016/s0386-1112(14)60209-0.

Jacobs G, Aeron-Thomas A, Astrop A (2000). Estimating global road fatalities. Crowthorne, Transport Research Laboratory, 2000 (TRL Report, No. 445).

Jägerbrand, A. K., & Sjöbergh, J. (2016). Effects of weather conditions, light conditions, and road lighting on vehicle speed. SpringerPlus, 5(1), 505.

Jaroszweski, D.; McNamara, T (2014). The influence of rainfall .on road accidents in urban areas: A weather radar approach. Travel Behav. Soc. 2014, 1, 15–21.

Jonsson, T., Ivan, J.N., and Zhang, C (2007). Crash Prediction Models for Intersections on Rural Multilane Highways: Differences by Collision Type. Transportation Research Record: Journal of the Transportation Research Board. 2007.

Karlaftis, M.G (2002). Effects Of Road Geometry and Traffic Volumes on Rural Roadway Accident Rates. Journal of Accident Analysis & Prevention. 2002; 34(3): 357-365.

LaFlamme L (1998). Social inequality in injury risks: knowledge accumulated and plans for the future. Stockholm, National Institute of Public Health, 1998.

Leard, B., & Roth, K. (2015). Weather, Traffic Accidents, and Climate Change. Resources For the Future Discussion Paper, 15-19.

Liu, A., Soneja, S. I., Jiang, C., Huang, C., Kerns, T., Beck, K., ... & Sapkota, A. (2017). Frequency of extreme weather events and increased risk of motor vehicle collision in Maryland. Science of the Total Environment, 580, 550-555.

Lord, D. and Persuad, B. N (2000). Accident Prediction Models With And Without Trend: Application Of The Generalized Estimating Equations Procedure. Transportation Research Record: Journal of the Transportation Research Board. 2000; 1717: 102-108.

Lovegrove, G. and Sayed, T (2006). Using Macro-Level Collision Prediction Models in Road Safety Planning Applications. Transportation Research Record: Journal of the Transportation Research Board. 2006; 1950: 73–82.

Lyon, C., and Persuad, B (2002). Pedestrian Collision Prediction Models for Urban Intersections. Transportation Research Record: Journal of the Transportation Research Board. 2002; 1818:102-107.

Master, A. O. (2017). The Atlas of Canada - Climate Change. Retrieved from https://web.archive.org/web/20120511103444/http://atlas.nrcan.gc.ca/site/english/maps/climatechange

Matout, N. (2013). Estimation of the Influence of Artificial Roadway Lighting on Road Collision Frequency (Doctoral dissertation, Concordia University).

Murray, I. J., Plainis, S., Chauhan, K., & Charman, W. N. (1998). Road traffic accidents: The impact of lighting. Lighting Journal, 63(3), 42-3.

Nantulya VM, Muli-Musiime F (2001). Uncovering the social determinants of road traffic accidents in Kenya. In: Evans T et al., eds. Challenging inequities: from ethics to action. Oxford, Oxford University Press, 2001:211–225.

National Research Council Canada. Ottawa. Canada. NRCC [online]. Available from http://www.nrc-cnrc.gc.ca/eng/services/sunrise/advanced.html.

NHTSA (2007), Nighttime Glare and Driving Performance: Research Findings Retrieved from https://www.nhtsa.gov/sites/nhtsa.dot.gov/files/glare_congressional_report.pdf

Nurmi, V.; Perrels, A.: Nurmi, P.; Michaelides, S.; Athanasatos, S (2012). Economic Value of Weather Forecasts on Transportation—Impacts of Weather Forecast Quality Developments to the Economic Effects of Severe Weather. Available online: http://ewent.vtt.fi/Deliverables/D5/D5_2_16_02_2012_revised_final.pdf

Odero W, Khayesi M, Heda PM (2003). Road traffic injuries in Kenya: magnitude, cause and status of intervention. Injury Control and Safety Promotion, 2003, 10:53–61.

Peden M, McGee K, Sharma G (2002). The injury chart book: a graphical overview of the global burden of injuries. Geneva, World Health Organization, 2002.

Peden, M,; Scurfield, R.; Sleet, D.; Mohan, D.; Hyder, A.A.; Jarawan, E.; Mathers, C (2004). World Report on Road Traffic Injury Prevention; World Health Organisation: Geneva, Switzerland, 2004.

Peden, M. (2004). World report on road traffic injury prevention: Information kit. Geneva, Switzerland: World Health Organization.

Perrels, A., Votsis, A., Nurmi, V., & Pilli-Sihvola, K. (2015). Weather conditions, weather information and car crashes. ISPRS International Journal of Geo-Information, 4(4), 2681-2703.

Perrels, A., Votsis, A., Nurmi, V., & Pilli-Sihvola, K. (2015). Weather conditions, weather information and car crashes. ISPRS International Journal of Geo-Information, 4(4), 2681-2703.

Phillips, D.. R. The Canadian Encyclopedia. (2006). Rainfall extremes. Retrieved June 14, 2018 From https://www.thecanadianencyclopedia.ca/en/article/rainfall-extremes/

Plainis, S., Murray, I. J., & Pallikaris, I. G. (2006). Road traffic casualties: understanding the night-time death toll. Injury Prevention, 12(2), 125-138.

Plainis, S., Murray, I. J., & Pallikaris, I. G. (2006). Road traffic casualties: understanding the night-time death toll. Injury Prevention, 12(2), 125-138.

Qiu, L., & Nixon, W. (2008). Effects of adverse weather on traffic crashes: systematic review and meta-analysis. Transportation Research Record: Journal of the Transportation Research Board, (2055), 139-146.

Rea, M.S., Bullough, J.D., and Zhou, Y. A Method for Assessing the Visibility Benefits of Roadway Lighting. Lighting Research Technology. 2009; 42: 215-241.

Rumar K (1999). Transport safety visions, targets and strategies: beyond 2000. Brussels, European Transport Safety Council, 1999 (1st European Transport Safety Lecture (http://www.etsc.be/eve.htm)

SAAQ, (2017). Road Safety Record. Retrieved from https://saaq.gouv.qc.ca/en/saaq/documents/road-safety-record/

Santiago-Chaparro, K. R., Qin, X., and Noyce, D.A (2010). Proposed Safety Index Based on Risk-Taking Behavior of Drivers. Transportation Research Record: Journal of the Transportation Research Board. 2010; 2147:51-57.

Schwartz, H. G., M. Meyer, C. J. Burbank, M. Kuby, C. Oster, J. Posey, E. J. Russo, and A. Rypinski, 2014: Ch. 5: Transportation. Sung, N. M. (2015, February 26). Road crashes have more impact on poverty than you probably thought.

The United States Naval Observatory. Virginia Beach. United States. USNO [online]. Available from http://aa.usno.navy.mil/faq/docs/RST_defs.php

Theofilatos, A.; Yannis, G (2014). A review of the effect of traffic and weather characteristics on road safety. Accid. Anal. Prev. 2014, 72, 244–256.

Tingvall C (1995). The Zero Vision. In: van Holst H, Nygren A, Thord R, eds. Transportation, traffic safety and health: the new mobility. Proceedings of the 1st International Conference, Gothenburg, Sweden, 1995. Berlin, Springer-Verlag, 1995:35–57.

Transportation Association of Canada. Guide for the Design of Roadway Lighting. Ottawa Canada: TAC Publications; 2006.

Transportation Association of Canada. The Canadian Guide to In-Service Road Safety Reviews. Ottawa Canada: TAC Publications; 2004.

US Department of Commerce, & National Oceanic and Atmospheric Administration. (2009, October 02). What is the difference between weather and climate? Retrieved from https://oceanservice.noaa.gov/facts/weather_climate.html

VIS, A. (1995). Street lighting and road safety on motorways. ROAD SAFETY IN EUROPE AND STRATEGIC HIGHWAY RESEARCH PROGRAM (SHRP), LILLE, FRANCE, SEPTEMBER 26-28, 1994 (VTI KONFERENS), (2A: 1).

Vititoe law group(2016). Retrieved from https://www.vititoelawgroup.com/a_closer_look_at_car_accident_statistics_at_night/

Vos, J.J. Reflections on glare. Lighting Research and Technology 2003; 35: 163–175.

Walton, N. E., & Rowan, N. J. (1974). Warrants for highway lighting (No. Final Rpt.).

Ward, H., Shepherd, N., Robertson, S., & Thomas, M. (2005). Night-time accidents: a scoping study. Report to The AA Motoring Trust and Rees Jeffreys Road Fund.

Williams, A., Atkinson, B., Garbesi, K., Page, E., & Rubinstein, F. (2012). Lighting controls in commercial buildings. Leukos, 8(3), 161-180.

World Health Organization (2013). Global Status Report on Road Safety 2013. Available at: http://www.who.int/violence_injury_prevention/road_safety_status/2013/en/index.html, accessed on January 13, 2013.

Yannis, G. Kondyli, A., and Mitzalis, N. Proceedings of the Institution of Civil Engineers, Transport, 2013; 166(TR5): 271-281.

Zein, S.R., Geddes, E., Hemsing, S., and Johnson, M (1997). Safety Benefits of Traffic Calming. Transportation Research Record: Journal of the Transportation Research Boar. 1997; 1578: 3-10.

Zhou, H. and Hsu, P (2009). Effects of Roadway Lighting Level on the Pedestrian Safety. Critical Issues in Transportation Systems Planning and Management, ASCE. 2009.

A. Method 1 Steps

- **Step 1:** All the weather dependent data consisting of parameters like Luminance, Illuminance and UGI are entered corresponding to each accident occurring in a specific weather type. The accidents layer shows the location of each accident and the weather type in which the accident occurred. It is saved as a layer.

- **Step 2:** The layer with the severity of accidents is spatially joined with the layer of 100m segment. A new database is created. A new column named count is inserted and it serves as the number of all the accidents for a particular stretch. This is saved as a new layer.

- **Step 3:** The newly created layer from the above mentioned step is spatially joined with the weather dependent layer formed in the first step of the procedure. This is exported as a new layer.

- **Step 4:** Weather independent layer created before is next spatially joined with new layer formed in the previous step. This is the final database which is subjected to further analysis.

- **Step 5:** The same method is repeated for creating 300m and 500m layers.

B. Method 2 Steps

- **Step 1:** All the weather dependent data consisting of parameters like Luminance, Illuminance and UGI are entered corresponding to each accident occurring in a specific weather type. The accidents layer shows the location of each accident and the weather type in which the accident occurred. It is saved as a layer.

- **Step 2:** The layer formed in the previous step is further classified based on the type of weather at the time of the accident. For each weather type such as clear, cloudy, snowy and rainy separate layers are formed and saved.

- **Step 3:** The next step is to separate the Dataset A on the basis of type of roads. The collector and arterial roads are considered as one because the weather dependent values are approximately the same. The classification is done by using the road classification column in the accident database. Table B.1 shows the sample database that is used for classifying the roads. Further, it is verified by placing the separated accident layer on a spatial interface. Thus two database consisting of street accidents and the other with the arterial and collector roads are saved as separate layers. This layer is formed into segments of 100m, 300m and 500m layers.

- **Step 4:** The layer with the severity of accidents is spatially joined with the layer of 100m segment using the ArcGIS software. A new database is created. A new column named count is inserted and it serves as the number of all the accidents for a particular stretch. This is saved as a new layer.

Table B.1 **Sample database to classify roads**

S.No	OccSol1	Classif1	Classif2	Classif3
1	Perimeter Urban	Arterial	Non MTQ	Arterial urban
2	Perimeter Urban	Arterial	Non MTQ	Arterial urban
3	Perimeter Urban	Collect	Local_1 (MTQ)	Collector municipal
4	Perimeter Urban	Collect	Local_1 (MTQ)	Collector municipal
5	Perimeter Urban	Collect	Local_1 (MTQ)	Collector municipal
6	Agriculture	Collect	Collector (MTQ)	Collector national
7	Agriculture	Collect	Collector (MTQ)	Collector national
8	Lot of structures	Local	Local_1 (MTQ)	Street
9	Lot of structures	Local	Local_1 (MTQ)	Street
10	Agriculture	Route	National	National
11	Agriculture	Route	National	National

- **Step 5:** The layer formed for each type of road is spatially joined with each and every layer of weather type. A new database consisting of average values of all weather dependent values for each 100m segment is created. Each weather type is exported as a new layer.

- **Step 6:** Weather independent layer created before is next spatially joined with new layers for each road and weather type that are formed in the previous step. This is the final database which is subjected to further analysis. In this research, as the sample size of the collisions of street roads are minimum,only arterial or collector roads are analyzed.

- **Step 7:** This method is repeated for creating and saving 300m and 500m layers.