REDUCING RISK ON ONTARIO'S HIGHWAYS

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A THESIS SUBMITTED TO THE FACULTY OF GRADUATE STUDIES
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF
MASTER OF SCIENCE

GRADUATE PROGRAM IN KINESIOLOGY AND HEALTH SCIENCES
YORK UNIVERSITY,
TORONTO, ONTARIO

OCTOBER 2010

Your file Votre référence
ISBN: 978-0-494-80622-7
Our file Notre référence
ISBN: 978-0-494-80622-7

Abstract

The costs arising from motor vehicle collisions (MVCs) on the 400-series highways in Ontario are immense. Ontario's highway interchanges are the sites of more collisions per kilometer driven than any other section of highways in Canada, but little is known about factors related to their safety. The objectives of this study were to investigate how driver-related and environmental risk factors are associated with MVCs and to examine the factors associated with collision risk at highway interchanges. A total of 52,131 vehicles involved in crashes from 2001 to 2006 were included in our analysis. Twenty-four interchange sites were analyzed. Identified risk factors include age, and sex of the driver, time of day and driving conditions, and highway design. Interventions to reduce deaths as a result of MVCs should focus on both structural (interchange spacing, number of lanes, lane divisions, and illumination) and behavioral modifications (winter and nighttime driving techniques).

Dedication

To my family, my love, and my friends. Without you continuous support, encouragement and affection none of this would have been possible. You were my rock through the entire process and I am forever thankful.

Acknowledgements

I would like to thank my supervisor – my mentor – Dr. Alison Macpherson for believing in me from day 1. This journey would not have been as exciting and enjoyable had it not been under your supervision. The teachings that you have instilled in me in- and outside of our office will forever stay with me.

Furthermore, I would like to thank Dr. Hala Tamim for her unconditional help and support throughout this experience. Additionally, I want to sincerely thank my defense committee, lab and class mates for sharing this wonderful journey with me.

Lastly, I would like to acknowledge the incredible support I received from the Ministry of Transportation of Ontario, both financially and academically through the invaluable assistance from Susan Nichol and John Zajac at the Traffic Office in St. Catherine's.

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Chapter 1
Introduction

Worldwide Burden

Although in 2004 the world disease burden rankings listed lower respiratory infections as the main leading cause of disease or injury, followed by HIV/AIDS, perinatal conditions, ischemic heart disease, and in ninth place, road traffic injuries (RTIs), the World Health Organization (WHO) predicts that by the year 2020, RTIs will become the third leading cause only following ischemic heart disease and unipolar major depression. (Krug, 2004)

Another WHO report estimated that as of 2004, 16,000 people were dying every day from injuries, and of these, close to 3,000 of these deaths were a direct result of RTIs. The problem is not new; indeed, the World Health Assembly adopted Resolution WHA27.59, in 1974 which declared road traffic accidents a major public health issue and the problem has only worsened in the last three decades (Peden et al., 2002).

Canadian Burden

So large has the problem of road traffic accidents become, that in 2004, the WHO declared the worldwide World Health Day to be Road Safety Day. In Canada, the problem is alarming; according to Transport Canada, the organization responsible for transportation policies and programs throughout the country, an average of 8 Canadians die on the roads every day, with a much larger number being injured (Transport Canada) Nonetheless, advances have been made and the numbers are promising.

In 2006, the total number of injuries that occurred in Canada as a result of road traffic collisions was 199,337; although it was such an astonishing number, it was considerably lower than the 280,605 injuries suffered in 1987.{{6 Road Safety Program Office 2006; }}

Ontario Burden

As of 2006, Ontario's roads were determined to be the safest in North America when fatality rates for all jurisdictions across the continent were compared. The latest available data showed that Ontario's fatality rate in 2006 was the lowest ever recorded in Ontario at 0.87 per 10,000 licensed drivers. Furthermore, fatalities among drivers aged 65 and over fell 10.9 per cent between 2005 and 2006 (Road Safety Program Office, 2006) However, unintentional injuries, which occur largely as a result of motor vehicle collisions, were deemed the 6th leading cause of death for Canadians (Ministry of Transportation of Ontario, 2010).With close to nine million drivers on Ontario's roads, the costs arising from motor vehicle collisions (MVCs) on the 400-series highways in Ontario which result in one or more fatalities are immense when all aspects are taken into account (Road Safety Program Office, 2006). A report released by the Ministry of Transportation of Ontario (MTO) in 2007, calculated the social costs of MVCs to be $18 billion in the year 2004 (Vodden, Smith, Eaton, & Mayhew, 2007). Additionally, fatalities were reported to have cost $11 billion (64% of the total social costs) even though fatal collisions represented less than 1% of the 231,548 Highway Traffic Act reportable collisions in 2004. The average social cost of a fatal collision in 2004 was $15.7 million (Vodden et al., 2007).

Conversely, even though the costs of MVCs represent a financial and social burden, it is important to highlight the advances the province has made in road safety, which include a decline in fatality rates over the past three decades. Since 1980, the number of licensed drivers has increased by almost 80% but the number of fatalities has decreased by 49% (Road Safety Program Office, 2006). However, in the five-year period spanning from 2001 to 2006, there were 815 fatal MVCs on Ontario's 400-Series Highways that in turn cost the province $12.8 billion, or almost $2.6 billion per year.

As a result of these costs, the province has invested and continues to invest millions of dollars every year in engineering and construction plans in order to improve our highways and subsequently decrease the number of MVCs. The following chapters will assess the current state of Ontario's drivers and highways, in an attempt to determine who is at increased risk of being involved in a fatal collision as well as where are drivers are more likely to be involved in a collision. This information can lead to further education, which will in turn lead to behavioral and structural modifications to make our province a safer place to drive and live in.

Risk Factors for Highway Fatalities

Previous research investigating driver characteristics and environmental risk factors associated with fatal motor vehicle collisions in Ontario suggest that the older driver population is at an elevated risk for being involved in fatal MVCs (Evans, Frick, & Frick, 1986; J. Zhang, Lindsay, Clarke, Robbins, & Mao, 2000). Zhang et al. employed the Canadian Traffic Accident Information Databank (TRAID) which is a surveillance database compiled from police reports of traffic crashes that occur on public Canadian roads. The study included data collected on Ontario's public roads between 1988 and 1993 at the scene of a collision in which at least one driver was aged 65 or older. The study found that as the age of the driver increased, so did the univariate Odds Ratio (OR) for a severe crash. Furthermore, after the authors adjusted for sex, driver condition, driver action, and time of event amongst other variables in the multivariate analysis, they found that the previously existing gradient remained, and drivers were 1.37 (95% CI; 1.10 – 1.72), 1.42 (95% CI; 1.11 – 1.82), and 2.26 (95% CI; 1.72 – 3.00) more likely to die as a result of a collision at ages 70–74, 75–79 and ≥80, respectively, when compared to the reference group (65–69). The study found that this pattern was observed for non fatal collisions as well, with minor and major injuries increasing as a function of age.

Further, studies that examine the relationship between younger age and the risk of being involved in fatal motor vehicle collisions suggest that younger drivers may be at an elevated risk due to different reasons, which include their risk-taking behavior which may be expressed by going at higher speeds, being involved in more driver conflicts, driving while impaired, and not wearing seat-belts (Jonah, 1986). Lillsunde et al. compared drug use between the years 1973 and 1993 that the rate of drug and alcohol use amongst younger suspects of impaired driving increased significantly which was supported by Mercer's study which noted the increase in impaired driving through the use of alcohol as well as various drugs which were frequently unnoticed by police officers (Lillsunde et al., 1996; Mercer & Jeffery, 1995).

In addition to age, sex has been studied as a possible risk-factor for the involvement in fatal MVCs Results from the Zhang et al. study showed that collisions involving elderly male drivers were 40% more likely to be fatal than those involving female drivers (AOR = 1.43; 95% CI, 1.16 - 1.77) even though previously, Zhang (1998) found no difference between male and female fatality rates in MVCs (J. Zhang, Fraser, Lindsay, Clarke, & Mao, 1998; J. Zhang et al., 2000). Interestingly, Singleton matched the motor vehicle collision records from the State of Kentucky for the years 2000 and 2001 with the corresponding hospital discharge database records in order to determine the factors associated with being involved in a severe MVC (Singleton, Huifang, & Jingyu, 2004). After conducting a multivariate logistic regression analysis on a sample of over 75,000 individuals involved in collisions during the study period, the authors found that females were 60% more likely than males to be seriously injured in MVCs (AOR = 1.62; 95% CI, 1.56–1.68 , $p<0.0001$). Further, Bedard's research team employed the fatal accident reporting system (FARS) in order to model risk factors associated with being involved in fatal collisions. The data used for the analyses spanned 24 years (1975-1998), and in order to be included, collisions had to have been single-vehicle collisions against fixed objects, and there had to have been at least one fatality. The study found that even though males were involved in fatal collisions more often and there were many more male fatalities amongst males than females during the study period, when involved in a fatal collision, females in the United States were 54% more likely to be involved in a fatal accident than their male counterparts (Bédard, Guyatt, Stones, & Hirdes, 2002)When examining environmental characteristics as risk factors for fatal collisions, Zhang found that elderly drivers were more likely to die in a collision when it was snowing (AOR = 1.62; 95% CI, 1.03 - 2.54). However, when elderly drivers were on roads that were covered with snow or ice, there seemed to be a protective effect that decreased their chances of dying if involved in a collision by 74% (AOR = 0.26; 95% CI, 0.16 - 0.43) (J. Zhang et al., 2000). In addition, the study found that dark or twilight conditions had no effect on an elderly driver's risk of fatality when involved in a collision. Lemieux found that when looking at MVCs in the Hamilton region of Ontario, weather did not play a significant role in the collisions that resulted in one or more fatalities (Lemieux, Fernandes, & Rao, 2008). Zhang reported that when elderly drivers were involved in collisions during the weekend (Friday-Sunday), they were 31% more likely to die than if involved in a weekday collision (AOR = 1.31; 95% CI, 1.10 - 1.57) (J. Zhang et al., 2000).

Valent conducted an analysis on fatal collision data in the region of Udine, Italy and found no statistically significant evidence for an increased fatality risk during weekends but the study did find a trend that indicated the same results as Zhang (2000)(Valent et al., 2002). The results supported previous findings by indicating that the data between the years 1991 and 1996 signaled an increased risk of being fatally injured when in a collision as age of the driver increased [$\geq$65 vs. $<$30(ref.)](AOR = 3.53; 95% CI, 1.42 - 8.78).

Highway Interchange Screening

Highway interchanges have been around for almost one century; it was in the 1920s, as vehicles became faster, more capable and obtainable, that the idea of controlled access facilities or interchanges was introduced to the realm of traffic control and safety (Soliman El-Basha, Hassan, & Sayed, 2007). Studies have identified interchanges as the most likely area for freeway collisions to occur; interestingly, not only do collisions happen at interchanges more often, but their severity is more grave than collisions away from these interchanges (McCartt, Shabanova, & Retting, 2004; Soliman El-Basha et al., 2007). Highway interchanges are the sites of more collisions per kilometer driven than any other section of highways in North America (Firestine, McGee, & Toeg, 1989). In the United States, with a freeway system similar to Ontario's, it was reported that 11% of fatal collisions occurred at interchanges (ICs), although they comprise less almost 5% of the entire highway system (McCartt et al., 2004). Interchanges vary in design, size and orientation.

Due to the fact that millions of drivers use interchanges on a daily basis, it is a priority for traffic and injury prevention researchers to determine the safest configuration of these interchanges, in order to minimize the frequency and severity of collisions that may occur at these sites. A study by Soliman and colleagues analyzed 13 interchanges on

Ontario's Highway 417. Their project focused on speed, traffic, and geometric data pertaining to the 13 interchanges. Their report commented that current design guides in Canada suggested that operation and safety could be enhanced on freeway interchanges by increasing the length of lane-change or merging lanes (Soliman El-Basha et al., 2007).

As mentioned above, studies have shown that interchanges are indeed, areas of higher risk to motorists and a possible explanation may the length of a major component of interchanges; the merging lane – where the interchange occurs. However, it would be incorrect to attribute the elevated risk entirely to the merging lane geometrics. Another factor that may play a significant role in determining the safety of an interchange is the illumination at the site, or lack of, which can make the required maneuvering easier or more challenging for some drivers.

Studies by Box tracked 21,000 collisions throughout interchanges in urban as well as suburban North America and found that proper lighting reduced accidents by an average of 40% during the night (Box, 1971; Box, 1972). The International Commission on Illumination released a report in 1992, which described the results of a before and after study which saw newly installed lighting systems consistently decrease nighttime collisions by 57% (CIE, 1992). In 2009, Wanvik studied European motorways to examine the effect of lighting on collision rates. The results showed that collision rates at night decreased significantly under proper lighting, particularly in the Netherlands, where the decrease was as high as 49% compared to entirely dark motorway conditions (Wanvik, 2009).

In 2001, Bruneau and colleagues released a report that compared lighting on motorways a little differently than most other studies. The researchers looked at dark conditions compared to interchange lighting alone, and interchange lighting + continuous lighting on the mainline highway segment. Their results, based on Quebec data, showed that continuous lighting reduced the overall collision rate by 33% ($p<0.001$) when compared to sites that had lighting solely through the interchange, and by 49% ($p<.05$) when compared to sites that were completely dark (Bruneau, Morin, & Pouliot, 2001).

McCartt studied collisions at ramps and interchanges in Northern Virginia and found that the three most prominent types of collisions were run-off road (single vehicle), rear-end, and sideswipe, since all three types together accounted for 95% of collisions in the study. In addition, the report added that single vehicle collisions were most often while exiting the mainline and rear-end as well as sideswipe were most common amongst drivers entering the motorway (McCartt et al., 2004).

Despite the advances made over the past decades, little is known about the causes for the increased driver risk at interchanges on highways. More specifically, research has not been conducted on Ontario's highway system, nor using a comprehensive data set which includes variables related to the interchange, the weather conditions, and the type of collision.

Chapter 2
Risk of Death on Ontario's Highways

Risk of Death on Ontario's Highways

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Abstract

Background: Motor vehicle collisions (MVCs) that result in one or more fatalities on the 400-series Highways represent a serious public health problem. MVCs resulting in one or more fatalities were reported to have cost $11 billion in 2004. To date, no studies have examined risk factors for fatal MVCs on Ontario's 400 series highways.

Objective: To investigate how driver-related and environmental risk factors are associated with fatal MVCs on Ontario's 400-Series Highways.

Methods: Data were provided from the Ontario Ministry of Transport database, and included driver characteristics, vehicle information, environmental descriptors, structural descriptors, as well as collision information (date and time) , and severity of the collision. Multivariate analysis was used to identify factors significantly associated with the odds of dying in a collision.

Results: There were 53,526 vehicles involved in collisions from 2001 to 2006 included in our analysis. Results from the multiple logistic regression analysis suggest that collisions with older age and male drivers were at an increased risk for being fatal MVCs. Highway 405 and an undivided 2-way design proved to be the most fatal structural configurations. Lastly, MVCs in the summer, Fridays, between 12am-4am, and in drifting snow conditions during the wintertime were shown to have a significantly increased risk of a fatal outcome.

Conclusion: Our results suggest that interventions to reduce deaths as a result of MVCs should focus on both structural and behavioral modifications.

Introduction

The latest data released by Statistics Canada (2005) indicate that accidents responsible for unintentional injuries (which include motor vehicle collisions) are the 5th leading cause of death in Canada, with over 4% of deaths being attributed to them. As of 2006, Ontario's roads were determined to be the safest in North America when fatality rates for all jurisdictions across the continent were compared. The latest available data showed that Ontario's fatality rate in 2006 was the lowest ever recorded in Ontario at 0.87 per 10,000 licensed drivers. Furthermore, fatalities among drivers aged 65 and over fell 10.9 per cent between 2005 and 2006 (Road Safety Program Office, 2006). However, unintentional injuries, which occur largely as a result of motor vehicle collisions, are the 6th leading cause of death for Canadians (Ministry of Transportation of Ontario, 2010). With close to nine million drivers on Ontario's roads, the costs arising from motor vehicle collisions (MVCs) on the 400-series highways in Ontario which result in one or more fatalities are immense when all aspects are taken into account. A report released by the Ministry of Transportation of Ontario (MTO) in 2007, calculated the social costs of MVCs to be $18 billion in the year 2004 (Vodden et al., 2007). Additionally, fatalities were reported to have cost $11 billion (64% of the total social costs) even though fatal collisions represented less than 1% of the 231,548 Highway Traffic Act reportable collisions in 2004. The average social cost of a fatal collision in 2004 was $15.7 million.

Conversely, even though the costs of MVCs are astonishing, it is important to highlight the advances the province has made in road safety, which include a decline in fatality rates over the past three decades. Since 1980, the number of licensed drivers has increased by almost 80% but the number of fatalities has decreased by 49% (Road Safety Program Office, 2006). However, in the five-year period spanning from 2001 to 2006, there were 815 fatal MVCs on Ontario's 400-Series Highways that in turn cost the province $12.8 billion, or almost $2.6 billion per year.

As a result of these astounding costs, the province has invested and continues to invest billions of dollars every year in engineering and restructuring plans in order to improve our highways and subsequently decrease the number of MVCs.

There has been previous research investigating driver characteristics and environmental risk factors associated with fatal motor vehicle collisions in Ontario. For example, studies suggest that the older driver population is at an elevated risk for being involved in fatal MVCs (Evans et al., 1986; J. Zhang et al., 2000). Further, younger drivers are at an elevated risk as well due to their risk-taking behavior which may be expressed by going at higher speeds or by using alcohol and/or drugs when driving (Jonah, 1986; Mercer & Jeffery, 1995; Seppala, Linnoila, & Mattila, 1979).

In addition to age, sex has been studied as a possible risk-factor for the involvement in fatal MVCs. Zhang found no difference between male and female fatality rates in MVCs (J. Zhang et al., 1998). Interestingly, Singleton et al. found that females were 60% more likely than males to be seriously injured in MVCs, and Bedard et al. explained that females in the United States were 54% more likely to be involved in a fatal accident than their male counterparts (Bédard et al., 2002; Singleton et al., 2004)Moreover, Lemieux found that when looking at MVCs in the Hamilton region of

Ontario, weather did not play a significant role in the collisions that resulted in one or more fatalities (Lemieux et al., 2008).

Objective

To date, there have been no studies conducted which examine Ontario's 400-Series highways and the risk for fatal MVCs on them. As a result, the objective of this study is to investigate how driver-related and environmental risk factors are associated with fatal motor vehicle collisions on Ontario's 400-Series Highways.

Methods

1. Data

A database including Road Traffic Accident Data from the Ministry of Transportation of Ontario (MTO) included all Highway Traffic Act (HTA) reportable accidents on Ontario 400-Series highways between January 1st, 2001, and December 31st, 2006. The data compiled by MTO is composed of information extracted from police reports of MVCs that take place on the province's 400-Series highway system. No data that could identify anyone involved in the collisions were requested; therefore approval from an Ethics Committee was not necessary.

Highway 407 and Highway 1 (also known as the Queen Elizabeth Way, or Q.E.W.) were excluded from our analyses. Highway 407 is the only private highway in the province and MTO does not routinely receive collision data from this highway without expressively requesting it. Additionally, the Q.E.W. was excluded due to the lack of data compatibility between datasets.

A total of 53,526 vehicles involved in collisions from 2001 to 2006 were included in our analysis. Two-wheel vehicles (motorcycles, mopeds and bicycles) were removed from the dataset in order to avoid confounding throughout the analyses. A sub-analysis comparing fatalities in these aforementioned vehicles to cars/trucks found that there was a 54% increased chance of a fatal outcome when a motorcycle, moped or bicycle were involved in a collision when compared to larger vehicles (OR=1.54, 95% CI 1.07-2.20). Previous research suggests that this may be due to a decreased amount of protection when driving a two wheeled vehicle in addition to greater risk taking behavior profile shown by motorcycle drivers (Horswill & Helman, 2003; Kweon & Kockelman, 2003).

Previous literature has found that the time of the day of a collision is related to one's chances of a fatal outcome (Singleton et al., 2004; Zhang et al., 2000). In order to investigate this relationship, we divided the 24 hours of the day into six four-hour periods.

Data included driver characteristics (e.g. age and sex), vehicle information (e.g. number of passengers and vehicle type), environmental (e.g. weather and road surface conditions) and structural descriptors (e.g. road characteristics and location on a highway), as well as collision information (e.g. time and day) and severity of the collision which ranged from 0-4.

Our primary outcome variable was if anyone (passenger or driver) died in the collision, compared to collisions where no-one died. Thus the numerator was the number of vehicles involving a fatality, while the denominator was all vehicles involved in collisions. We also examined collisions at different time periods, seasons, and months as co-variates. The initial analyses were conducted using SAS v 9.0 (SAS Institute Inc, 2000-2004).

After eliminating two-wheel vehicle cases (n=1,395), a total of 52,131 vehicles involved in MVCs between 2001 and 2006 on the 400-series highways in Ontario were available for analyses.

2. Statistical Analyses

Descriptive statistics were calculated for nine variables: Highway name, Season, Day of the week, Time period, Sex, Age group, Environment/Weather, Road Characteristic, and Road Surface Condition; they were categorized into three groups: Driver Characteristics (Sex and Age group), Highway Characteristics (Highway name and Road Characteristic), and Environmental Characteristics (Season, Day of the week, Time period, Environment/Weather, and Road Surface Condition).

Chi-Squared tests were conducted in order to detect differences in fatal injury rates among variables. Subsequently, crude odds ratios (OR) and their respective 95% confidence intervals (95% CI) were calculated using simple logistic regression in order to reveal the relationships between each one of the nine risk factors/variables and the possibility of a fatality as a result of a motor vehicle collision.

Multiple logistic regression was conducted to estimate ORs for each risk factor adjusting for all other variables in the model (Table 2) (SPSS Inc., 1998). Initially, all nine risk factors were included in the model; however, after observing collinearity between the Environment/Weather and Road surface condition variables, we decided to eliminate the latter from the model.

Table 1 shows the distribution of non-fatal and fatal injuries among all categories for the eight included variables and Table 2 displays the results of the univariate and multivariate regression analyses.

Results

1. Driver Characteristics

The analysis compared four different age groups based on Erikson's developmental stages (Erikson, 1950). Since the age groups are different in width, we could not use absolute motor vehicle collision numbers in order to observe injuries and fatalities. Instead, we analyzed fatality rates. Initially an increasing trend was observed; as one got older, the fatality rate when involved in a MVC became greater. As shown in Table 1, the fatality rates were 1.1%, 1.4%, 1.6%, and 2.3% for teenagers, early adults, middle adults, and older adults respectively. However, when the crude odds ratios were calculated for this relationship, they found that only someone in a car driven by an older adult was at a significantly higher risk for dying if involved in a MVC when compared to the teenage driver population (OR = 2.08; 95% CI, 1.29 – 3.36).

However, multivariate analysis suggested that the older the driver age group, the higher the odds of the driver or a passenger dying in a motor vehicle collision. Compared to teenaged drivers, cars with young adults drivers were 52% more likely to suffer a fatality in a collision (OR = 1.52; 95% CI, 1.01 – 2.28), and in addition, middle and older adults drivers had an 82% (OR = 1.82; 95% CI, 1.21 – 2.74) and 137% (OR = 2.37; 95% CI, 1.45 – 3.88) increased risk of being having a fatality in their vehicle when involved in a MVC respectively.

Sex was also associated with the odds of dying in a motor vehicle collision. Initial results showed that male drivers were involved in a collision with a fatal outcome 1.7% of the time. However, female drivers only found themselves in this situation in 1.1% of cases. When these rates where compared, the results showed that male drivers were at an almost 50% increased likelihood of having a fatality in their vehicle if they drove and were involved in a collision compared to their female counterparts (OR = 1.49; 95% CI, 1.26 – 1.76). Once all other variables were adjusted for, the relationship remained, but the results decreased slightly to a significant 43% increased fatality amongst male driven vehicles when compared to women (OR = 1.43, 95% CI, 1.21 – 1.71).

2. Highway Characteristics

The highways included in our analyses are similar; they are at least four lanes wide, divided in most areas, and post speed limits of 100 km/h throughout most of the system, with small segments which post 80 and 90 km/h speed limits.

After adjustment, our analysis found that only Highway 405 posed a significantly greater fatality risk with a 7-fold odd of a fatal outcome as a result of an MVC when compared to Highway 400 (Reference Group) (OR = 7.33; 95% CI, 3.39 – 15.85). Six of the 11 remaining highways showed a protective effect while the other 5 were not statistically different from Highway 400.

Initially, undivided 2-way segments as well as divided 2-way segments without barrier showed higher fatality rates than segments with any other design (3.9% and 5.0% respectively). When all designs were compared, the results remained stable; the two aforementioned highway characteristics posed a significantly higher risk than the other variants. An undivided 2-way design showed a fatality risk to occupants involved in a motor vehicle collision three times greater than the risk one is subject to on an undivided 1-way segment (OR = 3.00, 95% CI, 1.49 – 6.01) and a divided road without a barrier gave a collision an additional 86% likelihood of resulting in a fatality (OR = 3.86, 95% CI, 2.05 – 7.28).

Once all variables were examined using multiple logistic regression, the two designs remained as the only two with an increased risk of fatality. The magnitude of their effect increased as a result of adjustment for all other variables; the undivided 2-way design had an odds ratio of 3.63 (95% CI, 1.77 – 7.46) and the divided road with no barrier presented an effect size of 4.61 (95% CI, 2.42 – 8.79) when compared to an undivided 1-way road design.

3. Environmental Characteristics

The distribution of collisions among all four seasons of the year (winter, spring, summer, and fall) was similar. However, fatalities seem to make up a higher percentage of collisions during the summer (30.4%). Many factors distinguish driving conditions in the four different seasons. Some of these include: daylight time, temperature, environmental/road conditions, and traffic flow to different areas on different days and times of the week. When spring and summer were compared to winter, we found no difference when looking at the fatality rate amongst individuals involved in MVCs. Nonetheless, a difference was observed between fall and winter; we concluded that driving during the fall had a protective effect. In other words, those who were involved in a fall collision were less likely to die than those involved in collisions that took place during the winter (OR = 0.76; 95% CI, 0.62 – 0.94).

Initially, fewer collisions were reported from 2001 to 2006 in the summer months (n=13,128) compared to the winter season (n=13,980). However, once all other variables were added to the model, driving in the summer was associated with an increased fatality risk compared to the wintertime (OR = 1.58; 95% CI, 1.26 – 1.97). The protective effect of fall driving disappeared (OR = 1.07; 95% CI, 0.85 – 1.34) and spring remained similar to winter.

Due to the fact that all of the 13 highways analyzed are employed for various reasons such as commercial and leisure, they are used differently on every day of the week. Another purpose of the data analysis was to identify if there were any days of the week that were particularly more or less fatal than others. The number of collisions per day of the week were similarly distributed (mean = 7,335). Notwithstanding, Friday seemed to have an elevated MVC occurrence with a total of 8,566 over the span of five years. In addition, even though the fatality rate looked similar for most days when looking at the range in absolute terms (range = 1.1% – 1.9%), Friday (1.9%) showed an approximately 70% higher fatality rate than Tuesday (1.1%). Conversely, when the six days were compared to Sunday, only Tuesday was significantly different, showing a protective effect that indicated a 37% decreased risk of fatality in case of a MVC (OR = 0.63; 95% CI, 0.47 – 0.84).

After adjusting for all other variables, no days showed significant differences in fatality risk, with Friday being the closest to pose a significant increased risk of death for those involved in MVCs (OR = 1.28, 95% CI, 0.99 – 1.64).

From 4am until 8pm (early morning, morning, afternoon, and early evening), fatality rates amongst people involved in MVCs ranged from 1.2% to 1.4%. However, from 8pm to 12am (evening) it was elevated to 2.0% and during the nighttime (12am to 4am), it increased to 3.4%. When all time blocks were compared to the evening period, protective effects were seen by all but the night as predicted by the initial distribution. The night period had a significantly higher risk of fatality as a result of a MVC than the evening time period (OR = 1.77, 95% CI, 1.38 – 2.27).

Once all other variables were controlled for in the multivariate analysis, the association between time of day and risk of dying remained, with night being the most fatal period with a 67% higher risk of fatal MVCs than evening (OR = 1.67, 95% CI, 1.29 – 2.15).

Lastly, the association between weather condition and fatal MVCs on the 400-series highways in Ontario between 2001 and 2006 was examined. Fatality rates ranged from 1.4% in the 'clear' reference condition, to 12.8% under 'drifting snow' conditions. When the 7 'non-clear' categories were compared to the referent (clear), 'rain' showed a protective effect (OR = 0.71, 95% CI, 0.52 – 0.96), whereas 'snow', 'frozen rain', ‘drifting snow’, ‘wind’, and ‘fog’ showed detrimental effects, with ‘drifting snow’ posing the greatest increase in fatality risk (OR = 10.58, 95% CI, 7.87 – 14.21).

When the environment/weather variable was analyzed in a multivariate model, ‘drifting snow’, ‘wind’, and ‘fog’ were the only categories that remained significantly different from the ‘clear’ weather condition. Similarly to time of day, the effect sizes of the more difficult weather conditions became lower once all other variables were adjusted for. Nonetheless, ‘drifting snow’ still put drivers and passengers at an increased risk of death if involved in a MVC with a 7.5 greater fatality risk than people involved in MVCs under clear conditions (OR = 7.55, 95% CI, 5.34 – 10.67). Wind and fog contributed to significantly more dangerous driving conditions as well; windy conditions were associated with a 4 times increased risk (OR = 3.96, 95% CI, 1.87 – 8.40) and fog made a fatal outcome as a result of a MVC almost 3 times more likely than clear conditions (OR = 2.78, 95% CI, 1.63 – 4.74).

Discussion

We found an increased risk of fatality as a result of a motor vehicle collision for older drivers and males. Furthermore, undivided 2-way segments as well as divided 2-way segments were associated with increased fatality risk as a result of MVCs. Driving on Ontario’s Highway 405 was associated with the highest odds of fatality in a collision. In addition, various environmental conditions were associated with an increased risk of dying as a result of a motor vehicle collision and they included driving in the summertime, at nighttime, and in drifting snow weather.

Driver Characteristics

Age

The results in this study found that an increase in driver age was strongly associated with an increased odds of a fatality in the driver's vehicle as a result of a motor vehicle collision. Drivers over the age of 65 were almost 2.4 times more likely to be involved in a fatal motor vehicle collision than adolescents aged 16 to 19. These findings are consistent with previous literature (Bédard et al., 2002; Singleton et al., 2004; Valent et al., 2002; Zhang et al., 2000)

However, the magnitude of the effect age has on fatal outcomes varies throughout the literature; Bedard reported a five times higher risk of death among vehicles driven by 80+ year old drivers compared to middle aged counterparts and Singleton reported a 65% increase in chances of fatality when comparing adults drivers 60 years or older to younger 20 year old drivers. Most importantly, the direction of the relationship remains constant; however, the magnitude may differ due to the use of different reference and comparison groups, different settings (City vs. Highway MVCs), differing health practices in different geographical regions, and different adjustment for confounding variables in the multivariate analyses. The increased risk of fatality may be related to other age-related conditions, including co-morbid health conditions. Observing the increased risk that older drivers are at, the Canadian Association of Occupational Therapists released the "National Blueprint for Injury Prevention in Older Drivers" in 2010, which by various methods, is designed to increase awareness of the issue. For example, the blueprint outlines various partnerships established to promote older driver safety throughout the country in addition to interventions that include media coverage, brochures for families with older adult drivers and information for health care practitioners taking care of them (Canadian Association of Occupational Therapists, 2010).

Sex

Results showed that female drivers were involved in fewer motor vehicle collisions than men. Anyone in a car driven by a female was also less likely to die in a motor vehicle collision than occupants in a car driven by a male (Male Driver OR = 1.43, 95% CI; 1.21 - 1.71). This is consistent with some previous literature; a study by Turner and McClure in 2003 revealed that men scored significantly higher than females in the 'Driver Aggression' and 'Risk Acceptance' scales (Turner & McClure, 2003). In addition, Valent (2002) found that female drivers were 62% less likely to die in a collision compared to male drivers. Williams and Lemieux reported an increased rate of fatalities amongst male drivers compared to females. Nonetheless, some literature does support contradictory results; Bedard and Levine show up to a 50% increased risk for fatal injuries in women compared with men. However, they state that this difference seems to be present only in younger drivers and that it disappears once older adults are added to the model.

Highway Characteristics

Road Design

Our results suggest that, consistent with Zhang (1998), the undivided design poses an increased fatality risk, as does the divided road with no barrier design. Re-evaluating these two designs on Ontario's highways, and installing barriers in both of these designs may improve road safety in some areas.

Provincial Highway

Our results showed that Highway 405 posed a significantly increased fatality risk when involved in MVCs on this 8.5 kilometer segment which connects the Queen Elizabeth Way to the Queenston-Lewiston Bridge (Canada-US Border). No previous research has been done examining specific highways and the risk involved in driving on them. Although we have no evidence for why the fatality rate is higher than on most other highways, we hypothesize that there may be an elevated number of trucks on this highway because it is one of the arteries that connects Canada to the United States and therefore heavy transport vehicles are common. Collisions involving large trucks have been shown to be deadly more often than cars and small trucks (McCartt et al., 2004). This possibility warrants further investigation.

Environmental Characteristics

Season

Initially, in univariate analysis, we reported a protective effect of season on fatality during the fall. However, once all variables were included in the analysis, it became apparent that summer was associated with a significantly higher likelihood of fatality as a result of a MVC than winter (OR = 1.58, 95% CI, 1.26 – 1.97). These findings are consistent with past literature including Zhang (2000) who shows similar results before adjustment and even though the results were no longer significant after multivariate analysis, the trend remained the same with the summer season close to achieving a significantly more fatal status (OR = 1.28, 95% CI, 0.96 – 1.71). In his 1998 study, Zhang found that young drivers were at a 25% increased risk for fatality compared to middle aged drivers involved in MVCs during the summer.

Day of the week

Our study examined the association between day of the week and fatality on Ontario's highways. Initially, this study found that Friday seemed to have a disproportionally higher risk of fatality amongst drivers involved in MVCs compared to every other day of the week (1.9%). However, after all variables were analyzed through multiple logistic regression, no differences were found between the seven days of the week with Friday having a slightly increased risk for fatality (OR = 1.28, 95% CI, 0.99 – 1.64). Lemieux explains that most of the MVCs in the Hamilton-Wentworth Niagara Region of Ontario that resulted in fatalities occurred during Fridays and Sundays, however that study included city and rural roads as well as highways. Other studies including Valent, Zhang (2000), and Doherty compare fatality rates in different days of the week; however, they compare weekdays vs. weekend days rather than each day individually (Doherty, Andrey, & MacGregor, 1998).

Time of the day

Similarly to Valent who found that deaths increased as a results of MVCs between 1:00 and 5:00 a.m. by a factor of two, this study found that the night period (0:00-4:00 am) was the most fatal period of the day with a 67% higher risk of fatal MVCs than the evening (OR = 1.67, 95% CI, 1.29 – 2.15). Lemieux also reported that most of the fatal collisions in his study occurred between 6pm and 6am; however, he did not specify the distribution of fatal accidents between that half of the day. Possible reasons for an increased occurrence of fatal accidents during the nighttime/early morning hours include an increased use of alcohol and/or drugs while driving (Rice TM 2003) and tiredness or drowsiness while driving during these hours (Akerstedt 2001).

Environmental/Weather Conditions

We found that 'drifting snow', 'wind', and 'fog' were significantly associated with an increased fatality risk. After searching for literature, we concluded that we were the only ones to have looked at weather as a risk factor for fatalities on Ontario's provincial highways.

Strengths and Limitations

The main strength of this study is that it is the first one to evaluate the how driver-related and environmental risk factors are associated with fatal motor vehicle collisions on Ontario's 400-Series Highways. All major provincial highways were included in the analyses and the most comprehensive source for MVC data was used (Ministry of Transportation of Ontario) whose database included 96.1% of cases with no missing data, leaving only 3.9% of cases ineligible for some of the analyses.

Vehicles which were evidently at an increased risk for fatality when involved in a MVC (e.g. motorcycles and bicycles) were excluded in order to allow the analyses to approximate a more accurate fatality risk posed to occupants of vehicles with similar safety mechanisms and driving conditions.

The limitations of this study include a potential for misclassification bias since the data is entirely based on police reports. Also, the reports only include outcome data up to 30 days after the collision. Therefore, collisions that resulted in fatalities 30 days after they took place would have not been classified as fatal collisions. Finally, we had no information on driver distraction, kilometers driven, or other potentially confounding variables not included in the database.

Conclusion

Various characteristics related to the driver, highway, and the environment surrounding him/her, contribute to the likelihood someone dying if involved in a motor vehicle collision. Interventions to reduce deaths may focus on structural road redesign, as well as behavioral interventions reviewing driving practices by different age groups and drivers under different conditions. Further studies should be conducted in order to evaluate the effect that other variables have on one's fatality risk as a result of MVCs on Ontario's 400-series highways (e.g. speed, alcohol use, safety equipment use).

Chapter 3
Factors associated with an increased collision rate on Ontario’s Provincial Highway Interchanges

Factors associated with an increased collision rate on Ontario's Provincial Highway Interchanges

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Abstract

Background: Motor vehicle collisions (MVCs) on the 400-series highways in Ontario are a costly and important health problem. Ontario's highway interchanges are the sites of more collisions per kilometer driven than any other section of highways in Canada, but little is known about factors related to their safety.

Objectives: The objective of this study is to examine the factors associated with collision risk at highway interchanges.

Methods: Data on all collisions occurring at interchanges were provided by the Ministry of Transportation of Ontario. The interchanges were classified according to their performance. Performance indicators were based on previously published methods. We compared the best-performing (LOSS I) interchanges, to those that performed the worst (LOSS IV).

Results: A total of 9,176 vehicles involved in collisions in 24 selected interchanges from 2002 to 2006 were included in our analysis. Identified risk factors include short interchange spacing, poor road and interchange illumination as well as a high number of choices at an interchange.

Conclusion: Interventions to improve interchange performance and reduce collisions and deaths as a result of MVCs at interchanges on Ontario's 400-Series highways should focus on structural modifications such as interchange spacing, number of lanes, lane divisions, and illumination.

Introduction

Studies have identified highway interchanges as the most likely area for freeway collisions to occur; interestingly, not only do collisions happen at interchanges more often, but their severity is graver than collisions away from these interchanges (McCartt et al., 2004; Soliman El-Basha et al., 2007). Highway interchanges are the sites of more collisions per kilometer driven than any other section of highways in North America (Firestine et al., 1989). In the United States, with a similar freeway system to Ontario's, it was reported that 11% of fatal collisions occurred at interchanges (ICs), although they comprise less almost 5% of the entire highway system (McCartt et al., 2004). Interchanges vary in design, size and orientation.

Due to the fact that millions of drivers use interchanges on a daily basis, it is a priority for traffic and injury prevention researchers to determine the safest configuration of these interchanges, in order to minimize the frequency and severity of collisions that may occur at these sites. A study by Soliman and colleagues analyzed 13 interchanges on Ontario's Highway 417. Their report commented that safety could be enhanced on freeway interchanges by increasing the length of lane-change or merging lanes.

Aside from interchange length/spacing, another factor that may play a significant role in determining the safety of an interchange is the illumination at the site. Studies by Box found that proper lighting reduced accidents by an average of 40% during the night (Box, 1971; Box, 1972). The International Commission on Illumination released a report in 1992, which saw newly installed lighting systems consistently decrease nighttime collisions by 57% (CIE, 1992). Also, in 2009, Wanvik showed that proper lighting in the

Netherlands decrease collisions as much as 49% compared to entirely dark motorway conditions (Wanvik, 2009).

In 2001, Bruneau showed that in Quebec, continuous roadway lighting and throughout the interchange reduced the overall collision rate by 33% when compared to sites that had lighting solely through the interchange, and by 49% ($p<.05$) when compared to sites that were completely dark (Bruneau et al., 2001).

McCartt studied collisions at ramps and interchanges in Northern Virginia and found that the three most prominent types of collisions were run-off road (single vehicle), rear-end, and sideswipe, since all three types together accounted for 95% of collisions in the study. In addition, the report added that single vehicle collisions were most often while exiting the mainline and rear-end as well as sideswipe were most common amongst drivers entering the motorway.

Despite the advances made over the past decades, little is known about the causes for the increased driver risk at interchanges on highways. More specifically, research has not been conducted on Ontario's highway system using a comprehensive data set which includes variables related to the interchange, the weather conditions, and the type of crash.

Objective

The objective of this study is to examine Ontario's highway interchange network, and to investigate factors associated with an elevated collision risk at these sites. We seek to compare the best and worst performing interchanges and identify differences in interchange design, lighting and crash type between the two.

Methods

1. Data

Variables in the dataset included different types of collisions (e.g. single vehicle or side-swipe), time of day, and location within the interchange. All these data were captured by the Accident Information System (AIS) for all collisions within the Ministry of Transportation of Ontario's (MTO) jurisdiction. For the purposes of this analysis, the 5 variables used were interchange length/spacing, type of collision, place of collision, time of the day, and lighting conditions.

2. Inclusion Criteria

Highway interchanges (ICs) or sites are defined as the intersection of the mainline segment (e.g. Highway 401 or Highway 416) with another highway, parkway, road or avenue (e.g. Sheppard Ave., or Highway 24). In order to be considered a collision at an interchange, the collisions must occur within a kilometer of the interchange structure amounting to a maximum section length of mainline of 2 kilometers. It is worth noting that some of the interchanges, particularly in densely populated areas such as Toronto and London, are less than a kilometer apart, which means that some of the segments pertaining to a specific interchange may overlap those of other interchanges.

The first step was to find out which interchanges had a high risk of collisions. Initially, we analyzed the number of deaths at each IC and ranked all the interchanges in the dataset to observe which ones had the highest number of deaths. However, as expected, the busiest and most complex interchanges showed the highest numbers of fatalities and were seemingly the ones that performed the poorest. However, conducting an analysis on these ICs due to their apparently high fatality numbers would have been misleading. Without considering traffic density, a rural site which showed an average annual daily traffic (AADT) volume of 20,000 cars and 20 fatalities a month, would have not been a priority to us had it been compared to an urban IC with an AADT of 200,000 and an average of 40 fatalities a month.

We used a method to classify the interchanges based on formulae designed by the Ryerson University Department of Engineering (Persaud, 2009). This allowed us to rank interchanges while accounting/adjusting for traffic volume, type of interchange (group 1, 2, or 3) as well as length of the interchange (2km vs. less).

Initially, we determined the class of each interchange. In total, there were 362 interchanges on Ontario's 400-Series Highways (including the Queen Elizabeth Way (QEW)). For purposes of this project, QEW interchanges were excluded because no data at the vehicle/driver level were available. An MTO report prepared by iTRANS in conjunction with Ryerson in June 2000 classified 10 different classes of interchanges that varied in their configuration with respect to ramps, curves, number of lanes, number of entrances and exits, as well as other variables (Bahar, DiLorenzo, Munro, & Persaud, 2000). The report stated that there was insufficient variation in operational performance between interchanges to calibrate separate operational performance functions (OPFs) for each one of the 10 classes. As a result, the 10 classes were categorized in 4 different groups and their concurrent 4 performance functions.

In order to classify the 363 interchanges, we studied aerial pictures and diagrams supplied by MTO in order to determine how each IC's configuration compared to the 10 classes that had been previously established (Figure 1). Whenever there were uncertainties regarding which class an IC should be classified as, we consulted with the representative from MTO's Traffic Office in St. Catherine's, Ontario.

After each interchange was classified into one of the 10 classes, they had to be placed into their corresponding groups as follows:

Group 1: Full Diamond, Partial Cloverleaf, Partial Loop, Service Road

Group 2: 4-Quad Parclo, 4-Quad Loop, Full Cloverleaf

Group 3: Trumpet, Direct Link

Group 4: 10 – Other

In order to place each IC in its corresponding group, every highway segment within a region (e.g. 401 within Eastern region) was divided into 0.1 km segments. Data on fatalities, injuries and damaged property in the last 5 years (2002-2006) as well as traffic volume for each one of those years were included.

We were responsible for selecting every 0.1 km segment pertaining to a specific interchange and once all these were selected, we grouped their data (most of the time there were 20, for a 2 km total) which in turn resulted in overall values for that interchange.

For example, in order to classify the interchange "Highway 400 at Highway 401", we first determined the grouping, which in this case was Group 3. Then, the 0.1 km segments pertaining to this interchange and containing its data had to be selected (Figure 2a).

After all segments had been placed in their corresponding group spreadsheets, all the segments corresponding to the same interchange had to be labeled indicating so, in order for their data to be added accordingly (Figure 2b).

Once all segments pertaining to the same interchange were grouped, their data were coded as belonging to that interchange and were included into a e spreadsheet that included pre-established formulas used to define operational performance functions (OPFs) that had previously been developed by MTO and its partners at Ryerson University (Figure 2c).

These OPFs averaged the annual average daily traffic (AADT) volumes, and added the number of 'fatal', 'injury', and 'property damage only – PDO' collisions, while employing Bayes' Theorem which estimates the probability of an event occurring given its past or observed evidence. As a result, the end goal of employing these OPFs was to use the 5 years of data (2002-2006) to determine which interchanges performed as expected, better, or worse than expected. Based on the OPFs expected annual collision frequencies for all interchanges, expected excess annual collision frequencies and a rating scale referred to as 'Level Of Service of Safety' or simply, LOSS were calculated.

As explained by the Ministry of Transportation of Ontario, an OPF yields a predicted number of collisions for a certain highway interchange based on AADT and the structural design (group number).

Furthermore, there may be a certain degree of randomness in collisions. As a result, even though AADT and structural properties belonging to a site may not change year over year, the number of observed collisions will change as a result of this random factor. To counteract this randomness, the Empirical Bayes (EB) method statistically modifies the observed collision count to give an expected mean collision value that can then be compared to the value predicted by the OPF for similar locations.

The difference between the expected value achieved through the Bayes method and the predicted value obtained through the different OPFs is referred to as 'excess collisions'.

We used the Level of Service of Safety (LOSS) method developed by Kononov and Allery and later revised by Persaud et al. to classify how, in this case, an interchange performed by comparing the expected collision count to the value predicted by the OPF (Konovov & Allery, 2003). The expected collision counts were classified into one of four LOSS categories or levels:

LOSS I – Low potential for collision reduction
LOSS II –Better than expected safety performance
LOSS III –Less than expected safety performance
LOSS IV –High potential for collision reduction

The dividing line between LOSS I and II was -1.5 standard deviations from the OPF, and between LOSS III and IV fell +1.5 standard deviations (Figure 3).

Persaud et al revised the method designed by Kononov and Allery to use the EB estimate rather than observed collisions (Persaud, Begum, & Lyon, 2009). The LOSS classification gives an indication of where more (or fewer) collisions are occurring than the model predicts; however, it gives no indication of why the collisions are occurring which is one of the reasons why we compared LOSS I vs. LOSS IV sites.

After calculating a LOSS category for each one of the 362 interchanges, we selected the ones pertaining to LOSS I and IV categories since they were the ones furthest from the average. Comparing these two categories would allow us to compare the best and worst performing interchanges in order to gain insight into variables that might be modified to improve safety on Ontario highway interchanges.

Results

Road Design & Impact Location

Initially, a total of 31 interchanges fell in either category. Seventeen were LOSS I interchanges and the remaining 14 were LOSS IV. However, as mentioned previously, interchanges on the QEW were excluded due to incompatibility of datasets (n=7). 24 interchanges were available for analysis on the 400-Series Highways in Ontario.

Out of the 24 total interchanges included in this analysis, 14 were LOSS IV and 10 were LOSS I. Eleven of the 24 ICs were in Ontario's Central Region (CR) with 10 of these 11 being LOSS IV. The remaining 4 LOSS IV interchanges were in the Eastern Region (ER) with another 3 ER interchanges being classified as LOSS I. The remaining 6 interchanges were all in the Southwestern Region of Ontario (SW) and they were all deemed to be LOSS I sites.

In total, there were 9,176 vehicles involved in motor vehicle collisions at the interchanges of interest between the years 2002 and 2006 (Table 3). The main objective of the interchange analysis was to determine the differences between LOSS I and IV interchanges and attempt to find out what factors contributed to the poor performance of LOSS IV interchanges compared to their LOSS I counterparts.

We predicted that due to the implications of being a LOSS IV interchange, sites that were labeled as such would likely display a much greater number of collisions than LOSS I interchanges with regards to absolute number of collisions, fatal, injury-only, and PDO collisions. As predicted, 92.3% (n=8,473) of collisions included in our data occurred at LOSS IV sites, while the remaining 7.7% (n=703) happened at LOSS I interchanges.

One of the main variables of interest was the type of collision that drivers were involved in at both interchange categories. We wanted to understand if there was a difference in the type of collisions that drivers were involved in, and if so, we wanted to investigate factors related to such a difference.

The dataset was analyzed for the three most common types of collisions which collectively included 97.4% of all cases (n=8,931); they were: rear end, side swipe, and single vehicle collisions (Table 4). LOSS I interchanges showed an 18.9% lower rate of rear end collisions while the rate of single vehicle collisions was twice as high as it was amongst collisions at LOSS IV interchanges. The rate of side swipe collisions was similar between the two categories.

As a result of the preliminary difference, we further analyzed the dataset by screening each interchange and comparing the incidence of the three different types of collisions with their respective categories' (LOSS I or IV) rates.

Only 12 of the 24 interchanges showed irregular collision rates that differed significantly from the average rates; more specifically, 6 of 14 LOSS IV interchanges, and 60% of those classified as LOSS I (6 of 10). The unusual activity shown by the 6 LOSS IV interchanges was expressed as an elevated rate of single vehicle collisions compared to the average rate of 15.7%.

Single vehicle collisions could be a result of various factors; they involve some sort of loss of control which may be due to one or more of the following: weather conditions, high speed driving, mechanical issues, poor traffic signage, distractions inside or outside the vehicle (e.g. speaking on a cellular phone, eating), and wild animals that may interfere with the pre-established choice of travel, requiring the driver to quickly adjust to new conditions.

In order to try to find out what may have caused the higher rate of single motor vehicle collisions, we chose those interchanges with ≥50% of their collisions being classified as 'single vehicle' and further explored the time of these collisions as well as what agent the vehicles collided against hoping to find certain patterns that would explain these results.

When the 7 interchanges displaying ≥50% rates were analyzed (47500, 47820, 47960, 47980, 49160, 49260, and 49320 – See table 3), no rates were found regarding the different time periods of the day that differed significantly from their respective averages in relationship to the incidence of collisions. The distribution of collisions at different times of day were consistent, with the afternoon and early evening periods encompassing most of the collisions (45%) and the evening, night, early morning, and morning periods including the remaining 55% of collisions took place.

We subsequently analyzed the impact location of the collisions at each of these 7 interchanges of interest. Preliminary results on the entire dataset looking at 24 interchanges showed that 85% of all collisions occurred in a 'thru lane' portion of the roadway. According to the Ministry, a thru lane is a lane that is not designated for turning or for parking.

When we examined collisions that occurred at the 7 interchanges that had shown higher rates of single vehicle collisions, only 44% of them took place in a thru lane. When these results were stratified according to LOSS category, the results showed that vehicles which collided at the LOSS I interchanges, did so in the thru lane portion of the interchange 56% of the time as opposed to those collisions that took place in the thru lane of LOSS IV interchanges 40% of the time. Therefore, we decided to investigate other impact locations while studying the aerial photographs corresponding to each of the 7 interchanges to try to find an explanation for the marked difference in thru lane collisions between the entire dataset and these 7 interchanges of interest.

When focusing on collisions that occurred off road, which are defined as collisions occurring beyond the left and right shoulders with respect to the direction of travel, we initially found that only 2.1% and 2.3% of collisions took place off road to the left and to the right respectively when the entire sample was included in the analysis. However, when this same analysis was conducted on the 7 sites of interest, we observed sharp increases to 14.7% and 18.6% left and right correspondingly with both LOSS categories displaying similar results (14.7% and 14.9%) for off road left collisions. There was a difference between the two LOSS categories in collisions on the right side off the road. The 4 interchanges that were LOSS IV had 83 collisions off road right (22.6% of collisions at these 4 interchanges) compared to the 8 collisions suffered by the 3 LOSS I sites during the 5 year span in that location of an interchange (6.6% of collisions at the 3 interchanges).

The aerial images of all 7 interchanges were studied in order to identify possible causes for the difference between the categories in relationship to right sided off road collisions. When the number of entries and exits from the mainline segment were compared between the interchanges belonging to LOSS I versus those belonging to LOSS IV, no difference was found. Furthermore, the lengths of the exit and entry lanes were similar.

For example, as observed in Figure 4, the two interchanges belonging to the two different categories (LOSS I and IV) showed similar structures (with the exception of the direction of travel on the main segment). We checked for lighting differences between these interchanges but found no difference. Both interchanges were calculated to have a 2km long interchange spacing area.

We compared the time of the day during which the collisions occurred at these two sites. When these two interchanges were compared, 6 times more collisions occurred in the morning in the LOSS IV interchange compared to the LOSS I site.

We also examined rear-end collisions, which showed a marked difference between LOSS I and LOSS IV interchanges.

We compared the interchange spacing of the 14 LOSS IV interchanges with those of the 10 LOSS I sites and found an average difference between the two categories of 140 meters. The LOSS I interchanges averaged 1.8km in spacing between adjoining interchanges which is close to the 2.0km area of influence recommended by the Ministry aimed at decreasing turbulent driving conditions. On the other hand, the 14 LOSS IV interchanges were closer to other interchanges, with a 1.66km average spacing. Further, 60% of the interchanges in LOSS I were the recommended 2km away from other interchanges whereas 50% of the LOSS IV interchanges met this condition.

Subsequently, we focused on the interchanges that showed a ≥70% rate of rear-end collisions in order to capture those that fell above the average for the LOSS IV sites, or in other words, those who performed the worst in terms of rear-end collisions. In total, there were 5 interchanges which had rates above 70%, and they were all LOSS IV sites. The average spacing around these interchanges was 1.48 kilometers and their annual average daily traffic (AADT) ranged from 150,000 to 360,000 vehicles per day.

We studied the aerial pictures of the 5 aforementioned interchanges with the highest rates of rear-end collisions (4 pictures shown in Figure 5). In addition to having very high traffic volumes and shorter spacing, these interchanges showed complex configurations. The interchange in picture 1 had entry and exit points going in 9 directions while picture two had 13, followed by picture 3 which mapped Hwy. 401 at Yonge Street with 12 entry or exit points and the 4th diagram displaying 33 points of entry or exit at the junction between Hwy. 401 and Allen Road. The confusion presented by an increased number of entry and exit points, in addition to the traffic volume, and the sharp angles, may be related to the increased number of rear-end collisions at these interchanges.

Finally, we conducted an analysis comparing the groups of interchanges that made up the LOSS I and LOSS IV interchanges in order to see if any Group (1, 2, 3 or 4) had a greater presence amongst them. The results (Table 5) showed that Group 2 configurations (Quad Partial Cloverleaf, 4-Quad Loop and Full Cloverleaf) were the designs seen at almost 40% of collisions (66% for LOSS I and 37.5% for LOSS IV) while the remaining 60% were equally distributed amongst Group 1 and 3 configurations (30% each).

Illumination

We investigated the difference in lighting between LOSS I and LOSS IV interchanges in order to determine if the difference in their performance may be determined by their illumination conditions.

In total, there were 8,766 collisions reported at the 24 interchanges that had a record for the light conditions. The conditions of interest were 'Daylight', 'Dark', and 'DarkA'. The later referred to dark conditions with artificial lighting throughout the mainline segment and ramp portion of the interchange, whereas the 'Dark' condition was simply dark with no artificial lighting or partially lit at either the mainline segment or the ramp section of the interchange. When all 24 interchanges were observed, we noted that 72.5% of collisions occurred in the daylight while 14% transpired in dark conditions and the remaining 13.5% took place in dark conditions with artificial lighting. However, there were a few outliers that had a much greater occurrence of collisions in dark interchanges. Therefore, we contacted the Ministry of Transportation in order to obtain further information on the lighting conditions of these interchanges.

Illumination throughout interchanges can be configured in several ways. Some interchanges may have no lighting at all, some may only have lighting at decision points, ramp terminals, the mainline segment, or at any combination of these three lighting locations (Figure 6).

After obtaining data from the different regional offices, we investigated lighting conditions for 4 sites of interest. These sites of interest had a rate of collisions in the dark that were considerably higher than the 14% average rate for the entire 24 interchange cohort. Two of the 4 interchanges were LOSS I, while the other 2 were LOSS IV sites.

The Ministry clarified that interchanges which were not fully illuminated through the mainline segment and ramps were labelled as 'Dark' interchanges even though they may have contained some artificial illumination which could lead one to think of the site as a 'DarkA' rather than 'Dark' one. As a result, these interchanges that could be classified as 'Dark' were further labeled as 'Partially Illuminated' by the Ministry if they had any of the above illumination features.

The results showed that the interchange at Highway 401 and Highway 30 was only equipped with ramp terminal illumination during the study period which may explain why the rate of 'Dark' collisions was 36.6% between 2002 and 2006. Furthermore, the interchange at Highway 401 and Highway 77 (Comber Rd.), had 30.3% of its collisions occur during 'Dark' conditions, and only displayed partial illumination at decision points and at the ramp terminals. Also, the interchange at Highway 401 and Highway 27 which had a 'Dark' collision rate of 38.1% was initially reported as having partial illumination at the decision points and ramp terminals. However, after examining the contract dates for the installation of the illumination equipment at this site, it was determined that the site was entirely dark during the study period since the illumination equipment was only installed in the year 2008. In addition, with a 28.8% rate of 'Dark' collisions, the interchange at Highway 401 and Manning Road was categorized as a partially illuminated site with lighting at the decision points and ramp terminals. However, we determined that these lighting features were only present at the site for part of the study period (2002-2006), since the lighting was installed in 2005. Therefore, most of the data collected at the site during hours of darkness would have been under entirely dark conditions throughout the interchange.

In order to better estimate the effect of the installation at Highway 401 and Manning Road s, we conducted a sub-analysis comparing an average dark collision rate for the years 2002 until 2005 versus the rate of dark collisions in the year 2006, after the illumination had been installed at the decision points and ramp terminals. While keeping in mind that the mainline segment of the interchange was still dark after the 2005 upgrade, we found a drop in the incidence of collisions in the dark at this site that saw an average of 29.4% during the 4 year span decrease to 16.7% in the year 2006. Additional years of data would be required to confirm the impact of lighting at this interchange.

Discussion

There were significant differences in the number and type of collisions between those interchanges that have a high potential for a reduction in collisions (i.e., are currently at increased risk of collisions) compared to the lower ones. These differences were seen as a lower percentage of off-road right collisions at the better performing interchanges. Various reasons could account for the differences in other collision types between interchanges. The design of the interchange was one important variable that we examined. In Ontario, all provincial highways which were included in this study are maintained by the provincial traffic authority (MTO) and all interchanges should therefore, have similar maintenance standards. In addition, since the analysis was conducted on sites within one province (Ontario) and along the southern portion, climate and or weather conditions should not vary markedly between the sites.

When we compared two interchanges with a high incidence of single vehicle collisions (LOSS I and LOSS IV), we analyzed the time that the collisions took place at and since we found that 6 times more collisions occurred in the morning in the LOSS IV interchange compared to the LOSS I site, we suggested that a reason for this may be the morning commute difference in and out of the cities at both ends of the interchanges. If the LOSS IV interchange were to be located closer to a larger city, the morning commute could possibly account for the elevated number of morning collisions. Furthermore, the morning commute on highway 401 involves drivers going from the west heading east into the city of Toronto with the sun rising on the east. This may result in difficult driving conditions due to the intense morning glare. After analyzing the surrounding areas of both interchanges and observing their rural nature, we believed that other events may have been responsible for the differences in collisions (such as the presence of deer or other animals on the mainline). Unfortunately, the dataset obtained from MTO did not contain a variable explaining other events recorded at the scene of each collision, so the causes could not be properly determined. As a result, we contacted the Ministry with hopes of encouraging further research on these 7 interchanges of interest in order to try to determine why the incidence of single vehicle collisions was elevated amongst them.

We also found a difference in rear end collisions between the higher and lower performing interchanges. After comparing the spacing of the interchanges belonging to each category, we found that those that were performing well had greater spacing between interchanges, providing a potential explanation for the lower number of rear end collisions. As McCartt et al explain, increasing the length of acceleration lanes throughout an interchange may increase spacing and provide sufficient room to decrease rear end collision (McCartt et al., 2004). A possible explanation raised by McCartt is that shorter interchanges result in higher traffic congestion at the interchange since a greater number of vehicles are trying to enter and leave in a smaller than recommended space. We hypothesize that the relationship between interchange spacing and rear end collisions lies in the pressure that is put on the driver when driving in an interchange with shorter spacing. If the acceleration or deceleration lanes are not long enough, drivers may be forced to enter or exit the mainline at inappropriate speeds. If entering the mainline at a lower speed, there is a higher risk of being hit from the rear, while if one exits at a higher speed than needed, this driver may in turn collide with someone else's rear. Soliman et al. also believe that increasing the length of these merging lanes will enhance safety and operation of Canadian interchanges (Soliman El-Basha et al., 2007).

Another potential factor contributing to the increased number of rear end collisions related to interchange spacing may be interchange complexity. As seen in the diagrams, the complex interchanges which were lower performing had an overwhelming number of lanes, merging lanes, and entry and exit points. An interchange with so many options may pose a risk to the driver. According to the Hick-Hyman Law, the more options that are available to the subject, the longer that subject's choice reaction time will be before making the right decision (Hyman, 1953). Drivers faced with multiple lanes at an interchange including multiple exit and entrance options may have a decreased reaction time, which may result in an inadequate speed, ultimately resulting in rear end collisions.

The reasons for the different incidence of collisions by type of interchange (Table 5) are unknown. We hypothesize that the interchange designs in Group 2 may be more common in areas where the traffic density is greater. Further efforts to establish reasons for these differences are warranted.

Lastly, interchange illumination appears to be related to the number of collisions. Proper lighting or illumination has been shown to be related to the safety of motor vehicle users. With good lighting, drivers are able to see signs well and in advance which allows them to prepare for a sharp turn if the signs indicate so, or if one is seeking to exit at a pre-determined interchange, good lighting can allow the driver to make proper lane changes as necessary, and exit at the right point with sufficient time and caution. However, if illumination is minimal or not present, drivers may have a hard time seeing signs, obstacles, potholes, animals, or even an exit lane when relying solely on their vehicle's lights. Even though we did not find any differences in lighting between the LOSS categories, our results showed that when lighting was installed at one interchange, collision rates decreased substantially. These results are in agreement with the literature which states that partial lighting decreased overall collision rates. However, the same article further states that lighting through the entire interchange (including mainline segment) further improves collision rates (CIE, 1992). In addition, the results from Wanvik et al. further showed how important proper lighting is by showing a 49% decrease in collision rates when comparing well lit areas to entirely dark motorway segments (Wanvik, 2009).

Strengths and Limitations

One of the main strengths of our study was the use of a comprehensive dataset. Only 3.9% of its cases missed some data, and a large number of variables were available to us. Furthermore, the data were gathered using police reports, a standardized method of data collection, which have also been employed in previous literature (Agran, Castillo, & Winn, 1990). Also, our study made use of a multi-disciplinary approach, which included the epidemiology focus of our team combined with the engineering expertise provided by Ryerson's development of the OPFs, as well as a policy-based view by our colleagues at MTO's Traffic office. In addition, the way we defined the LOSS categories and classified the interchanges has been validated and shown to be the most rigorous and appropriate by MTO, specially compared to the previously attempted frequency method.

Some limitations of our study include the potential for misclassification bias in the police reports. Also, since the study was conducted using Ontario data, the generalizability of the results to other places remains in question. Lastly, our focus was strictly on Ontario's 400-series provincial highways; as a result, our findings cannot be extended other highway types in Ontario.

Conclusion

Although Ontario's roads have been shown to be the safest in North America, there is a gap in terms of performance between our safest interchanges and those that do not perform as expected. Therefore, there is still room for improvement and proper illumination and increasing spacing between interchanges may improve safety in those interchanges that are at increased risk.

Chapter 4
Global Discussion

Global Discussion

The two studies presented here represent an advance in our understanding of road traffic safety on Ontario highways. We have identified driver-related, environment-related, and road design-related risk factors for fatal collisions, and have identified similar factors that increase risk at interchanges. We found that male drivers, older drivers, nighttime driving, and undivided highways all pose an increased risk of a fatal outcome as a result of a collision. We also found that interchange spacing and illumination are key elements of interchange safety.

As the World Health Organization (WHO) predicts that by the year 2020 RTIs will become the third leading cause only following ischemic heart disease and unipolar major depression (Krug, 2004), it is paramount that this public health concern be addressed in Canada. Concurrently, Canada's population continues to increase at a steady rate, with Government of Canada projections predicting a 9 million hike in our country's population by 2036 (Statistics Canada, 2010).

In 2006, the total number of injuries that occurred in Canada as a result of road traffic collisions was 199,337. Closer to home, in Ontario, the calculated the social costs of MVCs were $18 billion in the year 2004 with each fatal collision costing an average of $15.7 million (Vodden et al., 2007).

In the five-year period that our studies investigated (2001 to 2006), the 815 fatal MVCs on Ontario's 400-Series Highways cost taxpayers close to $12.8 billion, or almost $2.6 billion per year. Our studies use an epidemiological approach to studying crashes on Ontario's major highways in their entirety with regards to structural, environmental, and driver related variables. We identified various risk factors that, when modified, may contribute to improved safety on Ontario's roads. We believe that the findings of these studies may be applicable in the rest of Canada, and around the world.

After conducting two different, yet interrelated studies, we report on several modifiable risk factors that can be addressed and that can in turn, significantly improve driver safety. Multiple studies have shown that certain types of highway design, acceleration lane, and lighting configurations produce safer driving conditions and our studies strongly supports some of these suggestions. With regards to highway/interchange design, we showed that, similarly to Zhang (1998), undivided 2-way segments as well as divided 2-way segments in addition to short and complex interchanges proved to increase fatality rates. Our results support previous work that identifies interchanges or highway segments with a combination of these factors demonstrate an increase risk of crashes or fatalities.

Installing barriers throughout heavily traveled highways may reduce reduction of fatal collisions. Furthermore, our analysis of aerial photographs showed that when interchanges were close in proximity, the complexity of these increased and this increased complexity was found to be closely related to being labeled as CAT IV sites. As a result, we suggest that highway interchanges should be at least the MTO recommended 2 km in spacing in order allow for proper acceleration and deceleration. These later recommendations are supported in the literature by Soliman and McCartt, who cite the importance of a properly constructed merging lane in an attempt to decrease rear end collisions. More specifically, if acceleration lanes are significantly extended at

LOSS IV interchanges, we believe that the collision rates at these sites will be significantly affected, and that these sites will have a great potential to become a lower LOSS category sites.

Furthermore, as Wanvik and the CIE have previously stated, lighting is of outmost importance in road safety. Whether it is 'some' or 'full' illumination, the more lighting that is available, especially at an interchange, the less likely a collision is to occur. Our study support this notion and although we would like to further analyze illumination through Ontario's highways, our results suggest that proper lighting is associated with a reduction in collision risk.

Lastly, in addition to tackling structural concerns, we believe that policy-makers should pay special attention to certain demographic groups, such as males and older drivers According to the literature and our supporting results, males seem to be the ones at highest risk for dying in an MVC due to their risk-taking behavior which may be expressed by going at higher speeds or by using alcohol and/or drugs when driving (Jonah, 1986; Mercer & Jeffery, 1995; Seppala et al., 1979). Furthermore, older drivers, as explained by Zhang (2000), may suffer cognitive impairment or decreased muscle strength, flexibility and reaction time, or have reduced dynamic visual acuity, night vision and visual field. As a result, possible routes of intervention may involve mandatory refreshment driving lessons or heftier insurance premiums. Also, a revision of Ontario's current graduated driver licensing (GDL) program may be necessary in order to take further precautions with these groups (males and elderly drivers). A 2009 Cochrane systematic review by Hartling et al. reviewed 12 articles and found that although GDL is effective in reducing the crash rates of young drivers, the magnitude of this effect is unknown and as a result, the authors recommended that further primary research be conducted on GDL (Hartling et al., 2004).

In addition, we believe that increased police presence at sites of high risk, including both interchanges and stretches of highway at increased risk may improve driver safety by promoting lower speeds. Although our dataset did not include a variable which indicated whether police was present at the scene of each collision or not, one Australian study supports the notion of police presence as a driver safety mechanism; Newstead found in 2001 that police presence in Queensland as part of a prolonged program to decrease collisions and fatalities decreased fatal collisions by 31% and overall collisions by 11% during the length of the program. The program yielded a benefit/cost ratio of 55:1. Based on the ability to identify areas of increased risk, a similar program in our province may be effective in reducing collisions (Newstead, Cameron, & Leggett, 2001)).

There were several strengths of our study that should be highlighted. We believe that this is the first to evaluate the how driver-related, environmental, and structural risk factors are associated with motor vehicle collisions on Ontario's 400-Series Highways. Further, it used a complete (96.1%) routinely collected database, stemming from standardized police reports, which included a large number of variables (n=54) available for the analyses of collisions in our province. Also, our study included most of the province, compared to the one section analyzed in Lemieux's study (2008). In addition, the outcome (fatal or non fatal collision) was assessed up to 30 days after the collision took place, which takes into consideration the possibility for in-hospital deaths. We excluded vehicles such as motorcycles and bicycles which were found to be at an increased risk for a fatal outcome when involved in a collision, thus restricting the results to automobiles and commercial vehicles. Finally, our study was the first to make use of a multi-disciplinary approach which included epidemiological, engineering and governmental approaches.

Some limitations include a potential for misclassification bias since the data is entirely based on police reports. The police may not always have been able to enter data completely and accurately. Also, information was not related to driver skill, distractions at the moment of impact, or cell phone use. Lastly, since our study examined Ontario's 400-series provincial highways, our findings cannot be extended other highway types in Ontario.

In conclusion, our research has highlighted risk factors that lead to increased risk of collisions on Ontario's 400 series highways. Many of these risks are modifiable, and include dividers for the highways, longer interchanges, increased lighting, and distance between interchanges. Other preventive strategies that could be tried and evaluated include an increased police presence at identified areas of risk, extension of Graduated Driver's Licensing, and driver education for those at risk.

Table 1. Distribution of Fatal and Non-Fatal Injuries by Risk Factor for 52,131 vehicles involved in collisions between 2001 and 2006 on Ontario's 400-series Highways

		Outcome – N (%)			
		Fatal	Injury	Total	% Total Fatalities
Highway					
	400	102 (1.9)	5,347 (98.1)	5,449	13.03%
	401	456 (1.4)	31,094 (98.6)	31,550	58.24%
	402	20 (3.4)	573(96.6)	593	2.55%
	403	40 (1.3)	3,124 (98.7)	3,164	5.11%
	404	13 (0.4)	3,088 (99.6)	3,101	1.66%
	405	9 (15.8)	48 (84.2)	57	1.15%
	406	18 (2,7)	640 (97.3)	658	2.30%
	409	1 (0.3)	352 (99.7)	353	0.13%
	410	10 (1.1)	907 (98.9)	917	1.28%
	416	5 (1.2)	416 (98.8)	421	0.64%
	417	82 (2.6)	3,013(97.4)	3,095	10.47%
	420	3 (1.7)	170 (98.3)	173	0.38%
	427	24 (0.9)	2,576 (99.1)	2,600	3.07%
Season					
	Winter	218 (1.6)	13,762 (98.4)	13,980	27.84%
	Spring	165 (1.4)	11,280 (98.6)	11,445	21.07%
	Summer	238 (1.8)	12,890 (98.2)	13,128	30.40%
	Fall	162 (1.5)	13,416 (98.5)	13,578	20.69%
Day of the Week					
	Sunday	109 (1.7)	6,300 (98.3)	6,409	13.92%
	Monday	114 (1.5)	7,292 (98.5)	7,406	14.56%
	Tuesday	81 (1.1)	7,452 (98.9)	7,533	10.34%
	Wednesday	98 (1.3)	7,290 (98.7)	7,388	12.52%
	Thursday	103 (1.3)	7,624 (98.7)	7,727	13.15%
	Friday	166 (1.9)	8,599 (98.1)	8,765	21.20%
	Saturday	112 (1.6)	6,791 (98.4)	6,903	14.30%
Time Period					
	Evening	114 (2.0)	5,722 (98.0)	5,836	14.56%
	Night	146 (3.4)	4,137 (96.6)	4,283	18.65%
	Early Morning	99 (1.3)	7,619 (98.7)	7,718	12.64%
	Morning	107 (1.1)	9,525 (98.1)	9,632	13.67%
	Afternoon	144 (1.4)	9,901 (98.6)	10,045	18.39%
	Early Evening	173 (1.2)	14,256 (98.8)	14,429	22.09%
Sex					
	Female	176 (1.1)	15,464 (98.9)	15,640	22.48%
	Male	607 (1.7)	35,884 (98.3)	36,491	77.52%
Age Group					
	Adolescence	26 (1.1)	2,267 (98.9)	2,293	3.40%
	Early Adulthood	363 (1.4)	25,742 (98.6)	26,105	47.51%
	Middle Adulthood	326 (1.6)	19,483 (98.4)	19,809	42.67%
	Late Adulthood	49 (2.3)	2,055 (97.7)	2,104	6.41%

Environment					
	Clear	549 (1.4)	39,598 (98.6)	40,147	70.11%
	Rain	45 (1.0	4,567 (99.0)	4,612	5.75%
	Snow	82 (1.5)	5,354 (98.5)	5,436	10.47%
	Frozen Rain	23 (2.7)	842 (97.3)	865	2.94%
	Drifting Snow	55 (12.8)	375 (87.2)	430	7.02%
	Wind	10 (7.9)	117 (92.1)	127	1.28%
	Fog	16 (4.1)	372 (95.9)	388	2.04%
	Other	3 (2.4)	123 (97.6)	126	0.38%
Road Characteristic					
	Undivided 1-Way	10 (1.3)	732 (98.7)	742	1.28%
	Undivided 2-Way	42 (3.9)	1,026 (96.1)	1,068	5.36%
	Dividing Barrier	318 (1.5)	21,463 (98.5)	21,781	40.61%
	Divided	301 (5.0	5,707 (95.0)	6,008	38.44%
	Ramp Road	37 (0.6)	6,096 (99.4)	6,133	4.73%
	Collector	30 (0.3)	8,798 (99.7)	8,828	3.83%
	Expressway	43 (0.6)	7,067 (99.4)	7,110	5.49%
	Transfer	2 (0.5)	416 (99.5)	418	0.26%

Table 2. Results of Single and Multiple Logistics Regression Analyses for 52,131 vehicles involved in collisions between 2001 and 2006 on Ontario's 400-series Highways

Risk Factor		Road Traffic Accident Mortality			
		OR	95%CI	AOR	95%CI
Highway					
	400	1.00		1.00	
	401	0.77	0.62 - 0.95	1.03	0.82 - 1.30
	402	1.83	1.21 - 2.98	0.42	0.24 - 0.73
	403	0.67	0.46 - 0.97	0.51	0.35 - 0.75
	404	0.22	0.12 - 0.39	0.20	0.11 - 0.36
	405	9.83	4.70 - 20.57	7.33	3.39 - 15.85
	406	1.47	0.89 - 2.45	0.82	0.47 - 1.41
	409	0.15	0.02 - 1.07	0.21	0.03 - 1.54
	410	0.58	0.30 - 1.11	0.36	0.18 - 0.69
	416	0.63	0.26 - 1.55	0.25	0.10 - 0.63
	417	1.43	1.06 - 1.91	0.83	0.61 - 1.14
	420	0.93	0.29 - 2.95	0.72	0.22 - 2.33
	427	0.49	0.31 - 0.76	0.79	0.50 - 1.25
Season					
	Winter	1.00		1.00	
	Spring	0.92	0.75 - 1.13	1.24	0.99 - 1.56
	Summer	1.17	0.97 - 1.40	1.58	1.26 - 1.97
	Fall	0.76	0.62 - 0.94	1.07	0.85 - 1.34
Day of the Week					
	Sunday	1.00		1.00	
	Monday	0.90	0.69 - 1.18	1.06	0.81 - 1.39
	Tuesday	0.63	0.47 - 0.84	0.77	0.57 - 1.03
	Wednesday	0.78	0.59 - 1.02	0.95	0.71 - 1.26
	Thursday	0.78	0.60 - 1.02	0.97	0.73 - 1.28
	Friday	1.12	0.87 - 1.42	1.28	0.99 - 1.64
	Saturday	0.95	0.73 - 1.24	0.95	0.72 - 1.26
Time Period					
	Evening	1.00		1.00	
	Night	1.77	1.38 - 2.27	1.67	1.29 - 2.15
	Early Morning	0.65	0.50 - 0.86	0.60	0.45 - 0.79
	Morning	0.56	0.43 - 0.74	0.53	0.40 - 0.70
	Afternoon	0.73	0.57 - 0.94	0.61	0.47 - 0.79
	Early Evening	0.61	0.48 - 0.77	0.66	0.52 - 0.84

Sex					
	Female	1.00		1.00	
	Male	1.49	1.26 - 1.76	1.43	1.21 - 1.71
Age Group					
	Adolescence	1.00		1.00	
	Early Adulthood	1.23	0.82 - 1.83	1.52	1.01 - 2.28
	Middle Adulthood	1.46	0.98 - 2.18	1.82	1.21 - 2.74
	Late Adulthood	2.08	1.29 - 3.36	2.37	1.45 - 3.88
Environment					
	Clear	1.00		1.00	
	Rain	0.71	0.52 - 0.96	0.76	0.56 - 1.03
	Snow	1.10	0.87 - 1.40	0.93	0.72 - 1.21
	Frozen Rain	1.97	1.29 - 3.01	1.32	0.82 - 2.12
	Drifting Snow	10.58	7.87 - 14.21	7.55	5.34 - 10.67
	Wind	6.16	3.21 - 11.82	3.96	1.87 - 8.40
	Fog	3.10	1.87 - 5.15	2.78	1.63 - 4.74
	Other	1.76	0.56 - 5.55	1.75	0.55 - 5.62
Road Characteristic					
	Undivided 1-Way	1.00		1.00	
	Undivided 2-Way	3.00	1.49 - 6.01	3.63	1.77 - 7.46
	Dividing Barrier	1.08	0.58 - 2.04	1.26	0.66 - 2.40
	Divided	3.86	2.05 - 7.28	4.61	2.42 - 8.79
	Ramp Road	0.44	0.22 - 0.90	0.52	0.26 - 1.07
	Collector	0.25	0.12 - 0.51	0.27	0.13 - 0.56
	Expressway	0.45	0.22 - 0.89	0.44	0.22 - 0.90
	Transfer	0.35	0.08 - 1.61	0.37	0.08 - 1.69

Table 3. Number and percent of collisions (Interchange-specific) on Ontario 400-series highways 2002-2006

IC Number	Frequency	Percent
46810	1164	12.7
47500	175	1.9
47643	1335	14.5
47652	827	9
47656	1680	18.3
47667	1272	13.9
47671	707	7.7
47730	284	3.1
47820	63	0.7
47826	41	0.4
47960	33	0.4
47980	25	0.3
48000	57	0.6
48320	161	1.8
48459	792	8.6
48983	77	0.8
48990	46	0.5
49160	50	0.5
49260	74	0.8
49320	69	0.8
49510	73	0.8
49520	44	0.5
49555	37	0.4
50205	90	1
Total	**9,176**	**100**

Table 4. Type of collision stratified by LOSS category, Ontario 400-series highways, 2002-2006

			Type of Collision			
			Rear End	Side Swipe	Single Vehicle	Total
LOSS	I	Count	307	126	198	631
		% LOSS I	48.7%	20.0%	31.4%	100.0%
	IV	Count	5610	1387	1303	8300
		% LOSS IV	67.6%	16.7%	15.7%	100.0%
Total		Count	5917	1513	1501	8931
		Total %	66.3%	16.9%	16.8%	100.0%

Table 5.Type of interchange where collisions occurred, stratified by LOSS category, Ontario 400-series highways, 2002-2006

			Interchange Group Number			
			1	2	3	Total
LOSS	I	Count	127	464	112	703
		% LOSS I	18.1%	66.0%	15.9%	100.0%
	IV	Count	2599	3176	2698	8473
		% LOSS IV	30.7%	37.5%	31.8%	100.0%
Total		Count	2726	3640	2810	9176
		Total %	29.7%	39.7%	30.6%	100.0%

Figure 1. Diagrams depicting the different classes of interchanges

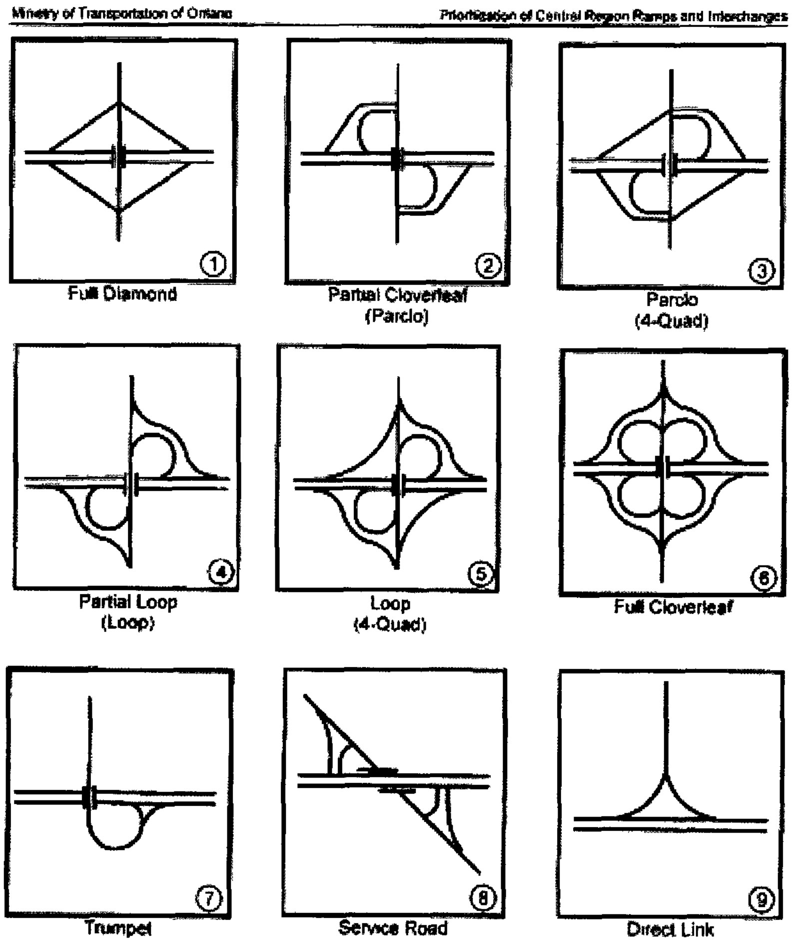


Figure 2. Examples from MTO data base used in the classification of interchanges into LOSS I and LOSS IV

	A	B	C	D	E	F	G	H	I	J
1	Region	IC#	IM#	Hwy_and_Segments	LHRS_Seg	AADT yr2002	AADT yr2003	AADT yr2004	AADT yr2005	AADT yr2006
203	CR	452	3	Hwy QEW-101420090 - E	101420090	124000	126000	130900	134200	134200
204	CR	453	3	Hwy QEW-101530090 - E	101530090	168900	169300	165800	170200	170200
205	CR	453	3	Hwy QEW-101530100 - E	101530100	168900	169300	165800	170200	170200
206	CR	453	3	Hwy QEW-101530110 - E	101530110	168900	169300	165800	170200	170200
207	CR	453	3	Hwy QEW-101530120 - E - AT RAMP 55(EB)TO WEST MALL	101530120	168900	169300	165800	170200	170200
208	CR	453	3	Hwy QEW-101530130 - E	101530130	168900	169300	165800	170200	170200
209	CR	453	3	Hwy QEW-101530140 - E - AT RAMP 66(WB)FROM WEST MA	101530140	168900	169300	165800	170200	170200
210	CR	453	3	Hwy QEW-101530150 - E	101530150	168900	169300	165800	170200	170200
211	CR	453	3	Hwy QEW-101530160 - E	101530160	168900	169300	165800	170200	170200
212	CR	453	3	Hwy QEW-101530170 - E	101530170	168900	169300	165800	170200	170200
213	CR	453	3	Hwy QEW-101550000 - E - EVANS AV IC-138 REFERENCE	101550000	168400	166100	171800	174200	174200
214	CR	453	3	Hwy QEW-101550010 - E	101550010	168400	166100	171800	174200	174200
215	CR	453	3	Hwy QEW-101550020 - E	101550020	168400	166100	171800	174200	174200
216	CR	525	3	Hwy 400-468000060 - W	468000060	89000	90000	90900	91900	91900
217	CR	525	3	Hwy 400-468000070 - W	468000070	89000	90000	90900	91900	91900
218	CR	525	3	Hwy 400-468000080 - W	468000080	89000	90000	90900	91900	91900
219	CR	525	3	Hwy 400-468000090 - W	468000090	89000	90000	90900	91900	91900
220	CR	525	3	Hwy 400-468000100 - W	468000100	89000	90000	90900	91900	91900
221	CR	525	3	Hwy 400-468000110 - W	468000110	89000	90000	90900	91900	91900
222	CR	525	3	Hwy 400-468100000 - N - HWY 401-M/C FRWY IC-21-NORTH Y	468100000	174100	176100	178100	180100	180100
223	CR	525	3	Hwy 400-468100010 - N	468100010	174100	176100	178100	180100	180100
224	CR	525	3	Hwy 400-468100020 - N	468100020	174100	176100	178100	180100	180100
225	CR	525	3	Hwy 400-468100030 - N	468100030	174100	176100	178100	180100	180100
226	CR	525	3	Hwy 400-468100040 - N	468100040	174100	176100	178100	180100	180100
227	CR	525	3	Hwy 400-468100050 - N	468100050	174100	176100	178100	180100	180100
228	CR	525	3	Hwy 400-468100060 - N	468100060	174100	176100	178100	180100	180100
229	CR	525	3	Hwy 400-468100070 - N	468100070	174100	176100	178100	180100	180100
230	CR	525	3	Hwy 400-468100080 - N	468100080	174100	176100	178100	180100	180100
231	CR	525	3	Hwy 400-468100090 - N	468100090	174100	176100	178100	180100	180100
232	CR	526	3	Hwy 400-468150110 - N	468150110	169200	178600	183900	189200	189200

2a)

	A	B	C	D	E	F	G	H	I	J
1	Region	IC#	IM#	Hwy_and_Segments	LHRS_Seg	AADT yr2002	AADT yr2003	AADT yr2004	AADT yr2005	AADT yr2006
203	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	124000	126000	130900	134200	134200
204	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	168900	169300	165800	170200	170200
205	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	168900	169300	165800	170200	170200
206	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	168900	169300	165800	170200	170200
207	CR	453	3	Hwy QEW-101530120 - E - AT RAMP 55(EB)TO WEST MALL	101530120	168900	169300	165800	170200	170200
208	CR	453	3	Hwy QEW-101530130 - E	101530130	168900	169300	165800	170200	170200
209	CR	453	3	Hwy QEW-101530140 - E - AT RAMP 66(WB)FROM WEST MA	101530140	168900	169300	165800	170200	170200
210	CR	453	3	Hwy QEW-101530150 - E	101530150	168900	169300	165800	170200	170200
211	CR	453	3	Hwy QEW-101530160 - E	101530160	168900	169300	165800	170200	170200
212	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	168900	169300	165800	170200	170200
213	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	168400	166100	171800	174200	174200
214	CR	453	3	Hwy QEW-101550010 - E	101550010	168400	166100	171800	174200	174200
215	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	168400	166100	171800	174200	174200
216	CR	525	3	Hwy 400-468000060 - W	468000060	89000	90000	90900	91900	91900
217	CR	525	3	Hwy 400-468000070 - W	468000070	89000	90000	90900	91900	91900
218	CR	525	3	Hwy 400-468000080 - W	468000080	89000	90000	90900	91900	91900
219	CR	525	3	Hwy 400-468000090 - W	468000090	89000	90000	90900	91900	91900
220	CR	525	3	Hwy 400-468000100 - W	468000100	89000	90000	90900	91900	91900
221	CR	525	3	Hwy 400-468000110 - W	468000110	89000	90000	90900	91900	91900
222	CR	525	3	Hwy 400-468100000 - N - HWY 401-M/C FRWY IC-21-NORTH Y	468100000	174100	176100	178100	180100	180100
223	CR	525	3	Hwy 400-468100010 - N	468100010	174100	176100	178100	180100	180100
224	CR	525	3	Hwy 400-468100020 - N	468100020	174100	176100	178100	180100	180100
225	CR	525	3	Hwy 400-468100030 - N	468100030	174100	176100	178100	180100	180100
226	CR	525	3	Hwy 400-468100040 - N	468100040	174100	176100	178100	180100	180100
227	CR	525	3	Hwy 400-468100050 - N	468100050	174100	176100	178100	180100	180100
228	CR	525	3	Hwy 400-468100060 - N	468100060	174100	176100	178100	180100	180100
229	CR	525	3	Hwy 400-468100070 - N	468100070	174100	176100	178100	180100	180100
230	CR	525	3	Hwy 400-468100080 - N	468100080	174100	176100	178100	180100	180100
231	CR	525	3	Hwy 400-468100090 - N	468100090	174100	176100	178100	180100	180100
232	CR	526	3	Hwy 400-468150110 - N	468150110	169200	178600	183900	189200	189200

2b)

	A	B	C	D	E	F	G	H	I	J
1	Region	IC#	IM#	Hwy_and_Segments	LHRS_Seg	AADT yr2002	AADT yr2003	AADT yr2004	AADT yr2005	AADT yr2006
14	CR	452	3	Hwy QEW-101420000 - E - WINSTON CHURCHILL BV I(	101420000	119882	121471	126329	129300	129300
15	CR	453	3	Hwy QEW-101550000 - E - EVANS AV IC-138 REFEREN	101550000	168775	168500	167300	171200	171200
16	CR	525	3	Hwy 400-468100000 - N - HWY 401-M/C FRWY IC-21-N	468100000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
17	CR	526	3	Hwy 400-468170000 - N - STEELES AV IC 27-NORTH Y(	468170000	144075	148675	154313	155150	155150
18	CR	527	3	Hwy 400-468180000 - N - 407 IC REFERENCE	468180000	104382	102164	105000	101218	101218

2c)

Figure 3. Depiction of Operational Performance Function for reference

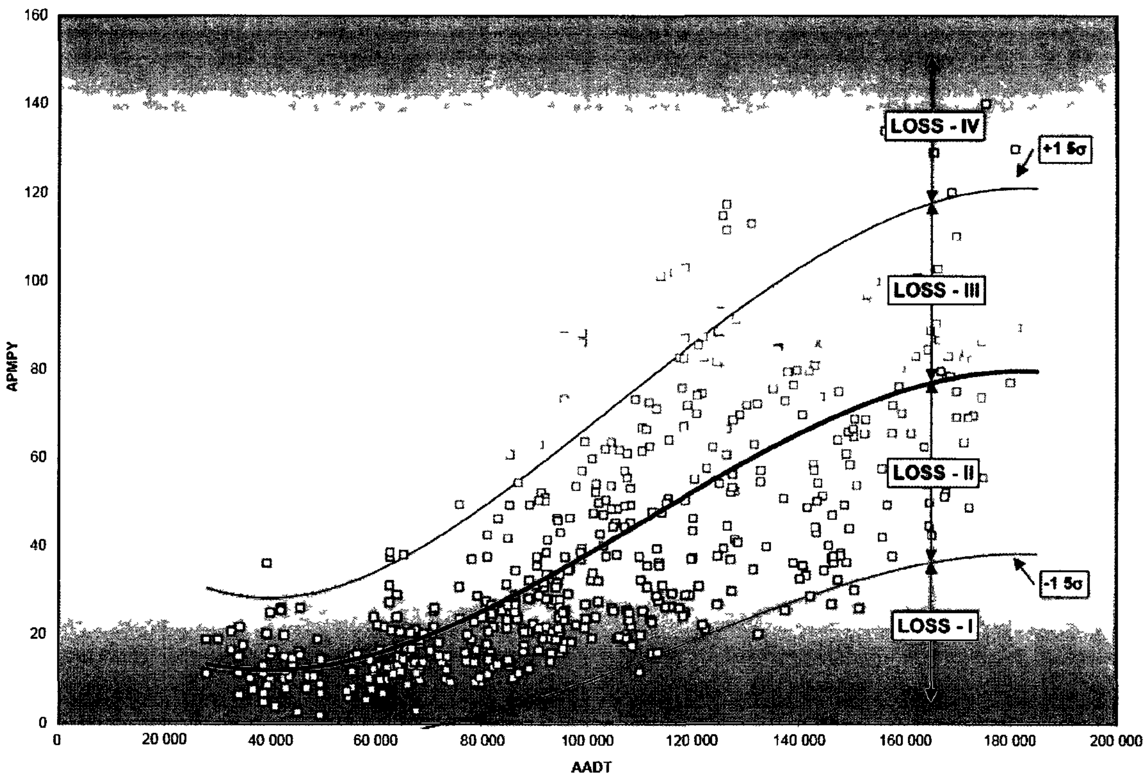


Figure 4. A comparison of characteristics of a LOSS IV and a LOSS I interchange (Hwy. 401 & Road 27 (LOSS IV) vs. Hwy. 416 & Road 21 (LOSS I))

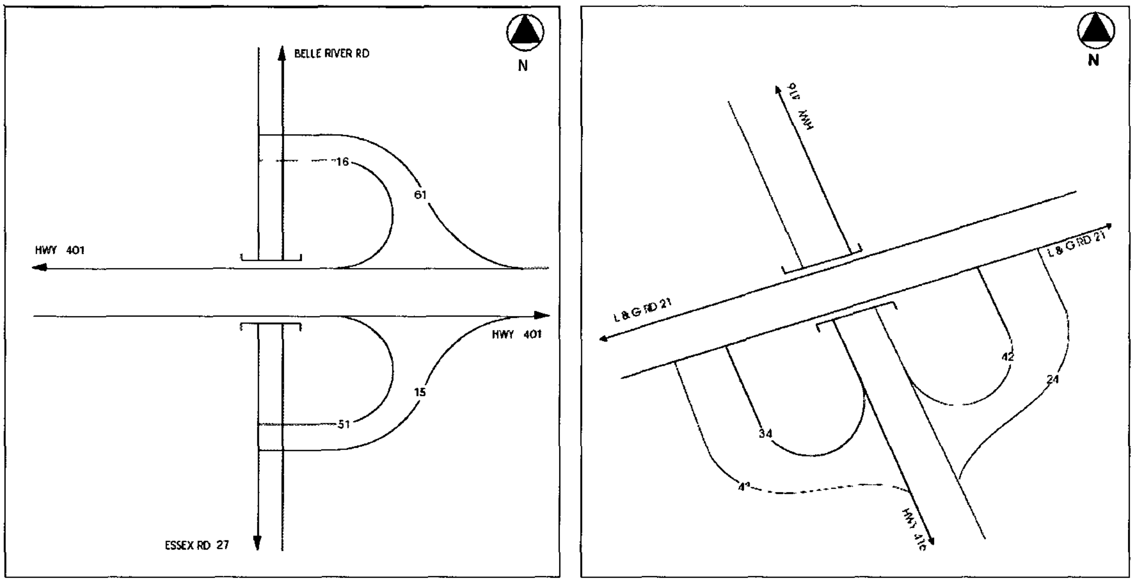
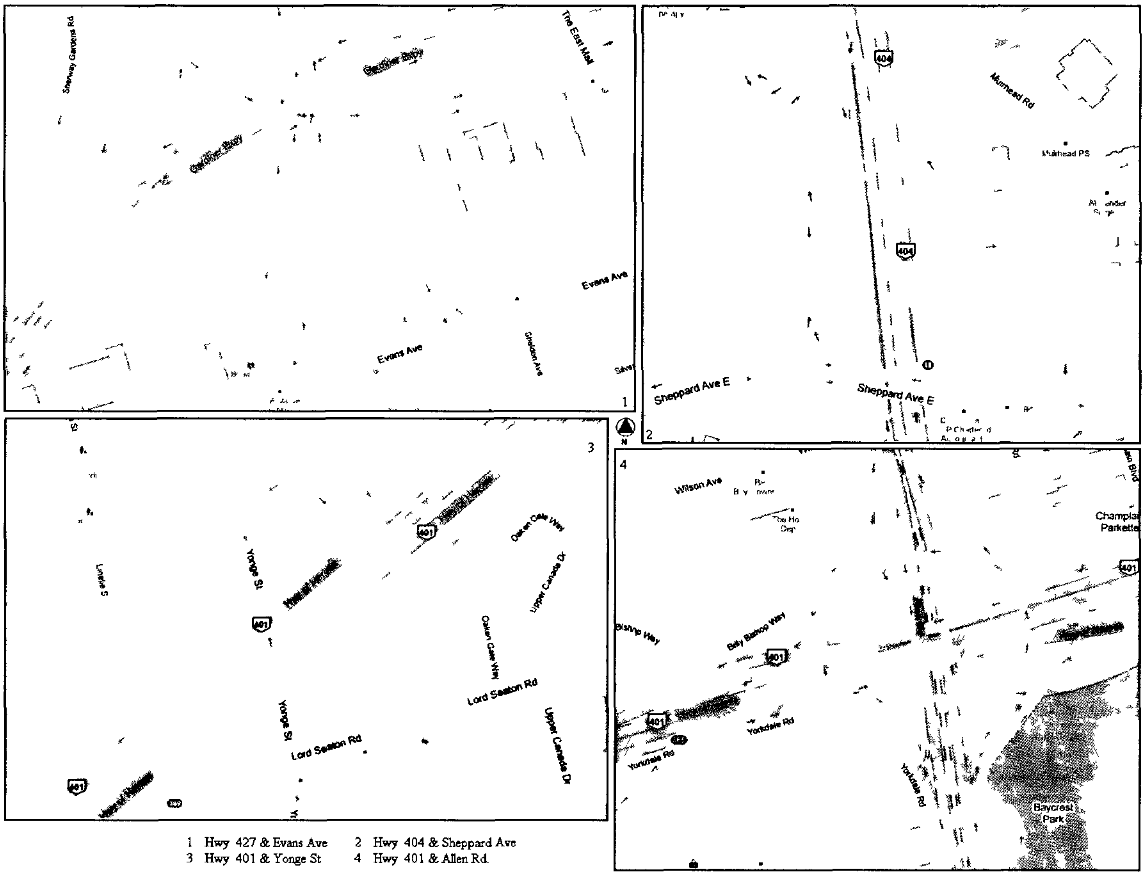
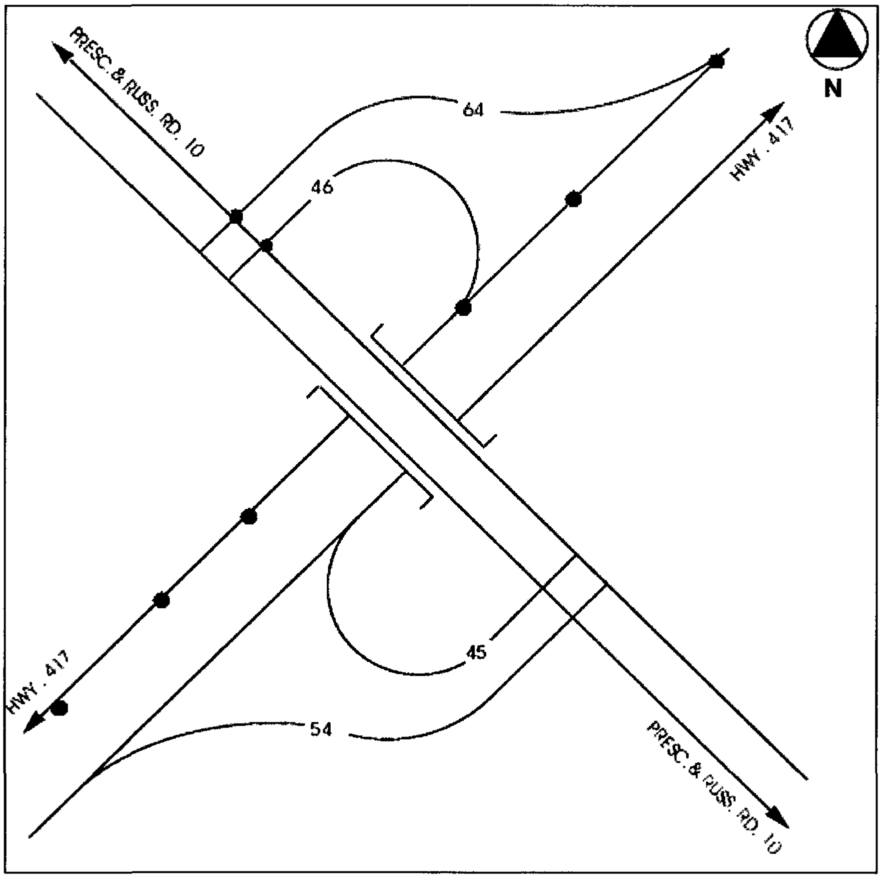


Figure 5. A depiction of LOSS IV Complex Interchanges



1 Hwy 427 & Evans Ave 2 Hwy 404 & Sheppard Ave
3 Hwy 401 & Yonge St 4 Hwy 401 & Allen Rd

Figure 6. Distribution of Interchange Illumination at the three points where illumination is placed



Red – Ramp Terminal / Purple – Decision Point / Green - Mainline

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