Factors Contributing to the Severity of Intersection Crashes in Alberta

Final Report

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Executive Summary

Road crashes are a leading cause of deaths and serious injuries in many developed and developing countries. Intersections are recognized as being among the most hazardous locations on the roads (PIARC, 2003). In Canada, for example, recent data showed that about 25% of all road users killed died at intersections (Transport Canada, 2004). Therefore, both Transport Canada's *Vision 2010* and the *Alberta Traffic Safety Plan* have set a target of 20% reduction in the number of deaths and serious injuries resulting from crashes at intersection. To achieve these goals and enhance road safety require a better understanding of the factors contributing to crashes at these hazardous locations in order to develop more targeted countermeasures.

The purpose of the study is to examine the effects of traffic characteristics, roadway design, surrounding land use, vehicle features, types of collision and road user characteristics on the severity of crashes at intersections in Alberta. To achieve this objective, our study provided a systematic review of the literature on intersection crashes in general and studies conducted on motor vehicles crashes in Alberta in particular.

Next, using the City of Calgary as a case study, the effects of several roadway characteristics on crash severity are examined. Our study found that the design of cross section elements is an important determinant of crash severity in the City of Calgary. In particular, relative to current designs, increasing the surface width of the roads, providing a median, increasing the width of the inside shoulder and reducing the outside shoulder width are likely to reduce the severity of crashes on urban roads. On the other hand, traffic volume (AADT) is not significant in determining crash severity. However, caution should be exercised in interpreting these results due to small and possibly biased sample. Of the 65, 129 intersection collisions reported in the city, only 263 have information on roadway characteristics.

Finally, a collision severity model was estimated to identify the major determinants of the severity of collisions at intersections in the City of Calgary. Due to the paucity of data on roadway characteristics, they are not included in the model. Results from our collision severity model revealed that time of year, time of day, number of vehicles involved in the crash, types of

crash, road surface conditions, age and gender of driver involved, types of vehicles involved, lighting and weather conditions have an effect on the severity of the crash.

The factors contributing to crash severity is complex and often interrelated due to driver behavior and risk compensation. Also, driver behaviors can be influenced by the design of the roadways. Therefore, understanding the major factors that contributes to both the frequency and severity of crashes are extremely important to provide evidence-based recommendations to improve the safety of our road users. More effort should be invested in collecting the key roadway information that are supposed to be included in the official crash database. Without a proper data on roadway characteristics, our understanding on the relative roles of various contributing factors will be limited in scope. Using the estimated statistics based on restricted data to target and prioritize road safety interventions, including enforcement activities, may not result in the most efficient use of scarce road safety resources.

1.0 Introduction

Road crashes are a leading cause of deaths and serious injuries in many developed and developing countries. Intersections are recognized as being among the most hazardous locations on the roads (PIARC, 2003). For example, about 43% of all crashes in the United States occur at or near an intersection (Lord et al, 2005) and about 40% of all casualty crashes in Norway occur at junctions (Elvik & Vaa, 2004). In Singapore, the annual road crash statistics show that more than one-third of crashes (34.31%) occurred at intersections during the period 1992-2002 (Tay and Rifaat, 2007). In Canada, recent data showed that about 25% of all road users killed died at intersections (Transport Canada, 2004). Therefore, both Transport Canada's *Vision 2010* and the *Alberta Traffic Safety Plan* have set a target of 20% reduction in the number of deaths and serious injuries resulting from crashes at intersection.

To achieve these goals and enhance road safety require a better understanding of the factors contributing to crashes at these hazardous locations in order to develop more targeted countermeasures. There are usually several major factors influencing accident occurrences at intersections including traffic characteristics, traffic control measures, geometric design and driver characteristics. Many studies have examined the impact of traffic and geometric characteristics on the frequency of crashes at intersections including lane arrangement (Wang and Abdel-Aty, 2006), signal timing (Wang and Abdel-Aty, 2006), curvature (Savolainen and Tarko, 2005), collision type (Abdel-Aty et al, 2005; Jagannathan et al, 2006), and intersection approach conditions (Poch and Mannering, 1996; Kulmala, 1995; Pickering et al, 1986). In addition, several studies have also examined the influence of these factors on the severity of crashes at intersections (Abdel-Aty and Keller, 2005; Abdel-Aty, 2003; Jagannathan et al, 2006).

While there are numerous studies done elsewhere, only a few studies have been conducted in Alberta that dealt with collisions at intersections. In one of the few studies, Hamilton-Finn (2005) estimated a very basic model to examine the impact of traffic volume on crash frequencies at signalized intersections in Alberta. Little or no attention, however, has been devoted to analyzing the severity of crashes at intersections in Alberta or other factors that may affect the frequency and severity of intersection crashes. The safety of road users can be improved through a reduction in crash frequency as well as a reduction in crash severity. Understanding the factors that contribute to the severity of crashes will assist transportation engineers and safety professionals to better design road intersections and develop suitable treatments for these high collision locations, thereby improving the safety of the road system.

2.0 Objectives of Research

The purpose of the study is to examine the effects of traffic characteristics, roadway design, surrounding land use, vehicle features, types of collision and road user characteristics on the severity of crashes at intersections in Alberta. This study will complement and extend the work of Hamilton-Finn (2005) which developed accident prediction models for crashes at intersections in the City of Calgary using only the average daily traffic of the major and minor roads. Their models ignore the effects roadway design, environment factors, road user characteristics and vehicle attributes which are likely to be important in determining both the frequency and severity of crashes. Moreover, their models are restricted to predicting the frequency of crashes whereas this study will focus more on the severity of crashes.

Road crashes are a leading cause of deaths and injuries in Canada and extract a huge cost on society. In 2001, for example, motor vehicle collisions claimed the lives of 2,778 Canadians, in addition to causing 20,000 severe injuries and 220,000 minor injuries, resulting in an estimated social cost of more than $25 billion (Transport Canada, 2004). In the Province of Alberta, about 400 road users are killed annually in over 120,000 crashes each year, resulting in an estimated social cost of about $4.7 billion (Alberta Transportation, 2004).

Consequently, governments at all levels and many of the major stakeholders are committed to initiatives to reduce the frequency and severity of traffic accidents. In an effort to reduce the road trauma, Transport Canada has formulated *Vision 2010*; the province of Alberta has developed the *Alberta Traffic Safety Plan*. These plans will form the basis of road safety measures to be implemented in the local communities, province and throughout Canada. One of the explicitly targeted areas in these strategic plans is a 20% reduction in crashes at intersections (Transport Canada, 2004; Alberta Transportation, 2004).

This research will provide some evidence-based recommendations to reduce the severity of collisions at intersections and contribute to reducing the huge social cost associated with road crashes in Alberta.

3.0 Literature Review

Intersections are the locations within the road traffic network where two or more traffic flows converge and therefore, by their very nature, provide points of potential conflict. The successful negotiation of intersections is dependent upon careful attention to the road environment which includes the adherence to the road traffic rules which govern the entry into and the exit out of an intersection (Zaal, 1994). The decision to obey the road traffic rules is dependent upon a number of factors which relate to:

- The driver: behavioural and attitudinal aspects as well as knowledge of the particular road environment, and the perceived risk of being detected
- The vehicle: traffic volume, traffic speed, speed and position of particular driver within the traffic stream
- The road environment: lane width, number of lanes, turning lanes, traffic signal timing, road condition and time of day
- The social environment: includes attitudes towards speeding, red light running, enforcement and road traffic laws

3.1 Motor Vehicle Crashes in Alberta

The traffic safety problem in the Province of Alberta has generally been deteriorating over the past five years (See Table 3.1). The number of traffic fatalities has increased from 321 in 2003 to 402 in 2007 while the number of traffic collisions increased from 113,357 to 153901 in 2007.

Table 3.1
Motor Vehicle Collisions in Alberta

	2003	2004	2005	2006	2007
Fatal	321	339	392	404	402
Injury	18,447	17,248	17,726	18,831	17,857
PDO	94,589	94,966	106,088	123,357	135,642
Total	113,357	112,553	124,206	142,592	153,901

(Source: Alberta Transportation)

A substantial proportion of motor-vehicle crashes occur at intersections because intersections are recognized as being one of the most hazardous locations on the roads (Tay and Rifaat, 2007; Elvik & Vaa, 2004; Lord et al, 2005; PIARC, 2003). In the Province of Alberta, for example, about 25% of all crashes occurred at intersections (Alberta Transportation, 2004). Although intersection related crashes pose a serious safety problem across Alberta, they are especially significant in urban areas due to the higher concentration of intersections in cities. Moreover, intersection crashes form a substantial portion of the fatal and injury crashes in urban areas.

For example, in recent years, the City of Edmonton has averaged approximately 21,350 total collisions annually, resulting in approximately 6,850 injuries, 22 fatalities and $ 78,000,000 in property damages per year (Cebryk and Bell, 2004). Approximately 55 % of these collisions (about 11,742 crashes per year) occurred at intersections, accounting for 66% of the total injuries and 42 % of the total fatalities reported (Cebryk and Bell, 2004). Similarly, there were 41,489 intersection crashes for the period, 2003 to 2005 (about 13,830 crashes per year) in the City of Calgary and 41.4% were classified as injury crashes.

3.2 Profiles of Drivers Involved in Intersection Crashes

In order to improve the success rate of road safety countermeasures, it is important to understand not only the issues involved but also the road users targeted. The Alberta Traffic Collision Statistics, however, does not provide any demographic characteristics of road users involved in motor vehicle collisions at intersection. Nevertheless, a driver profile of intersection crashes for the City of Edmonton was provided by Tay (2008) and a summary of the data are reported in

Tables 3.2a & 3.2b shown below. It be noted that the profiles of drivers involved in intersection crashes are very similar for 2004 and 2005. It is therefore reasonable to assume that these profiles are typical of the profile for recent years. It should also be noted that a single crash may have multiple drivers involved.

Table 3.2a
2004 Demographic Profile of Drivers (%)

	Under 16	**16-25**	**26-65**	**Above 65**	**Total**
Male	0.3	15.1	42.0	4.4	61.7
Female	0.1	9.7	26.1	2.3	38.3
Total	0.4	24.8	68.1	6.7	100.0
Note: N = 20,771					

Table 3.2b
2005 Demographic Profile of Drivers (%)

Age	**Under 16**	**16-25**	**26-65**	**Above 65**	**Total**
Male	0.3	15.6	41.2	4.5	61.6
Female	0.1	9.9	26.3	2.2	38.4
Total	0.4	25.5	67.5	6.7	100.0
Note: N = 21,440					

In addition, collision data from the County of Strathcona from 2001-2006 were also provided by Tay (2008). Of the 7,082 drivers involved in intersection crashes, the age and gender of 6,994 were known. Their distribution is shown in Table 2.3c below. Not surprisingly, the demographic profile of the drivers in Strathcona County is quite similar to the demographic profile of the drivers in the City of Edmonton who are involved in intersection crashes.

Table3.2c
Demographic Profile of Drivers (%)

Age	**Under 16**	**16-25**	**26-65**	**Above 65**	**Total**
Male	0.2	16.1	36.4	4.0	55.3
Female	0.1	11.3	30.2	1.7	44.7
Total	0.3	27.4	66.6	5.7	100.0
Note: N = 6994					

In general, male drivers made up a slightly greater proportion (55.3%) of the crash-involved drivers. Interestingly, they are also slightly more represented than females in all age groups. This higher representation may partly be due to their greater propensity to take risks (Tay, forthcoming; Lewis et al, 2007b; Ulfarsson & Mannering, 2004; O'Brien et al, 2004; Williams & Shabanova, 2003; Tay et al, 2003; Tay, 2002; Harre et al, 1996; Mannering, 1993). Boyce and Geller (2002), however, found no significant gender differences in risk taking behavior. An alternative explanation for the crash rates is the higher exposure of male drivers. The distribution between male and female drivers involved in intersection crashes is very similar to other types of crashes in Edmonton and Alberta as a whole (Alberta Transportation, 2006).

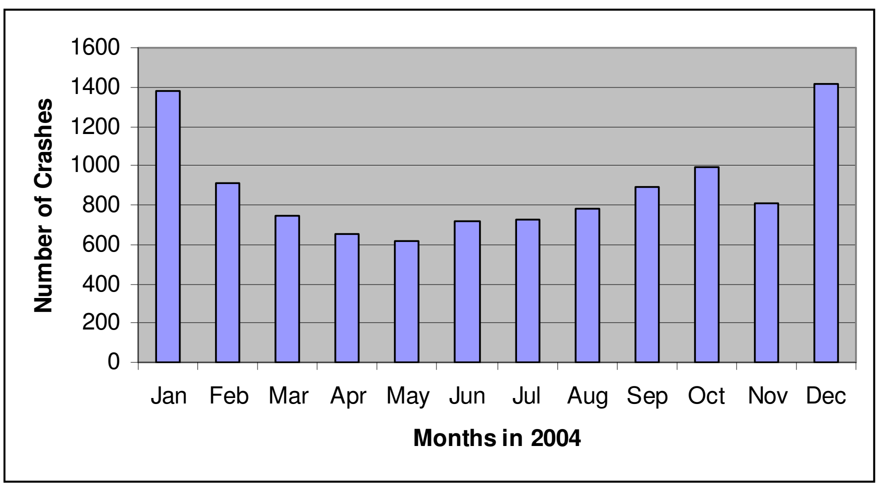
The two groups with the lowest relative involvement rates are drivers who are under the age of 16 and drivers who are 65 years or older. The group with the highest share (over two-thirds) of crash involved drivers is the middle-age group or drivers between the ages of 26 and 65. This result is expected because they comprise the majority of the drivers on the roads. In terms of population, this group represents slightly over half of the population in the Edmonton census metropolitan area (Statistic Canada, 2007). Although their crash involvement rate appears to be higher per capita, a large part of it may be due to the higher percentage of the population in this group who are driving. Even though no data for Edmonton and Strathcona are available, the provincial data indicates that this group represents about three-quarter of the driving population in Alberta (Tay, 2008).

Finally, the group with the second highest share (one quarter) of crash involved drivers is the youths or drivers between the ages of 16 and 24. In terms of population, this group represents slightly over 15% of the population in the Edmonton census metropolitan area (Statistic Canada, 2007). Again, although no data for Edmonton and Strathcona are available, the provincial data indicates that this group represents about 16-17% of the driving population in Alberta (Tay, 2008). It is therefore quite clear that this group is over-represented in crashes per capita and crashes per licensed driver. Therefore, they should definitely be included as the primary target group in any campaign.

3.3 Seasonal Effects

It is well known that crashes tend to have a seasonal effect, with relatively more total crashes but fewer fatal crashes occurring in the winter months. This seasonal effect for the total number of intersection crashes in the City of Edmonton for 2004 and 2005 are tabulated by Tay (2008) and shown in Figures 3.3a and Figure 3.3b. In addition, the data for Strathcona County from 2001 to 2006 have also been summarized and shown in Figure 3.3c below.

Figures 3.3a
Seasonal Effects of Intersection Crashes in Edmonton - 2004



Figures 3.3a
Seasonal Effects of Intersection Crashes in Edmonton - 2005

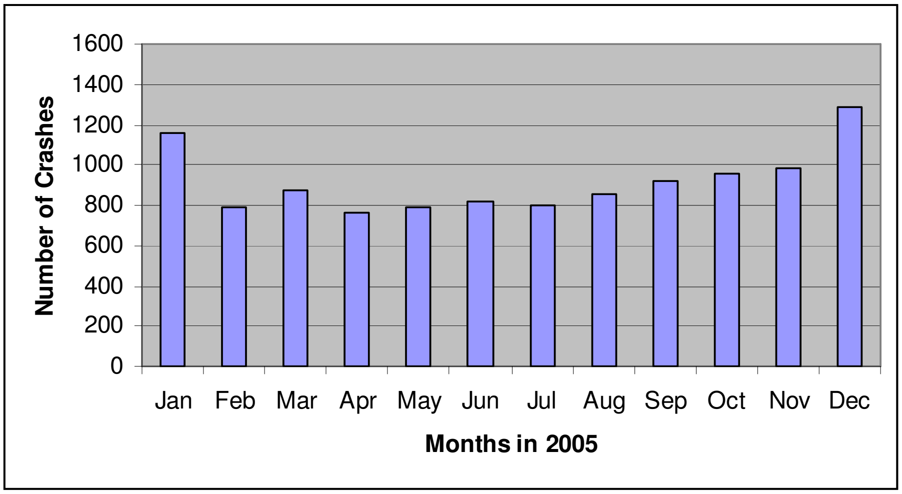
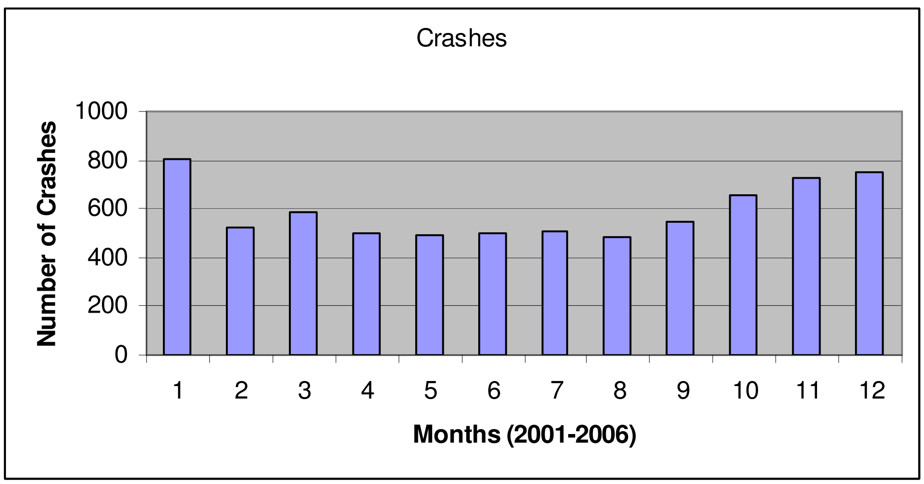


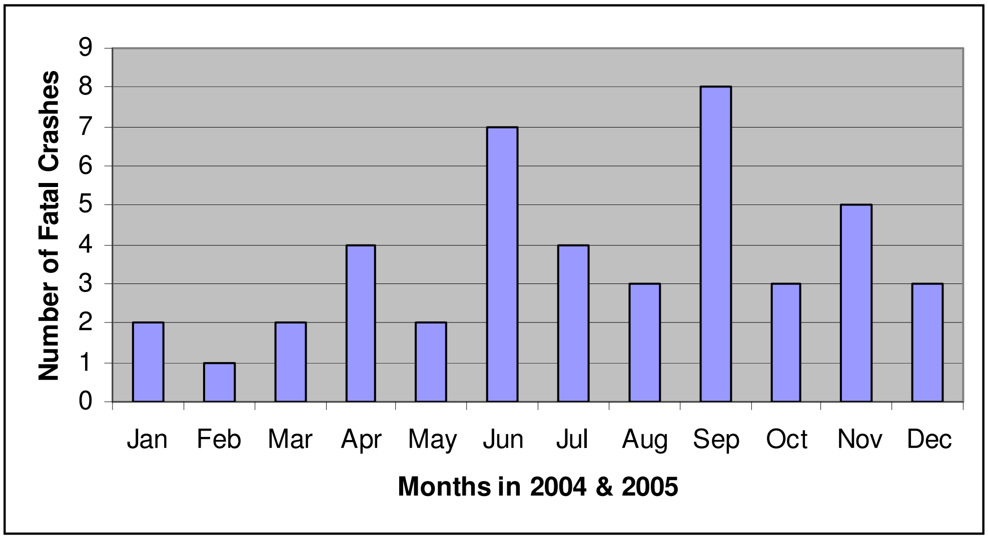
Figure 3.3c
Seasonal Effects of Intersection Crashes in Strathcona County



It is clear that the total number of crashes per month has two peaks in the months of December and January in both 2004 and 2005 for the City of Edmonton as well as for the County of Strathcona. These peaks confirm that the number of crashes per month is highest during the winter months.

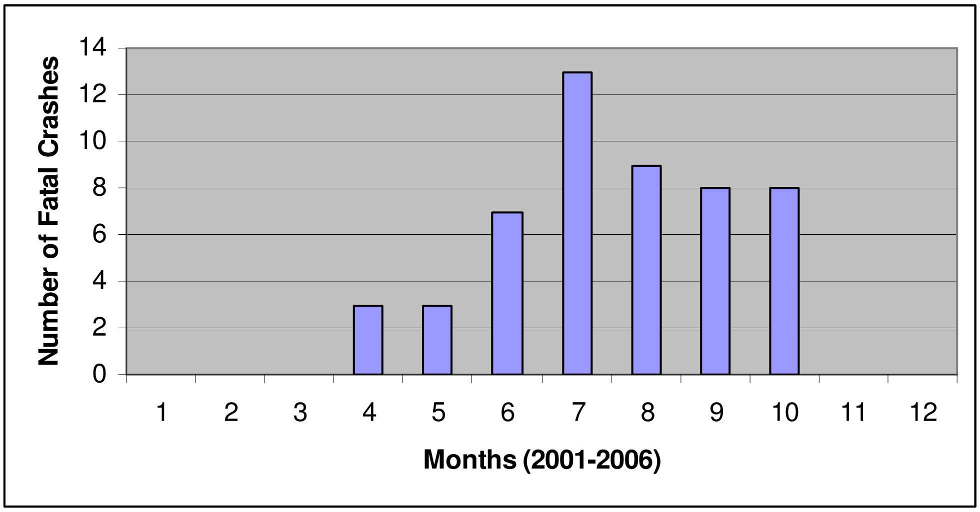
On the other side of the previous hypothesis is that there are more fatal crashes in the summer months than the winter months. Since fatal crashes are very rare events, the number of fatal crashes for both 2004 and 2005 are added and shown in Figure 3.3d. Also, data on fatal crashes from the Strathcona County are also summarized and shown in Figure 3.3e.

Figure 3.3c
Seasonal Effects on Fatal Intersection Crashes in Edmonton



As shown in Figure 3.3c, the number of fatal crashes per month has two peaks in June and September, marking the beginning and end of summer. The number of fatal crashes per month is also relatively high in the other summer months. Although not as obvious as total crashes in all locations (Alberta Transportation, 2006), the pattern is still discernable. It should be noted, however, that the number of fatal crashes per month is also relatively high in the months of November and December when the total number of crashes is relatively high as well. This result is not as surprising since the severity of intersection crashes tend to be quite high because a large share of the crashes consists of side-impact crashes or crashes involving pedestrians.

Figure 3.3d
Seasonal Effects on Fatal Intersection Crashes in Strathcona County



Again, the data from Strathcona County from 2001 to 2006 are also summarized and shown in Figure 3.3d. There were 51 fatal intersection crashes of which 13 occurred in the month of July, 9 in August, 8 each occurred in the months of September and October, 7 occurred in the month of June, and 2 each in the months of April and May. These data provide clear support for the second part of our hypothesis that more fatal crashes occur during the summer months and fewer fatal crashes occur in winter months.

3.4 Road Users Behavior Factors

In order to better target the campaign, the behavior of road users involved in intersection crashes should be examined. Crash data provided by the City of Edmonton for the years 2004 and 2005 were examined by Tay (2008) and shown in Table 3.4a below. Since the frequencies are relatively similar between both years, the numbers in Table 3.4a can be assumed to be representative for recent years. Note that the road user behavior that contributes to the largest number of intersection crashes is following too closely. Fortunately, following too closely usually results in rear-end crashes which tend to be less severe.

Table 3.4a
Road Users Behavior Factors for Intersection Crashes in Edmonton

Road Users Behavior Factors	**2004**	**2005**	**Total**
Followed too closely	4,649	4,912	9,561
Left turn across path	1,658	1,763	3,421
Failed to observe traffic signal	1,261	1,238	2,499
Stop sign violation	964	946	1,910
Ran off road	430	403	833
Changing lane improperly	358	383	741
Yield sign violation	324	295	616
Improper turn	282	315	597
Failed to yield to pedestrians	156	170	326
Backed unsafely	127	140	267
Failed to yield - no control	95	92	187
Left of centre	53	55	108
Failed to yield to cyclist	37	50	87
Struck parked vehicles	35	46	81
Improper passing	31	43	74
Pedestrian error/violation	24	34	58
Cyclist error/violation	27	25	52
Signed forced turn violation	21	22	43
Others/Unknown	63	61	124
Total	**10,595**	**10,993**	**21,588**

On the other hand, the left turn across path action usually results in a side-impact crash or a crash involving pedestrian, which tends to be more severe. Since these crashes are not classified as failure to observe traffic signals, they are more likely to be turning during the permissible green period or at the end of the green light and beginning of the red light. The first improper action is likely to be the result of poor gap selection by the turning vehicle while the second is more likely to be the result of aggressive start movement by the straight-ahead vehicles. Interestingly, this type of collision, although very common and often deadly, can easily be reduced by restricting turning movements during the normal green light and permitting turning movements only under protected turn periods. This restriction, however, will decrease the efficiency and reduce traffic flow or capacity.

The other road user behavior of major concern is the failure to observe traffic signals. Since these are signalized intersections, the right of way is usually very clear. Therefore, most of these crashes are a result of red light running behavior by drivers. This improper action is likely to result in side-impact crashes which tend to be more severe. The next two behaviors with high frequencies of crashes are stop and yield sign violations. Again, since these regulatory signs are quite clear on the right of way, the failure to stop or give way is likely to be due to aggressive driving or inattention. Like failure to observe traffic signals, these improper actions are likely to result in side-impact crashes which tend to be more severe.

The next driver behaviors that we may want to keep in mind is single vehicle run-off-the-road incident due to its relatively high frequency. Single vehicle run off the road crashes are often associated with excessive speed and alcohol, especially when the road surface condition is dry. The next two driver behaviors that have a relatively high frequency of occurrence are improper lane changing and turning behaviors. Finally, two other related driver actions that should be targeted for countermeasures and treatments are failure to yield to pedestrians and cyclists. Although these actions are not as high as some of the other improper actions, they deserve to be targeted for action because of the vulnerability of pedestrians and cyclists. Crashes involving these vulnerable road users are usually quite severe because they are not well protected.

Again, the data for Strathcona County are summarized and reported in Table 3.4b. Note that the driver behaviors reported by the police in Strathcona County may not be exactly the same as those reported by the police in the City of Edmonton. Also, the behaviors of all drivers are included in the summary regardless of fault and there may be multiple drivers in some crashes. It is clear from the table that ‘left turn across path and following too closely’ are also the top two driver behaviors that are alleged to have contributed to intersection crashes, followed by disobeyed traffic signal and improper turn. Stop sign violation and ran off the road are also relatively frequent. Since the above results are very similar to those obtained for Edmonton, the same interpretations and recommendations are applicable.

Table 3.4b
Road Users Behavior for Intersection Crashes in Strathcona

Road Users Behavior Factors	Frequency
Followed too closely	1032
Left turn across path	777
Disobeyed traffic signal	281
Improper turn	134
Stop sign violation	338
Ran off the road	100
Improper lane change	81
Backed unsafely	61
Failed to yield to pedestrian	35
Left of centre	29
Improper passing	19
Failed to yield at uncontrolled intersection	15
Hit parked vehicle	10
Other	171
Unknown	518
Driving Properly	3444
Total	**7082**

3.5 Engineering Studies of Intersection Crashes

There are many studies that examined some of the major engineering factors influencing collision occurrences at intersections including traffic characteristics, traffic control measures, geometric design, and driver characteristics. Many of the engineering studies have examined the impact of traffic and geometric characteristics on the frequency of crashes at intersections including lane arrangement (Wang and Abdel-Aty, 2006), signal timing (Wang and Abdel-Aty, 2006), curvature (Savolainen and Tarko, 2005), collision type (Abdel-Aty et al, 2005; Jagannathan et al, 2006), and intersection approach conditions (Poch and Mannering, 1996; Kulmala, 1995; Pickering et al, 1986). In addition, several studies have also examined the influence of these factors on the severity of crashes at intersections (Abdel-Aty and Keller, 2005; Abdel-Aty, 2003; Jagannathan et al, 2006; Riffat & Chin, 2007; Tay & Riffat, 2007; Barua & Tay, 2007).

While there are numerous studies done elsewhere, only a few studies have been conducted in Alberta that dealt with collisions at intersections. In one of the few studies, Hamilton-Finn (2005) estimated a very basic model to examine the impact of traffic volume on crash frequencies at signalized intersections in Alberta. Their accident prediction model is given in Figure 3.5a below:

Figure 3.5a: Accident Prediction Model for Alberta

$$Predicted = a_0 \times V_1^{a_1} \times V_2^{a_2}$$

Where: Predicted = 3-year total number of predicted collisions;
V_1 = major street ADT;
V_2 = minor street ADT; and,
a_0, a_1 and a_2 are area-specific model parameters.

(Source: Hamilton-Finn, 2005)

They estimated the above model for The Province of Alberta and the City of Calgary and their results are shown in Figure 3.5a and Figure 3.5b below:

Figure 3.5b: Calibrated Parameters for Alberta Model

Equation Category	a_0	a_1	a_2	Sample Size	k-Value
Rural, Signalized	0.02235455	-0.4079	1.199	30	3.862
Rural, Unsignalized	0.00486956	0.07241	0.8319	141	2.792

k = over-dispersion parameter of the negative binomial distribution, the larger the value of K, the smaller the variance and the better the model.

(Source: Hamilton-Finn, 2005)

Figure 3.5b: Calibrate Parameters for City of Calgary Model

Equation Category	a_0	a_1	a_2	Sample Size	k-Value
3-Legged Unignalized	0.00005	0.8023	0.426	34	3.002
4-Legged, Unsignalized	0.00096	0.6772	0.2182	82	2.272
3-Legged Signalized	0.00008	0.7724	0.4609	73	3.194
4-Legged, Signalized	0.0005	0.4755	0.6326	112	5.109

k = over-dispersion parameter.

(Source: Hamilton-Finn, 2005)

According to Hamilton-Finn (2005), the both the City of Edmonton and the City of Red Deer have also developed its own accident prediction model by modifying existing accident prediction models using a calibration factor, and the models for the City of Red Deer which are given in Figure 3.5d and Figure 3.5e below:

Figure 4.5d: Modified Model for Signalized Intersection Crashes in City of Red Deer

Pattern	Formula*	Coefficient Estimates		k
		b_0	b_2	
Right Angle	$E = (b_0 \times F_1^{bo}) \times 0.810$	8.1296×10^{-6}	0.3662	5.51
Left Turn	$E = (b_0 \times F_1 x F_2^{b2}) \times 1.063$	0.0418×10^{-6}	0.4634	2.10
Rear End	$E = (b_0 \times F_1) \times 0.887$	0.3066×10^{-6}	-	3.28

- Equations based on the study "Estimation of Safety at Signalized Intersections", Transportation Research Record 1185, National Research Council, Washington, D.C., 1988
- k = over-dispersion parameter of the negative binomial distribution, the larger the value of k, the smaller the variance and the better the model.

(Source: Hamilton-Finn, 2005)

Figure 3.5e: Modified Model for Unsignalized Intersection Crashes in City of Red Deer

Pattern	Formula*	Coefficient Estimates			k
		b_0	b_1	B_2	
T-intersection	$E = (b_0 \times (ADT_{maj\ rd}/1000)^{b1}) \times (ADT_{min\ rd}/1000)^{b2}) \times 0.994$	0.3111	0.4531	0.5806	2.34
4-legged	$E = (b_0 \times F_1 x F_2{}^{b2}) \times 1.063$	0.5135	0.4890	0.6475	2.17

- Equations based on the study "Accident Prediction Models for Stop-Controlled Intersections in British Columbia", Transportation Research Record 1665, National Research Council, Washington, D.C., 1999
- k = over-dispersion parameter of the negative binomial distribution, the larger the value of k, the smaller the variance and the better the model.

(Source: Hamilton-Finn, 2005)

Although the above models are useful in providing limited information on the potential number of crashes that can be expected at the various types of intersections, they provided no information on the factors that contribute to increasing or decreasing the number of crashes. Therefore, few evidence-based recommendations can be derived from these models that can be used to improve the safety of the intersections in Alberta

3.6 Studies of Traffic Enforcement at Intersections

In an effort to reduce crashes at intersections, many jurisdictions around the world, including the City of Edmonton, have relied on intelligent transportation systems and advanced technologies such as red light cameras to reduce the incidences of collisions at signalized intersections (TRB, 2003; AustRoads, 2004; Gains et al, 2003; Tay & deBarros, 2006). It should be noted the effectiveness of intersection safety cameras in reducing crashes has been a topic of constant debate in the literature (Erke forthcoming). Many studies found that they are effective in reducing crashes, especially side impact or T-bone crashes which tend to be more severe (Chin 1989; Chin & Quddus 2003; Ng et al 1997; Retting et al. 1999a,b; Blakey 2003; TRB 2003; Gains et al. 2004; Council et al. 2005; FHWA 2005). However, there are some concerns that using the intersection safety cameras at certain locations may produce some counter-productive outcomes such as an increase in rear end crashes (Langland-Orban et al. 2008; Garber et al. 2007; Burkey & Obeng 2004; Synectics 2003; Golob et al. 2003; Andreassen 1995).

3.7 Studies on Educational Campaigns Targeting Intersection Crashes

Although educational and publicity campaigns have been widely used around the world to change driver behavior, most of these campaigns, especially the high intensity television advertising campaigns, focus on drinking and driving, speeding and not wearing seat-belts, relatively little attention has been focused on reducing deviant road user behaviors at intersections. Not surprisingly, a search of the published scientific literature did not discover any research articles on the effectiveness of such campaigns (Tay, 2008). In addition, feedback from several major road safety research centers in Canada, USA, UK, The Netherlands, Australia, New Zealand, Hong Kong and Singapore confirmed that little research had been done in this area (Tay, 2008).

However, there is also a general consensus that there is much local educational and publicity effort that aims to reduce collisions at intersections (Tay, 2008). This focus on localized effort is understandable because intersection safety tends to be viewed more as a localized issue. For example, the Insurance Corporation of British Columbia and the Vancouver Police conducted a campaign in 2006 which targeted aggressive driving and intersection (ICBC, 2007). The capital region of the Province of Alberta has also been running such campaigns for several years and their effectiveness has recently been evaluated by Marko et al (2005). The review identified the need to better target the campaigns and utilize theoretical models of behavior change to guide the development of the campaigns in order to increase their effectiveness.

To address the critical problems associated with intersection safety, a number of agencies in the Edmonton region combined their efforts in 2001 to form the Capital Region Intersection Safety Partnership (CRISP). The aim of CRISP is to look at ways to combine education, engineering and enforcement strategies to make intersections in Edmonton safer. In addition to engineering and enforcement measures such as the intersection safety camera program, CRISP has also developed and implemented a variety of publicity campaigns over the years. These campaigns utilized a general exposure approach that used a combination of billboards, newspaper, transit, and radio advertisements. The use of road safety publicity campaigns is not new but their effectiveness have been a topic of constant debate (Tay & deBarros, 2008; Lewis et al, 2007a,b,c; Tay, 1999, 2001, 2002, 2004, 2005a,b,c; Tay & Watson, 2002; Tay & Ozanne, 2002; White et al, 2000; Oppe & Bijleveld, 2003; Macpherson & Lewis, 1998; Cameron et al, 1993, 1998; Elder et al, 2004).

4.0 Roadway Characteristics and Crash Severity

4.1 Description of Collision Data

It is important when examining the factors contributing to intersection crashes in Alberta to delineate between urban and non-urban intersection because they have very different design characteristics, driving population and enforcement agencies. The initial focus of this research will be on urban intersections because they comprise a larger proportion of the crashes reported in Alberta. For this purpose, collisions at road intersections in Calgary between 2003 and 2005 will be compiled for analysis. The data used for this analysis will be extracted from the official crash database maintained by Alberta Transportation.

The database is supposed to contain a variety of information on the road users involved as well as data on the vehicle, road and environmental characteristics. However, data on roadway characteristics are missing for the majority of the observations. Of the 69, 127 observations, only 263 observations have data on most of the engineering factors. This lack of interest in collecting important information on crashes does not reflect well on the priority of the city or the province. More importantly, there is no impetus under the current Alberta Traffic Safety Plan initiatives to increase this effort to collect even the basic information required in the collision report form.

4.2 Road Characteristics and Crash Severity

From the descriptive statistics presented in Table 4.2, it is clear that the 263 observations with some roadway information are not randomly distributed across the city but concentrated along certain roadways, probably provincial roads or expressway where the speed limit is usually higher. Therefore care should be exercise in interpreting the results, especially not to generalized the findings. Moreover, the sample size if quite small, particularly for fatal crashes, and many of the tests, especially for the chi-square tests, may not be reliable.

Table 4.2
Roadway Characteristics by Crash Severity

Contributing Factors	Fatal (N=9)	Injury (N=51)	Non Injury (N=203)	Total (N=263)
Continuous Variables				
Outside Shoulder Width (m) ***				
Mean	2.530	2.250	1.620	2.450
Standard Deviation	0.819	1.000	1.041	0.882
Inside Shoulder Width (m) ***				
Mean	0.000	0.863	1.174	1.073
Standard Deviation	0.000	0.974	1.147	1.118
Road Surface Width (m) ***				
Mean	10.644	11.547	12.234	12.046
Standard Deviation	2.082	1.926	1.888	1.932
Median Width (m) ***				
Mean	0.000	7.532	9.732	8.971
Standard Deviation	0.000	9.438	10.428	10.220
AADT (1000 vehicles)				
Mean	5.907	10.846	11.986	11.557
Standard Deviation	4.020	9.755	9.110	9.164
Categorical Variables (% distribution)#				
Speed Limit (km/h)				
80	6.1	14.3	79.6	18.6
90	0.0	8.3	91.7	4.6
100	4.5	21.1	74.1	50.6
110	0.0	21.7	78.3	26.2
Highway Type				
Gravel	0.0	0.0	100.0	0.8
2-lane Divided	7.1	22.0	70.9	48.3
4-lane Divided at Grade	0.0	12.3	87.7	21.7
4-lane Divided Not at Grade	0.0	22.2	77.8	23.9
6 or more Lanes	3.4	19.4	77.3	5.3
Surface Type				
Gravel/Graded	0.0	0.0	100.0	0.8
Seal Coat	2.6	19.2	78.1	57.4
Asphalt Concrete Pavement	4.5	20.0	75.5	41.8
Shoulder Type				
None	0.0	0.0	100.0	0.8
Pavement	3.4	19.5	77.0	99.2

Note: # Row % in columns 2-4 add to 100 and column % in column 5 add to 100
*, ** & *** denotes statistically significant at $\alpha = 0.10, 0.05$ & 0.001

Of the 263 crashes, 9 (3.4%) were fatal, 51 (19.4%) were injury and 203 (77.2%) were property-damage-only crashes. Relative to the entire dataset of 65, 129 crashes, fatal and property damage only crashes are over-represented whereas injury crashes are under-represented in this sample. Therefore, caution should be exercised in interpreting the results. Within these constraints, there are several observations that are worth noting.

Among the continuous variables examined, traffic volume is found to be statistically insignificant in determining crash severity. This finding is consistent with the suggestion by Kim et al (2007) that exposure variable such as AADT which accounts traffic volume is not expected to have a significant effect in our model because the dependent variable is the probability of an injury given that a crash has already occurred. Although exposure is significant in determining the frequency or likelihood of a crash, it impact on crash severity is minimal, especially under free flow conditions (Kim et al., 2007).

More interestingly, there appears to be a significant relationship between the cross sectional elements of a roadway and crash severity. First, total surface width is negatively related to severity; that is, wider roads tend to have lower severity crashes. Therefore, widening the roads slightly, without adding lanes, may improve safety. This finding is consistent with the general findings in the literature (Elvik and Vaa, 2004). Given a constant road width, the way that space is allocated is also significant in determining the crash outcomes.

In general, roads with medians are safer than roads without median, at least in terms of crash severity. Therefore, efforts should be devoted to providing a median in urban highway design. Complementing this finding, this collision sample also revealed that the width on the inside shoulder is negatively correlated with crash severity whereas the width of the outside shoulder is positively correlated with crash severity. Therefore, it is better to have a slightly wider inside and a slightly narrower outside shoulder than current designs adopted for Calgary's roads to reduce the severity of crashes.

Since none of the chi-square tests yielded statistically significant results and the counts for some cells are too small for the test to be reliable, no explicit inference will be made on the categorical variables. As a rule of thumb, each cell should have at least 5 counts for the chi-square test to be sufficiently reliable. This rule is violated for the number of fatal crashes once they are distributed across different categories of a particular roadway characteristic.

4.3 Conclusions

The number of observations with roadway information is extremely low. Only 263 crashes out of 65, 129 crashes in the City of Calgary have any information recorded for roadway characteristics and these are all on high speed roads. The paucity of data on engineering factors is very disappointing but not all together unexpected since the main focus of police in collecting crash information is to determine whether any road user should be prosecuted and not to improve the design of the roadway.

Nevertheless, more effort should be invested in recording the engineering factors involved in motor vehicle collisions. Without sufficient information on the influence of one of the important pillars (engineering, enforcement and education), any countermeasures implemented or planned, including enforcement, may not be targeted appropriately and thus scarce road safety resources may not be used efficiently. Hence, a high priority should be given to collecting the information that is supposed to be collected in the official crash database.

Given these limitations on the data, this study found that the design of cross section elements is an important determinant of crash severity in the City of Calgary. In particular, relative to current designs, increasing the surface width of the roads, providing a median, increasing the width of the inside shoulder and reducing the outside shoulder width are likely to reduce the severity of crashes on urban roads.

5.0 Collision Severity Model

5.1 Ordered Probit Model

The severity of crashes is usually classified into three or four categories in most countries. In Alberta, the official collision database maintained by the traffic police classifies collision severity into fatal, injury and property damage only crashes based on the worst condition of the road users involved. Recognizing the discrete and ordinal nature of collision severity, an ordered categorical response model such as the ordered probit or ordered logit model would be more appropriate than the standard regression model to analyze the collision data.

These models have been widely used in analyzing transportation and safety data (O'Donell and Connor, 1996; Duncan et al, 1998; Khattack, 2001; Kockelman and Kweon, 2002; Quddus et al, 2002; Rifaat & Chin, 2007). The main difference between the logit and probit models lies in the assumption regarding the distributional form of the error term. The logit model assumes a logistic distribution whereas the probit model assumes a normal distribution. In practice, however, many studies have found that the results obtained from both models are very similar (Maddala, 1988; O'Donnell & Connor, 1996; Greene, 2003).

In this study, the more widely used ordered probit model will be chosen for estimation. The dependent variable used is collision severity which may take one of three values based on the highest degree of injury involved, i.e., fatal, serious injury and minor or no injury. The ordered probit model is usually motivated in a latent variables framework. The general specification is given by:

[1] $$y_i^* = \boldsymbol{X}_i \boldsymbol{\beta} + \varepsilon_i$$

where y_i^* is a latent variable measuring the injury severity of i^{th} collision

$\boldsymbol{X}_i$ is a vector of explanatory variables

$\boldsymbol{\beta}$ is a vector of unknown parameters

ε_i is the Normally distributed error term

Since there are only three ordinal categories for the response variable in this study, if the severity index y_i^* is above an upper threshold ($\mu_2 \le y_i^*$), then a fatal crash is recorded (y = 3). On the other hand, if the severity index is below a lower threshold ($y_i^* \le \mu_1$), then a minor crash is recorded (y = 1). Finally, if the severity level is between the two thresholds ($\mu_1 \le y_i^* \le \mu_2$), then a serious injury crash is recorded (j = 2). Thus, the estimated probability that road user *i* sustains an injury of level is equal to the probability that the unobserved injury risk, y_i, takes a value within the appropriate ranges.

[2]
$$\Pr(y_i = 1 \mid \mathbf{x}_i) = \Phi\{\mu_1 - (\mathbf{x}_i\boldsymbol{\beta})\}$$
$$\Pr(y_i = 2 \mid \mathbf{x}_i) = \Phi\{\mu_2 - (\mathbf{x}_i\boldsymbol{\beta})\} - \Phi\{\mu_1 - (\mathbf{x}_i\boldsymbol{\beta})\}$$
$$\Pr(y_i = 3 \mid \mathbf{x}_i) = 1 - \Phi\{\mu_2 - (\mathbf{x}_i\boldsymbol{\beta})\}$$

where Φ is the cumulative density function for the normal distribution. For all the probabilities to be positive, it is required that $0 < \mu_1 < \mu_2$. These relations are illustrated in Figure 1.

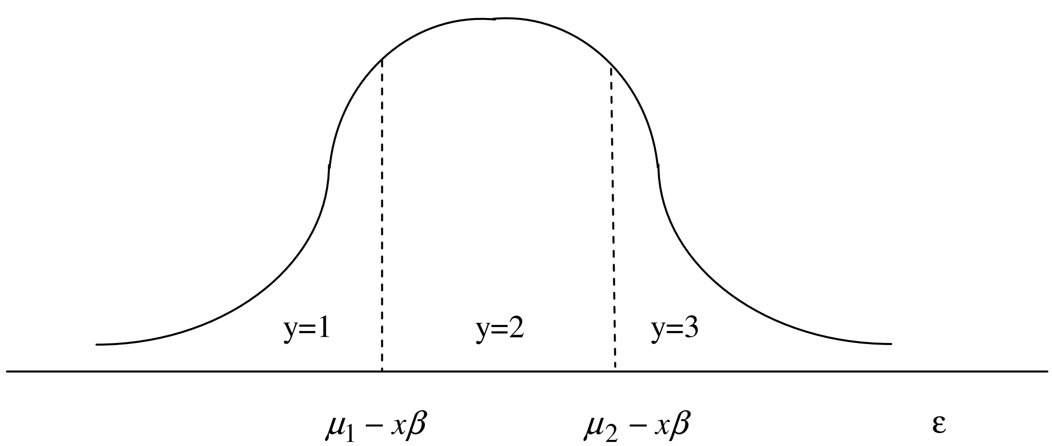


Figure 1: Probabilities in Ordered Probit Model

Note that the model is unidentified since a change in the intercept (β_0) in the structural model can always be compensated by a corresponding change in the thresholds. Hence, either β_0 or μ_1 is usually constrained to be zero and β_0 is chosen in this analysis for convenience. The above model will be estimated using the maximum likelihood procedure in the statistical software package SPSS.

5.2 Description of Data

Traffic crash data in Alberta are generally compiled from the police report maintained by the Office of Traffic Safety, Alberta Transportation. Intersection crashes for the period, 2003 to 2005, in the City of Calgary are extracted for this study based on the availability of traffic crash data. During this period, there were 65, 129 reported crashes occurring at intersections in Calgary. However, many of the observations have missing values for the factors considered in this study and thus were not included in the analysis. The final sample contains 41,761 observations. Among these, 56.7% of the cases were classified as property damage only (PDO), 41.4% were classified as injury crashes, and the rest 1.9% were fatal crashes. A fatal crash is defined as a reportable motor vehicle crash which resulted in at least one fatality, where death occurred within 30 days of collision. An injury crash is defined as a reportable motor vehicle crash which resulted in at least one injury but not death within the timeframes set out in the definition of a fatal crash. Lastly, a non-injury or property damage crash is defined as a crash associated with no injury but only damage to the vehicles or other properties.

As discussed in Section 4, many of the data fields in the collision database have missing values for the vast majority (over 99.9%) of the observations. The problem is especially serious for data on roadway and vehicle characteristics. Therefore, these important crash contributing factors cannot be included in this study. The descriptive statistics of the factors included in the model are reported in Table 5.2.1. Note that there are 10 factors included in the final model. However, since most of the factors are categorical in nature, several dichotomous variables are created to capture each of these factors. For example, there are three time-of-day categories used in recording the collision data. Therefore, three dichotomous variables are created to represent the three time-of-day categories but one of them would be used as a reference and excluded in the model.

Table 5.2: Summary Statistics of Explanatory Variables

Explanatory Variables	Description of Variables	Mean	Std Dev
1. Season			
Summer	Summer =1; otherwise = 0	0.23	0.42
Others	Others = 1; otherwise = 0	0.77	0.42
2. Time of the day			
Peak	Peak Hours = 1; otherwise = 0	0.37	0.48
Off-Peak	Off-Peak =1; otherwise = 0	0.32	0.47
Night-time	Night-time = 1; otherwise = 0	0.31	0.46
3. Number of Vehicles			
Single Vehicle	Single Vehicle =1; otherwise = 0	0.15	0.36
Two Vehicle	Two Vehicle = 1; otherwise = 0	0.78	0.10
Three Vehicle or more	Three Vehicle or more = 1; otherwise= 0	0.07	0.25
4. Types of Collision			
Rear End	Rear End = 1; otherwise = 0	0.31	0.46
Right Angle	Right Angle = 1; otherwise = 0	0.09	0.29
Head On	Head On = 1; otherwise = 0	0.01	0.09
Others	Others = 1; otherwise = 0	0.59	0.49
5. Road Surface Condition			
Dry	Dry = 1; otherwise = 0	0.59	0.49
Wet	Wet = 1; otherwise = 0	0.07	0.26
Others		0.34	0.47
6. Age of the Driver (yrs)			
Age < 25	Age < 25 = 1; otherwise = 0	0.35	0.48
25 ≤ Age ≤ 44	25 ≤ Age ≤ 44 = 1; otherwise = 0	0.62	0.48
45 ≤ Age ≤ 69	45 ≤ Age ≤ 69 = 1; otherwise = 0	0.42	0.49
70 ≤ Age	70 ≤ Age = 1; otherwise = 0	0.08	0.27
7. Gender			
Male	Male = 1; otherwise = 0	0.75	0.43
Female	Female = 1; otherwise = 0	0.51	0.50
8. Types of Vehicle			
Pick-up or Van	Pick-up Van = 1; otherwise = 0	0.20	0.40
Mini-Van	Mini-Van = 1; otherwise = 0	0.16	0.36
Trucks	Trucks = 1; otherwise = 0	0.04	0.18
Others	Other Vehicles = 1; otherwise = 0	0.61	0.48
9. Lighting Condition			
Daylight	Daylight = 1; otherwise = 0	0.65	0.48
Sun Glare	Sun Glare = 1; otherwise= 0	0.01	0.08
Dark but Artificially Lighted	Artificially Lighted = 1; otherwise = 0	0.20	0.40
Others		0.15	0.34
10. Environmental Condition			
Clear	Clear = 1; otherwise = 0	0.69	0.46
Raining	Raining = 1; otherwise = 0	0.06	0.28
Snow	Snow = 1; otherwise = 0	0.05	0.22
Others	Other = 1; otherwise = 0	0.20	0.42

The 10 factors are selected based the findings of previous studies and specific local conditions which suggest that they may be significant in determining the severity of intersection crashes in Calgary. It should be noted that several other factors were considered but not included in the final models because they were found to be insignificant in preliminary analyses. Also, the list of variables did not include most of the engineering factors as well as a few other variables that were found in previous studies to be significant in determining the severity of crashes because no data were available.

5.3 Estimation Results

The estimation results are reported in Table 5.3. The data fitted the model well, with a very large chi-square statistic and an extremely small p-value. As expected, the severity of crashes is higher during the summer months when the roads are dry and drivers have the tendency to drive faster than during winter. Also, drivers have a tendency to drive later into the night when fatigue plays a significant part in increasing both the likelihood and severity of a crash. This result is consistent with the findings of Tay (2008) for the City of Edmonton and the County of Strathcona.

As shown in Table 5.3, night-time crashes tend to be more severe while daytime off-peak crashes tend to be less severe. Besides higher speed, night time crashes tend to be associated with higher incidences of driving while fatigue as well as drinking and driving. These factors are significant in contributing to the severity of crashes. On the other hand, crashes during daytime peak hours tend to be more severe than daytime off-peak hours because drivers are often in a rush and tend increase their speed when possible which ultimately results in highly severe crashes. At intersections, these influences tend to result in higher incidences of red light running. Also, during the daytime peak periods, there are more likely to be vulnerable road users crossing at intersections.

Table 5.4: Parameter Estimates of the Model

Number of Observations: 41761
Log likelihood = -14909.96
Chi-square = 2047.65
P-value < 0.0001

Variables	β-value	Std. Error	z-stat	p-value
1. Season (Reference Case: Others)				
Summer	0.0481	0.0201	2.32	0.020
2. Time of the day (Reference case: Peak)				
Off-Peak	-0.0334	0.0199	-1.68	0.093
Night-Time	0.0532	0.0242	2.19	0.028
3. Number of Vehicles (Reference case: Single Vehicle)				
Two-Vehicle	-0.6088	0.0255	23.90	<0.001
Three-Vehicle or more	-0.1737	0.0349	-4.98	<0.001
4. Types of Collision (Reference case: Others)				
Rear End	0.3273	0.0206	15.91	<0.001
Right Angle	0.4826	0.0276	17.48	<0.001
Head On	0.8757	0.0797	10.98	<0.001
5. Road Surface Condition (Reference case: Others)				
Dry	0.2876	0.0283	10.15	<0.001
Wet	0.3289	0.0412	7.74	<0.001
6. Age of the Driver (Reference case: Age < 25)				
$25 \leq$ Age ≤ 44	0.1439	0.0193	7.45	<0.001
$45 \leq$ Age ≤ 69	0.1110	0.0181	6.11	<0.001
$70 \leq$ Age	0.2175	0.0294	7.40	<0.001
7. Gender (Reference case: Female)				
Male	0.0746	0.0216	3.45	0.001
8. Types of Vehicle (Reference case: Others)				
Pick-up or Van	-0.0996	0.0211	-4.72	<0.001
Mini-Van	-0.1341	0.0229	-5.84	<0.001
Trucks	-0.0886	0.0461	-1.92	0.055
9. Lighting Condition (Reference case: Others)				
Daylight	0.1496	0.0342	4.37	<0.001
Sun Glare	0.6049	0.0816	7.44	<0.001
Dark but Artificially Lighted	0.2483	0.0356	6.97	<0.001
10. Environmental Condition (Reference case: Others)				
Clear	0.1323	0.0342	3.86	<0.001
Raining	0.1019	0.0368	2.77	0.006
Snow	0.1230	0.0437	2.82	0.005

Compared to single-vehicle crashes, two-vehicle crashes are less likely to result in injuries or fatalities. Many of the single-vehicle crashes involve vulnerable road users like pedestrians or are single vehicle run-off-the road crashes. Crashes involving pedestrians are usually more serious because they are not protected by any vehicle. On the other hand, run-off-the-road crashes typically involve high speed vehicles and loss of control, which often result in injuries and fatalities.

As expected, our results showed that head-on crashes have the highest likelihood of resulting in injuries or fatalities because of the large amount of kinetic energy involved in this type of crashes. Besides head-on crashes, side impact crashes or right angle crashes also have a much higher tendency to result in more serious outcomes due to the relatively less protection afforded the vehicle occupants by the vehicle being hit at the side. Finally, relatively to other types of crashes (sideswipes, angle crashes, etc), rear end crashes at intersections also tend to have a slightly higher likelihood of injuries. Rear end crashes often result in whip lash injuries although the likelihood of a fatality is much lower.

With respect to road conditions, crashes on wet and dry road surfaces tend to result in more severe crashes compared to other surface conditions such as snow and ice. When the road is covered in snow or ice, drivers tend to slow down significantly. Although there are more crashes, these crashes tend to be less severe due to the lower speed involved. On the other hand, wet surfaces are associated with higher severity crashes because it is less likely for Calgary drivers to slow down when the road surface is wet. With lower road friction, the impact speed tends to be higher on wet roads.

Given that a crash has occurred, the severity of the crash is dependent on the physical conditions of the drivers. Not surprisingly, there is an age effect found in our study, with older drivers (70 years old or older) being the most likely to suffer serious injuries. Note that this finding is contrary to finding that younger drivers (drivers under 25 years old) are involved in more crashes and higher severity crashes. Part of the reason for this difference is the restriction on the category of crashes considered - intersection related crashes in an urban setting. Many of the fatal crashes involving young drivers involve male drivers and night-time single vehicle run-off-the-road crashes involving speed, alcohol and/or fatigue. Most of these crashes occur at speed highway, especially around curves, and not at urban intersections. Also, many of these factors have already been explicitly controlled for this our study, thus elevating the effects of physiological condition on the crash outcomes.

As shown in Table 5.3, crashes at urban intersections involving male drivers tend to be more serious than crashes involving female drivers. This result is expected because male drivers tend to have a higher propensity to take risks and drive more aggressively which often results in more severe crashes (Evans, 2004; Tay 2002; O'Brien et al, 2005; Tay et al, 2003, 2008, forthcoming; Lewis et al, 2007b; Tay 2005a, 2002b).

With respect to vehicle types, mini-vans or passengers vans are found to the least likely to result in serious injuries. These vehicles are typically family vehicles and often driven by parents with children. Hence, they are less likely to be driven more aggressively. Besides mini vans, trucks and pickups are also found to be associated with less severe crashes than passenger cars. Large vehicles, especially trucks, are often driven at low speed in an urban. It is also less likely for another vehicle to run a light when a truck is approaching due to its size, obvious threat and conspicuity.

As expected, sun-glare can be a serious problem at intersections because of the difficulty in seeing some of the traffic lights. It is therefore not surprisingly that sun-glare is found to be associated with higher severity in a crash. In addition, crashes at intersections of dark but lit streets also tend to be more severe than dark but unlit streets. This finding can partially be explained by driver risk compensation behaviors. When the streets are not lit, drivers tend to drive more carefully and lower their speed. Unlit streets in an urban area are also more likely to be residential and local roads that have a lower speed limit or more traffic calming measures.

For the same road surface conditions, crashes occurring on a clear day tend to be associated with higher severity. Again, this outcome can be explained by driver risk compensation behaviors, particularly drivers' speed choices. On the other hand, compared to other weather conditions (cloudy, unknown, etc), raining and snowing weather are associated with higher severity collisions. These latter weather conditions are associated with poor visibility issues which may have an effect on sight distances and impact speed.

5.4 Conclusions

Results from our collision severity model revealed that time of year, time of day, number of vehicles involved in the crash, types of crash, road surface conditions, age and gender of driver involved, types of vehicles involved, lighting and weather conditions have an effect on the severity of the crash. It also showed that the factors contributing to crash severity is complex and often interrelated due to driver behavior and risk compensation.

More importantly, this study found that the data on most of the roadway characteristics are missing in the official crash database. This shortcoming limited the application of our statistical model to examine the effects of many engineering factors. Without a good understanding on the contribution by engineering factors, safety resources may be allocated inefficiently because engineering is a critical part of road safety.

6.0 Discussions and Conclusions

As discussed in Sections 4 and 5, many of the data fields in the collision database have missing values for the vast majority (over 99.9%) of the observations. The problem is especially serious for data on roadway and vehicle characteristics. Only 0.4% of the reported intersection crashes in the City of Calgary have information on the roadway characteristics that are supposed to be included in the official crash database. More effort should be invested to ensure that these data are routinely collected by the police. Although they are not useful in the prosecution of errant drivers, they are crucial to our understanding of crash contributing factors. Without a proper data on roadway characteristics, our understanding on the relative roles of various contributing factors will be limited in scope. Using the estimated statistics based on restricted data to target and prioritize road safety interventions may not result in the most efficient allocation of scarce road safety resources.

Given the limitations on the data available, this study found that the design of cross section elements is an important determinant of crash severity in the City of Calgary. In particular, relative to current designs, increasing the surface width of the roads, providing a median, increasing the width of the inside shoulder and reducing the outside shoulder width are likely to reduce the severity of crashes on urban roads. On the other hand, traffic volume (AADT) is not significant in determining crash severity.

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