Crash Severity Analysis at Roundabouts: A case study in Quebec, Canada

Shaun Burns[1], Research Assistant
Department of Civil Engineering and Applied Mechanics, McGill University
Room 391, Macdonald Engineering Building, 817 Sherbrooke Street West
Montréal, Québec, Canada H3A 0C3
Email: shaun.burns@mail.mcgill.ca

Luis Miranda-Moreno, Assistant Professor
Department of Civil Engineering and Applied Mechanics, McGill University
Room 268, Macdonald Engineering Building, 817 Sherbrooke Street West
Montréal, Québec, Canada H3A 0C3
Phone: (514) 398-6589
Fax: (514) 398-7361
Email: luis.miranda-moreno@mcgill.ca

Nicolas Saunier, Assistant Professor
Department of civil, geological and mining engineering
École Polytechnique de Montréal, C.P. 6079, succ. Centre-Ville
Montréal, Québec,Canada H3C 3A7
Phone: +1 (514) 340-4711 ext. 4962
Email: nicolas.saunier@polymtl.ca

Karim Ismail, Assistant Professor
Department of Civil and Environmental Engineering
Carleton University
Ottawa, Ontario, Canada K1S 5B6
Tel: (613)520-2600, Ext 1709
Email: karim_ismail@carleton.ca

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[1] Corresponding Author

ABSTRACT

Numerous studies both in North America and abroad have studied the roundabout as a means to improve the capacity and safety of intersections. The focus of these studies has been to reduce both the number and the severity of accidents, and have generally come to agreeable results. Nevertheless, few studies have dealt with the identification of accident factors within roundabouts. The varied physical and environmental characteristics of Quebec’s roundabouts and the behavioral traits of its drivers requires further study in order to help reduce the occurrence and severity of accidents. This paper presents a crash severity analysis to identify the effects of different contributing factors on injury severity outcomes. To achieve this, an ordered logit modeling technique was used for the analysis. Moreover, an important effort was made to integrate an accident database containing accident records from the year 2000 to 2011.

Among other results, it was found that factors such as a larger number of involved vehicles, accidents occurring within the intersection, vehicle rollovers, the involvement of buses, accidents occurring in the dark on unlit roads and snow conditions led to increased injury severity within roundabouts, whereas factors associated to accidents involving only cars, animal strikes and snow-covered roadways were found to be associated with less severe injuries.

INTRODUCTION

The occurrence of road vehicle accidents is well documented with respect to the adverse economic and emotional effects they inflict on society (*1*). Because of this, traffic engineers and policy makers have shown considerable interest in finding ways to identify critical factors of both accident occurrence and their severity outcomes (*2*) (*3*). International experience with roundabouts tends to indicate improved safety and performance when compared to traditional sign- and signal-controlled intersections. The inherent safety benefits of a roundabout are often attributed to the fundamental design features which lead to lower travel speeds, the elimination of head-on and right-angle conflict areas and the need for pedestrians to only cross one vehicle movement at a time (*4*) (*5*) (*6*). However, largely due to the relative scarcity of roundabouts within the North American road network compared to typical intersection controls, few studies have investigated the severity of accidents occurring in or around roundabouts. Most of the previous work on roundabouts has been related to accident frequency or occurrence (*7*).

Roundabouts first started appearing in the Province of Quebec in 1998, and have been the subject of increasing popularity. Because of this, Quebec now has the highest number of roundabouts in Canada (*8*). Consequently, there are concerns as to the applicability of roundabouts in terms of both safety and performance due to the particular weather and driver behavioral conditions that exist within the province (*9*). It is therefore suggested that detailed safety studies be conducted in order to better understand which factors increase or decrease the frequency and severity of accidents. This could help identify countermeasures or actions that decrease accident consequences in roundabouts. Changes to the established design guides may be required in order to better suit local conditions.

In order to improve the safety of all road users within a roundabout, planners and engineers must be able to modify the physical environment in such a way as to reduce the dangers within each facility. Factors relating to vehicle, driver, roadway design and weather conditions need to be studied to better understand how each characteristic affects the injury severity outcome of a given roundabout. In this way, designers would be able to estimate the safety benefits of a specific design element change by holding all other factors constant.

This paper aims to investigate a number of factors which may be associated with the injury severity outcomes of accidents occurring in and around roundabouts. Accordingly, the most significant factors which affect the severity of accident injury outcomes were identified using an ordered logit regression model. The studied variables pertain to roadway, environmental, vehicle and human behavior characteristics that are thought to impact injury outcomes (*10*) (*11*).

This research is part of a larger effort to measure the safety of roundabouts in Quebec, through the analysis of crashes, surrogate events (conflicts) using video data collection and road user surveys. It is based on a dataset containing all recorded motor-vehicle accidents within the Province of Quebec for the period of 2000 to 2011, from which the accidents occurring within proximity of a roundabout were extracted. The data was provided from the Quebec Ministry of Transportation (MTQ) and Quebec's Automotive Insurance Board (Société de l'assurance automobile du Québec (SAAQ)). Each record contains information on the time, date and location of the accident, as well as characteristics of the roadway, the environment, the vehicle and the driver. The injury severity levels of all individuals involved in a given accident are also included in the dataset.

LITERATURE REVIEW

Over the last few decades, there has been extensive literature on injury severity analysis in road safety based on historical accident records. An important part of this literature deals with the identification of accident factors that are associated to injury severity outcomes at various levels. Among these factors, one can mention road geometry, signs and traffic control characteristics at the accident location, traffic conditions at the moment of the accident, and vehicle and passenger attributes including driver, weather, visibility, surface conditions, etc. As a unit of analysis, severity studies commonly use the individual (passenger and driver), vehicle or accident level. The analysis level selected is often dependent on data constraints (*12*). In this important literature, some studies have also looked at accident occurrence outcomes classified by injury severity types. Also, to model injury severity outcomes, many statistical methods have been proposed including traditional ordered response models to take into account the inherent ordering of the reported injury severity levels (*13*). Other models such as probit, multinomial, mixed logit and latent class model have been used (*14*) (*15*) (*16*). For a comprehensive literature review of the statistical methods used in this topic, one can refer to (*1*). Many injury severity studies have also identified the contributing factors of accidents at different location types such as rural roads, signalized urban intersections or special facilities such as highway railway crossings and freeway ramps (*2*) (*17*) (*18*).

In this rich literature dealing with a variety of issues, various reports have investigated the safety of roundabouts. In this type of intersection, a particular aspect that has attracted a lot of attention is the effectiveness of roundabouts when compared to either sign- or signal-controlled intersections. Many before-after studies have investigated this important question in Europe and North America. The effects of converting intersections to roundabouts have been documented in various literature-review studies. For instance, one can refer to the work of Elvik (2003) that carried on a meta-analysis of studies reported outside the United States. This study concluded that roundabouts are associated with a 30% to 50% reduction in the number of injury accidents and fatal accidents are reduced by 50% to 70% (*19*). The changes on property damage crashes are highly uncertain, and an increase often can occur in some conditions (e.g., three-leg intersections). Some North American studies of roundabout accident frequency have been documented, and have noted several safety benefits. For instance, Retting et al. (2001) studied the benefits associated with roundabouts. Using a dataset with 17 converted roundabouts on high-speed rural roadways, this research conducted a crash injury frequency analysis. Among the main findings, they show that the average injury crash frequency (before and after the transformation) was reduced by 84%, average injury crash rate was reduced by 89%, angle crashes were reduced by 86%, and fatal crashes were reduced by 100% (*4*). An important NCHRP report, *entitled Roundabouts: An Informational Guide*, has also made an important effort to summarize this literature (*6*). An overall conclusion of the international literature is that important benefits can be expected from the conversion of traditional intersections to roundabouts, with some exceptions for pedestrian and bicycle accident risk, which is less clear. Accident frequency modeling (safety performance functions) has also been used to investigate the link between geometry and traffic conditions and crash occurrence (*20*).

Despite this rich literature covering several issues in roundabout safety, very few studies have investigated which factors have the highest influence on the injury severity outcomes at roundabouts. Perhaps the only study looking at injury severities at the vehicle and crash level is the recent study of Daniels et al. (2011). They investigated the factors associated to severity of crashes or injury outcomes at roundabouts - using injury crash records on roundabouts in

Flanders-Belgium. Logistic regression was used for this purpose to represent the two grouped outcomes (fatal and serious injuries as one category, and minor or property damage only in the second category). Among other results, they found that crash severity is strongly dependent of the involved types of road users. In particular, vulnerable users (pedestrians, bicyclists, moped riders and motorcyclists) have a higher probability of getting seriously injured in a roundabout crash. Bicyclists represent almost half of all those killed or seriously injured in multiple-vehicle collisions at the investigated roundabouts. As in other facilities, the effects of age, geometry and light conditions are less substantially correlated to the injury severity (*20*). No studies of this type have been reported in North America, in particular in Canada. This can be associated to the lack of data and spatial location of crashes. This paper aims at investigating potential factors that have a large influence on the injury severity outcomes of accidents at roundabouts. To our knowledge, this is the first severity study of this type in Canada and the Unites States.

DATA

The data used in this paper was obtained from the MTQ as well as the SAAQ as part of a joint research project being conducted with Transportation Engineering groups from two Montreal Universities: École Polytechnique and McGill University. The data was presented as a digitized collection of accident reports originally filled in by law enforcement officials at the scene of an accident between the years 2000 and 2011. The reports provide a wide range of characteristics with the goal of capturing the exact circumstances of a given accident. From the information available in the accident reports, the variables considered to estimate the models are presented in TABLE 1.

Two subsets were identified within the data, and are distinguishable according to whether the accident record exists in the MTQ or SAAQ datasets. A degree of redundancy was observed between the two datasets. For this reason, only unique records were taken from the MTQ database to complement the SAAQ dataset.

According to data availability and various physical characteristics, 37 sites were considered in this study, as seen in FIGURE 1. Although a large amount of data was provided, it was necessary to discard any records that occurred before the construction of a given roundabout. Furthermore, it should be noted that a weakness of Quebec’s accident records is that many police authorities fail to properly geocode accident location data. This is due in large parts to a lack of proper GPS-enabled equipment. In order to reduce the bias effects that may be included in the data if only geocoded records were used, roundabouts from a given municipality were dropped from the analysis if over 25 % of the accident records within the municipality were lacking positioning information. In all other cases it was assumed that the non-geocoded records would not significantly affect the result.

From the remaining accident records, the reduced dataset was mined to extract the records that occurred within the roundabout’s area of influence. The area of influence includes the area within the roundabout’s boundaries, as well as a certain distance along the approaches, whereby drivers begin to respond to stimuli at the periphery of the intersection (*21*). The area of influence is difficult to define, and tends to vary for each intersection. For this study the area of influence was taken to be the land contained within a 100 m radius from the center of the roundabout. This value falls within the range of influence area sizes of 15-150 m which can be found in the literature. The size of the influence area considers the size of the intersection as well as the posted speed limits (*21*).

Caution was taken when multiple intersections were present within the area defined to be a roundabout's area of influence. For these sites the data had to be further reduced to ensure that the accidents were not being influenced by an intersection other than the roundabout. This was done by considering the proximity to other intersections, the direction of travel and other characteristics of the accident.

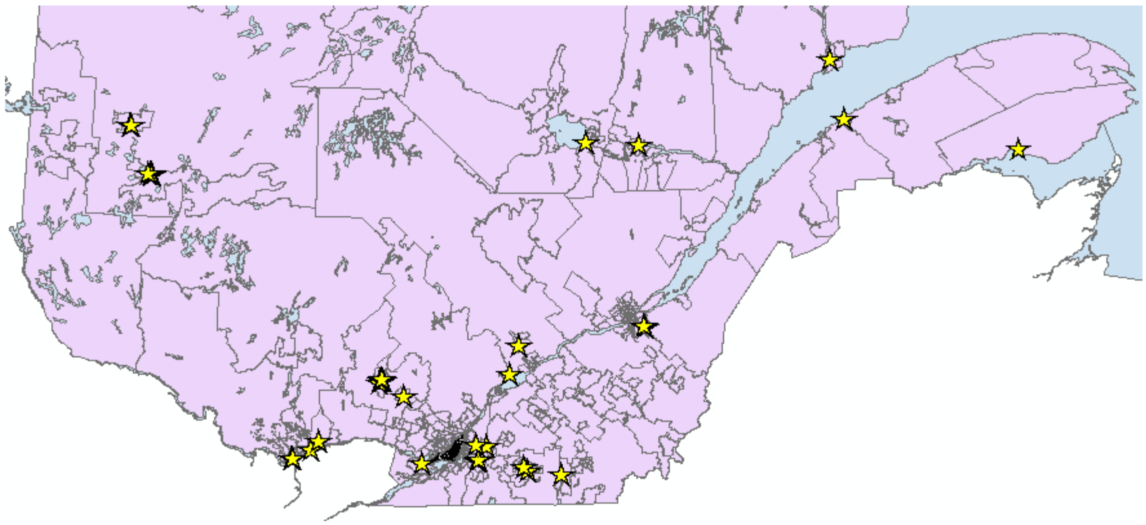

FIGURE 1 Study Site Locations

TABLE 1 Variables Available for Analysis and Their Legend

Category	**Variable**	**Legend**
DEPENDENT	Crash Level	0=Property Damage Only, 1=Minor injuries, 2=Severe and Fatal Injuries
INDEPENDENT		
Season	Winter	0=Not Winter, 1=Winter (Dec-Jan-Feb-Mar)
Day of Week	Weekday	0=No, 1=Yes
	Friday	0=No, 1=Yes
	Weekend	0=No, 1=Yes
Time of Day	Day (6:00-18:00)	0=No, 1=Yes
	Evening (18:00-24:00)	0=No, 1=Yes
	Night (24:00-6:00)	0=No, 1=Yes
Lighting	Daylight	0=No, 1=Yes
	Nightlight	0=No, 1=Yes
	Dark (Night, no lights)	0=No, 1=Yes
	Twilight	0=No, 1=Yes
Accident Size	Number of Vehicles	Continuous
Vehicle Type	Truck	0=No, 1=Yes
	Bus	0=No, 1=Yes
Collision Type	Animal (Vehicles strikes animal)	0=No, 1=Yes
	Pole (Vehicle strikes utility, sign pole)	0=No, 1=Yes
	Vehicle (Vehicle strikes another vehicle)	0=No, 1=Yes
	Structure (Vehicle strikes building, bridge)	0=No, 1=Yes
	No Impact (Vehicle rolls over, falls in ditch)	0=No, 1=Yes
	Guardrail (Vehicle strikes a guardrail)	0=No, 1=Yes

TABLE 1 (continued) Variables Available for Analysis and Their Legend

Surface Condition	Dry	0=No, 1=Yes
	Wet	0=No, 1=Yes
	Snow_Ice	0=No, 1=Yes
	Bad Surface (Effects of both wet and snow)	0=No, 1=Yes
Weather	Clear	0=No, 1=Yes
	Rain_Fog	0=No, 1=Yes
	Snow	0=No, 1=Yes
Accident Type	Single Vehicle	0=No, 1=Yes
	Intersection (Occurred at an intersection)	0=No, 1=Yes
	Lane Change	0=No, 1=Yes
	Hit and Run	0=No, 1=Yes

From the initial datasets, a total of 1675 motor-vehicle accident records were found to satisfy the above-mentioned requirements; 1200 are from the SAAQ dataset and a further 475 are supplemented from the MTQ dataset. It is worth noting that each record contains the data of a given accident. In other words, the available records are presented in an aggregate accident-level format, which limits the availability of both individual and vehicle-based information. For the analysis of accident-level data, the injury severity was taken as the worst injury that occurred as a consequence of that accident (*22*).

TABLE 2 presents the distribution of crashes by severity level, as taken from the accident reports. Looking at this table, it can be seen that a majority of accidents (91.16 %) are of the property damage only type. This agrees with the findings of several studies in the United States which have found that accidents at roundabouts tend to be less severe than at typical intersections due to the exchange of the most severe crossing conflicts for less severe merging conflicts (*6*). It must be kept in mind that the distribution seen in TABLE 2 may be skewed due to the different reporting rates present across severity levels. Accidents causing only minor damage are much less likely to be reported than accidents that cause injuries. This variation is influenced by factors such as accident severity, time of day and number of users involved. Higher severity accidents tend to have higher reporting rates than damage-only accidents (*1*) (*22*).

TABLE 2 Frequency Distribution of Accident Severity Categories

Crash Level	Frequency	Percent
Property Damage Only	1,527	91.16
Minor Injuries	141	8.42
Severe Injuries	5	0.30
Fatality	2	0.12
Total	1,675	100.00

Due to the small amount of observed severe and fatal injuries, as well as the similarity of their consequences, these two categories were combined together. According to (*23*), this merging will also help reduce the potential correlation effects between the closely related categories.

METHODOLOGY

As is evidenced through many of the most common classification methods, accident severity data displays an inherently ordinal nature in the form of no injury, minimal injury, minor injury, severe injury and fatal injury outcomes (*1*) (*23*) (*24*). Using the ordinal nature of the outcome variable is vital in the selection of an appropriate modeling approach (*1*).

Although numerous modeling methods are applicable to accident severity data, some of the better results have been obtained using extensions of basic multinomial logit modeling (*23*). One of the most fundamental concepts to remember when using these models is that the models are only applicable for the assumption that an accident has already occurred; these models do not attempt to predict accident occurrence, only their injury severity outcomes (*25*).

The model considered in this paper is a single-level ordered logit model. The goal of this analysis is to predict the most severe injury level expected to result in a given accident based on the variables presented in TABLE 1. For this analysis, three injury severity outcomes are being considered: Property Damage Only (PD), Minor Injury (MI) and Severe/Fatal injury (S/F).

An ordered response model is used in conjunction with a latent variable framework, and focuses on the principle that the choice process is based on a uni-dimensional index function. The general form of the model function is shown in Equation 1:

$$\boldsymbol{y^*}_{\boldsymbol{i}} = \boldsymbol{\beta X_i} + \boldsymbol{\varepsilon_i} \tag{1}$$

where

y_i^* = latent variable measuring injury risk of each accident *i*,
X_i = vector of observed explanatory variables measuring the characteristics of accident *i*,
β = vector of estimated parameters
ε_i = random error term.

As is the case with ordered logit models, all error terms are assumed to have a zero mean, and are assumed to be uncorrelated between observations (*26*). The goal of the model is to estimate the values of the unknown vector β. Standard regression techniques cannot be applied, however, as the dependent variable is unobservable. Within the dataset, however, we are provided with the observed variable Y_i, which is coded to represent the most severe injury outcome of a given accident (Y_i=0 if accident *i* results in property damage only; Y_i=1 if accident *i* results in minor injuries; Y_i=2 if accident *i* results in severe or fatal injuries). The relationship between the injury severity variable Y_i and the latent injury risk variable y_i^* is defined using threshold values as follows:

$$Y_i = \begin{cases} 0 & if -\infty \leq y_i^* \leq \psi_0 \\ 1 & if \quad \psi_0 \leq y_i^* \leq \psi_1 \\ 2 & if \quad \psi_1 \leq y_i^* \leq \infty \end{cases} \tag{2}$$

where the values $\psi_0$and $\psi_1$are unknown parameters that also need to be estimated. From here, the probability that injury *i* occurs during accident *j* is equal to the probability that injury risk y_i^* is found to be within a given set of thresholds. The probabilities are calculated as follows:

$$
\begin{aligned}
P(Y_i = 0) &= P_{0j} = CDF(\psi_0 - \beta X_i) \\
P(Y_i = 1) &= P_{1j} = CDF(\psi_1 - \beta X_i) - CDF(\psi_0 - \beta X_i) \\
P(Y_i = 2) &= P_{2j} = 1 - CDF(\psi_1 - \beta X_i)
\end{aligned} \tag{3}
$$

where CDF represents the cumulative distribution function of the random error term ε_i, and all other terms are as previously defined. The ordered logit model was applied to the dataset using Stata data analysis and statistical software (Version 10).

RESULTS

Multiple variable combinations were tested in order to obtain the best possible model. Subsequent models were compared using the likelihood-ratio test to ensure that any additional parameters provided sufficient explanatory power to the model. Furthermore, variables that fell outside of a 90 % confidence interval were not considered for the model. After numerous trials, the optimal model given the available data was obtained. In the analysis, correlation among variables was verified to avoid co-linearity. The results are presented in TABLE 3 below.

TABLE 3 Results of Ordered Logit Model

Independent Variable	Coefficient	t-ratio	Significance
Number of Vehicles	1.0838	4.18	0.000
Intersection	0.6750	2.96	0.003
Vehicle	-2.1676	-7.24	0.000
Animal	-2.2385	-2.11	0.035
No Impact	0.5806	2.00	0.046
Bus	1.4109	2.59	0.010
Dark	1.0914	2.61	0.009
Hit & Run	-0.5178	-1.83	0.067
Snow	0.8153	2.16	0.031
Snow & Ice	-0.6449	-2.05	0.040
Constant 1	2.9305		
Constant 2	6.1716		

As can be seen in TABLE 3, the variables retained in the final model were found to be statistically significant to a 90 % confidence interval. Parameters of interest during the model testing include the log likelihood value as well as the pseudo R^2 value. The goal for these parameters was to maximize the log likelihood value, and for the pseudo R^2 to be as close to 1 as possible. For the optimal model in this report a log likelihood value of -478.7 was obtained, as well as an R^2 value of 0.0943. Although these values could be improved, they are the best that were found given the available data.

Interpretation of Results

From the obtained model results, a number of interesting findings can be extrapolated. Both the sign and magnitude of the coefficients can be used to quantify the sensitivity of the latent injury severity measure with respect to the value of a given variable. A list and a brief explanation of the possible reasons for the coefficient signs are provided below. These explanations are provided in order to put the coefficient signs into context, and to indicate to the reader that the coefficients obtained from the model are reasonable. As the accidents were not directly observed for this study, other explanations are also possible.

A number of parameters within the model were found to have negative coefficients. Parameters with negative coefficients tend to decrease the injury severity measure. They are as follows:

- *Snow_Ice*: As evidenced in a number of studies, snow and ice-covered roads lead drivers to be more cautious, often cancelling the effects of the increased risk (*27*) (*28*).
- *Vehicle*: Due to the reduced severity of the conflicts present in or around roundabouts, two vehicles colliding have a smaller probability of severe injuries occurring (*6*).
- *Animal*: Due to the reduced speeds in or around roundabouts (20), it is unlikely that striking an animal would result in severe injuries.
- *Hit & Run*: Accidents in which a driver can leave the scene with a functional vehicle tend to indicate minor damage, and a lower risk of severe injuries.

A number of parameters were also found to have positive coefficients, which act to indicate factors present in accidents with increased injury severity outcomes. A list and a brief explanation of the possible reasons for the sign are provided below.

- *Number of Vehicles*: As evidenced by the data, crashes involving more vehicles tend to cause more severe injuries.
- *Snow*: During snow-storms the risk of injury can increase because of slippery conditions as well as a lack of visibility can exist. This should not be confused with the Snow_Ice variable (above), which indicates snow which is already on the roadway.
- *Intersection*: Although roundabouts have less conflict points than typical stop and signal-controlled intersections, conflicts still exist which could increase the risk of injury over the base case (i.e. on the approaches).
- *NoImpact*: Accidents such as rollovers and vehicles that fall into a culvert (without necessarily impacting another vehicle) tend to suffer more severe injuries.
- *Bus*: Due to their size and lack of seat belts, accidents involving buses have a greater risk of severe injuries.
- *Dark*: Accidents occurring on unlit roadways during the night tend to cause more severe injuries. This can be due to a lack of visibility.

The elasticity effects for the model are presented in TABLE 4. These effects are calculated by setting the dummy variables (those with possible values of either 0 or 1) to their default value of 0, whereas the continuous variable is set to its mean value. The elasticity for a given variable is then calculated by changing the desired dummy variable to a value of 1, or by adding an increment to the mean value of the continuous variable, with all other variables staying the same (*26*). Since the continuous variable deals with integer values only, the increment is taken to be a 1 unit increase.

TABLE 4 Probability Elasticity of the Final Model

Independent Variable	Severity Level		
	$P(Y_i=0)$	$P(Y_i=1)$	$P(Y_i=2)$
Vehicle	0.392	-0.838	-0.884
Number of Vehicles	-0.383	0.761	1.856
Intersection	-0.235	0.478	0.931
No Impact	-0.200	0.410	0.762
Bus	-0.496	0.956	2.884
Dark	-0.386	0.766	1.877
Animal	0.397	-0.849	-0.892
Hit & Run	0.147	-0.311	-0.400
Snow	-0.286	0.578	1.210
Snow & Ice	0.178	-0.377	-0.471
Probability at mean value (%)	68.2	30.0	1.8

Looking at TABLE 4, these values provide interesting results inasmuch that researchers can predict which factors are most strongly related to injury severity. Furthermore, this is beneficial with respect to the allocation of limited accident and injury prevention resources. Using models such as the one presented above, researchers will be better able to determine the true effects of a proposed countermeasure by controlling for the effects of other significant factors.

As can be seen in TABLE 4, by far the largest elasticity can be found to occur with a change in value of the *bus* predictor variable. According to the calculations, an accident involving a bus reduces the risk of a no injury accident by half, and increases the risk of a severe injury accident by as much as 2.88 times.

It can also be seen that the magnitude of the elasticity effects decreases significantly for the *major injury* category. This indicates that it is much more likely that an accident changes from *no injury* to *minor injury* than from *minor injury* to *major injury* given the introduction of one of the presented variables. This makes sense as a majority of accidents fall into the *no injury* category under base conditions. This result further indicates that it would take a considerable change in the input variables for an accident to fall into the *major injury category*.

LIMITATIONS

Several potential accident contribution factors were not examined in this paper due to a number of limitations imposed by the accident data. In an effort to limit the sharing of vehicle occupants' personal information (age, gender, location in vehicle, injury severity, etc.), certain areas of the accident reports were censored from the authors, effectively blocking access to any data at the occupant-level for analysis and therefore limiting the study to the collision-level for analysis. At this time, steps are being taken to recover some of this missing data from the source.

As is typical with accident data records, the limited number of recorded events at the higher severity levels tends to reduce the power of the models to identify salient accident factors. Issues have also been identified relating to the quality of record-keeping within the province, as a number of fields on the accident reports are being left blank. Because of the lack of detailed accident records, several interesting variables had to be dropped from the analysis. Methods that can take into account these missing values will be investigated in future work.

CONCLUSIONS AND FURTHER WORK

This study has identified and explored a number of factors and their effects on the injury severity levels of accidents that occur in or around roundabouts in the Province of Quebec. An ordered logit model was successfully estimated for accident data reported from 37 roundabouts within the road network.

It was found that the factors that significantly influence injury severity outcomes include: the season, the number and type of vehicles involved in the crash, the type of impact, the road surface conditions and the weather at the time of the accident, whether a hit and run was observed, the lighting conditions at the time of the accident, and also whether the accident occurred on an approach to the roundabout or within it.

One of the more interesting results from the model is the fact that vehicle occupants are 49.6 % more likely to suffer an injury during an accident involving a bus (given an accident occurring under base-value conditions). Furthermore, accidents involving multiple vehicles as well as those occurring in the dark are approximately 39 % more likely to experience injuries. These findings help reinforce the idea that roundabout designs need to consider the needs of the road users. For example, the geometry must be able to safely accommodate larger vehicles, such as buses; the lighting design should ensure that all areas are well lit for visibility purposes; and finally sight distances should be far enough so as to ensure that drivers can safely avoid obstacles or other vehicles on the road, but not so large as to encourage faster driving speeds (*29*).

The analysis of injury severity models can help improve safety at roundabouts by considering conditions unique to roundabouts in the Province of Quebec. The identification and analysis of the factors presented throughout this paper is the first step in a roundabout safety research project that will eventually help both designers and policy-makers alike determine the best route to take to reduce the likelihood of major incapacitating crashes from occurring,

The contributing factors identified in this study were based on the available data for Quebec roundabouts. A major limitation of this study was the limited information that could reliably be extracted from the dataset. The estimated model within the paper will be used as a basis for future work aimed at expanding the analysis after further collection efforts are completed, and building upon more complex statistical models. Efforts will specifically target the influence of both geometric features and of vehicle speeds within roundabouts on accident severity, as well as obtaining data to perform a vehicle or occupant-level injury severity analysis. Furthermore, data pertaining to roundabout risk exposure (vehicle flow data) will be collected in order to expand the scope of the study to include a comparison safety study between roundabouts and signal-controlled intersections. This work will be complemented by other approaches based on video analysis of road user behavior, conflict analysis and on road user surveys.

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