INVESTIGATION OF PEDESTRIAN INJURY SEVERITY LEVELS IN THE HALIFAX REGIONAL MUNICIPALITY

Justin Forbes, MPS Candidate, Dalhousie University
Muhammad Ahsanul Habib, Assistant Professor, Dalhousie University

Introduction

Active transportation refers to any form of human-powered transportation including, but not limited to, walking and cycling. Halifax Regional Municipality (HRM) has one of the highest proportion of pedestrian commuters of census metropolitan areas in Canada at 8.5%, surpassing Toronto, ON (4.6%), Vancouver, BC (6.3%), and Calgary, AB (4.9%). AT is on an upward trend in HRM and the Province of Nova Scotia. This is apparent when considering the development and implementation of municipal and provincial AT plans, policies, and programs, such as the Thrive! Strategy, the Active Transportation components of the Sustainable Transportation Strategy, and the development of the provincial Active Transportation Policy.

From 2007 to 2011, there were 1751 pedestrian collisions in Nova Scotia, 65% of these occurring in HRM. Of the pedestrian collisions in HRM, 79% resulted in injuries while 7.4% resulted in major injuries or fatalities. These statistics indicate that pedestrian safety is a great concern for HRM. Any effort to reduce the social and economic burden of these collisions and enhance pedestrian safety requires an understanding the factors that contribute to collision likelihood and pedestrian injury severity in the event of a collision. This paper uses HRM as a case study to examine the effect of the built environment on injury severity of pedestrians using an ordered response model. In this study, built environment characteristics include land use types, road network connectivity, transit supply, and demographic characteristics. These effects on injury severity are examined together with other variables including pedestrian and driver characteristics, collision characteristics, and environmental conditions.

When considering the variety of road user groups, pedestrians are often considered the most vulnerable. Evidence-based safety improvements require an understanding of the relevant factors that contribute towards increasing the severity of these collisions. Many studies have focused on injury and fatality risks of pedestrians, examining vehicle characteristics, roadway design characteristics, pedestrian and driver behaviors, types of collisions and environmental conditions. Although the effects of numerous factors have been explored in past studies, little research has been done to explore the effect of the built environment on injury severity.

When analyzing injury severity outcomes, the application of an appropriate econometric model is an important consideration. Typically, pedestrian injury severity is reported as an ordered variable resulting in frequent employment of ordered response models for analyzing the factors affecting injury severity levels. The most commonly employed approach to pedestrian injury severity is the ordered logit and probit models which recognize the inherent ordering in the severity variable while appropriating the probability of injury severity to various alternatives based on population specific thresholds. In this study, we apply an ordered probit modeling approach to examine the factors affecting injury severity levels for pedestrians.

Organization of the rest of the paper is as follows. First, we provide a discussion on previous research on pedestrian injury severity modeling while positioning the current study. Second, we provide details on the econometric model framework used in the analysis. Third, we describe the data source and preparation process. Following this, we present the model estimation results and discussion. The final section concludes the paper with recommendations and directions for future research.

Literature Review

Many studies have examined pedestrian injury severity to understand the factors affecting pedestrian collision frequency and injury severity. Typically, these studies fall into one of two categories. The first category concerns studies on pedestrian collision frequencies or on the exposure measure of pedestrian collision risk. The second category involves studies that examine the determinants of injury severity in the event of a pedestrian collision. The literature reviewed in this section will describe only studies that fall into the second category. Table 1, adapted from a recent study by Yasmin et al., (2013), provides a summary of earlier research on pedestrian injury severity studies and provides information on the analysis framework used, and the variables considered in the analysis.

TABLE 1 Summary of Existing Pedestrian Injury Severity Studies

Study	Analysis framework employed	Pedestrian injury severity representation	Characteristics/factors considered	
Zajac and Ivan, (2003)	Ordered probit	Fatality, Disabling injury, Not disabling injury, Probable injury, No injury	Crash	---
			Vehicle	Yes
			Roadway design & land use	Yes
			Environment	Yes
			Pedestrian	Yes
			Driver	---
Ballesteros et al., (2004)	Logistic regression	Mortality, Non-mortality/Injury severity score <16 and ≥16	Crash	---
			Vehicle	Yes
			Roadway design & land use	Yes
			Environment	---
			Pedestrian	---
			Driver	---
Roudsari et al., (2004)	Multivariate logistic regression	Severe injury, Non-severe injury	Crash	---
			Vehicle	Yes
			Roadway design & land use	Yes
			Environment	---
			Pedestrian	Yes
			Driver	---
Lee and Abdel-Aty, (2005)	Ordered probit	No injury, Possible injury, Non-incapacitating injury, Incapacitating injury, Fatal injury	Crash	---
			Vehicle	Yes
			Roadway design & land use	Yes
			Environment	Yes
			Pedestrian	Yes
			Driver	---

Sze and Wong, (2007)	Binary logistic regression	Killed or severe injury, Slight injury	Crash Vehicle Roadway design & land use Environment Pedestrian Driver	Yes --- Yes Yes Yes ---
Eluru et al., (2008)	Mixed generalized ordered logit, Ordered logit	No injury, Non-incapacitating injury, Incapacitating injury, Fatal injury	Crash Vehicle Roadway design & land use Environment Pedestrian Driver	Yes Yes Yes Yes Yes Yes
Kim et al., (2008)	Heteroskedastic generalized extreme value logit	Fatal, Incapacitating injury, Non-Incapacitating injury, Possible or No Injury	Crash Vehicle Roadway design & land use Environment Pedestrian Driver	Yes Yes Yes Yes Yes Yes
Kim et al., (2008)	Logistic regression	Serious injury, Non-injury	Crash Vehicle Roadway design & land use Environment Pedestrian Driver	--- --- Yes Yes Yes ---
Clifton et al., (2009)	Generalized ordered probit	No injury, Injury, Fatality	Crash Vehicle Roadway design & land use Environment Pedestrian Driver	Yes --- Yes Yes Yes ---
Kim et al., (2010)	Mixed logit model	Fatal injury, Incapacitating injury, Non-incapacitating injury, Possible/no injury	Crash Vehicle Roadway design & land use Environment Pedestrian Driver	--- Yes Yes Yes Yes Yes
Kwigizile et al., (2011)	Ordered probit, Multinomial logit	No/possible injury, Non-incapacitating injury,	Crash Vehicle Roadway design & land use Environment	Yes Yes Yes ---

		Incapacitating injury, Fatal injury	Pedestrian Driver	Yes Yes
Moudon et al., (2011)	Binary logistic regression	Severely injured/dying, Suffering minor/no injury	Crash Vehicle Roadway design & land use Environment Pedestrian Driver	--- --- Yes Yes Yes Yes
Rifaat et al., (2011)	Multinomial logit	No injury, Injury, Fatality	Crash Vehicle Roadway design & land use Environment Pedestrian Driver	--- --- Yes Yes --- Yes
Tay et al., (2011)	Multinomial logit	Minor injury, Serious injury, Fatal injury	Crash Vehicle Roadway design & land use Environment Pedestrian Driver	--- Yes Yes Yes Yes Yes
Zahabi et al., (2011)	Ordered logit	No injury, Minor injury, Fatal/Major injury	Crash Vehicle Roadway design & land use Environment Pedestrian Driver	Yes Yes Yes Yes --- ---
Abay, (2013)	Ordered logit, Mixed ordered logit, Multinomial logit, Mixed multinomial logit	Slight/no injury, Serious injury, Fatal injury	Crash Vehicle Roadway design & land use Environment Pedestrian Driver	Yes Yes Yes Yes Yes Yes
Aziz et al., (2013)	Random-parameter multinomial logit	Property damage and	Crash Vehicle Roadway design & land use Environment Pedestrian Driver	Yes Yes Yes Yes Yes ---
Mohamed	Latent Class	Injury and Fatal	Crash	---

et al., (2013)	Clustering: Ordered probit, K-Means: Multinomial logit	injury, No injury, Minor Injury and Fatal injury	Vehicle Roadway design & land use Environment Pedestrian Driver	Yes Yes Yes Yes Yes
Tefft, (2013)	Logistic regression	Severe injury, Non-severe injury/Fatal injury, Non-fatal injury	Crash Vehicle Roadway design & land use Environment Pedestrian Driver	Yes Yes Yes --- Yes ---

From reviewing Table 1, we can see the dependent variable (pedestrian injury severity) typically ranges from two (fatality/severe injury to slight injury/property damage only) to five (fatality, disabling injury, not disabling injury, probable injury to no injury). We can also see that that logistic regression and the ordered probit and logit models are the most prevalent econometric frameworks used to examine pedestrian injury severity. The summary also indicates that limited research has considered variables from all categories (crash, vehicle, roadway design and land use, environment, pedestrian and driver characteristics). Yasmin et al.'s review (2013) determined that the findings of earlier research are usually consistent. The most common factors that increase pedestrian injury severities include older pedestrians, male pedestrians, intoxicated pedestrians and/or drivers, occurrence of crash in darkness (with or without lighting), vehicle speeding, crash location is in a commercial area or on highways, and collisions involving a bus or truck. Factors found to reduce pedestrian injury severities in earlier research include, older drivers, presence of traffic signal control, snowy weather, and collision occurrence during the day.

Data Used in the Empirical Application

Data Source

Pedestrian collision data for HRM is drawn from the Nova Scotia Collision Record Database (NSCRD) for the years 2007 through 2011. In Nova Scotia, all collisions involving property damage over $1000 and injuries or fatalities occurring on a public road, as defined by the Motor Vehicle Act, require reporting. The NSCRD database consists of over 74,000 collisions involving about 208,700 individuals. A number of collision-related factors are recorded in the database including characteristics of individuals involved, vehicle characteristics, roadway design attributes, environment factors, and crash characteristics. The injury severity of each individual involved in the accident is recorded on a five point ordinal scale: (1) not injured, (2) minor – no treatment, (3) moderate – treated & released, (4) major – hospitalized, and (5) fatal.

Data Preparation

The pedestrian collision records were geocoded using GeoPinpoint. Built environment characteristics are derived by means of the spatial join function in ArcGIS to combine the collision location with dissemination area (DA) data from the 2011 Canadian Census and 2011 National Household Survey data. Joined data includes average household income, average number of rooms, housing stock, and dwelling type counts. Land use and built environment measures are computed using the Halifax Regional Municipality Corporate Dataset, Nova Scotia Topographic Data, and Desktop Mapping Technologies Inc. at a 250-meter buffer from each collision to capture the context of the area where the collision occurred. Finally, adapting a classification scheme from Rifaat et al. (2011), street pattern is classified into six categories: gridiron, fragmented parallel, warped parallel, loops and lollipops, lollipops on a stick, and mixed pattern, and examined with other factors to determine influence on injury severity.

Methodology

Injury severity is an inherently ordered outcome and therefore, the ordered probit model has become a widely used econometric framework in safety literature for analyzing injury severity outcomes. The ordered probit model can be written as a linear combination of predictors and an error term:

$$Y_i^* = \beta' Z_i + \varepsilon_i \tag{1}$$

Where Y_i^* is the latent & continuous measure of injury severity faced by pedestrian i in a collision, $Z_i$is a vector of explanatory variables describing personal, collision, and built environment characteristics, ε_i is a random error term assumed to be standard normal distribution, and $\beta'$is a vector of parameters to be estimated.

The injury severity outcome, Y_i^*, takes on values 0 through m generating an ordered partitioning of the latent risk propensity into the observed severity categories according to the following scheme:

$$-\propto < \theta_1 < \theta_2 < \ldots.. < \theta_{m-1} < \propto \quad (2)$$

Where θ represents threshold parameters in which $\theta_0 = -\propto$ and $\theta_m = \propto$. The observed injury severity level can therefore be represented as:

$$\begin{aligned} y_i^* &= 0 \text{ if } y_i^* \leq 0 \\ &= 1 \text{ if } 0 < y_i^* \leq \theta_1 \\ &= 2 \text{ if } \theta_1 < y_i^* < \theta_2 \\ &\ldots\ldots\ldots.. \\ &= m \text{ if } y_i^* > \theta_{m-1} \end{aligned} \quad (3)$$

The estimation of this ordered probit model is straightforward. This model is an extension of a probit model for a binary outcome whereby the probability of observing a particular ordinal outcome can be represented generically as:

$$Prob(y_i = m) = \phi(\theta_m - \beta X_i) - \phi(\theta_{m-1} - \beta X_i) \quad (4)$$

Assuming an indicator variable ψ_{im}, which equals 1 if the pedestrian sustains an injury of level m, and 0 otherwise, the log likelihood can be written as follows:

$$lnL = \sum_{i=1}^{n} \sum_{m=0}^{m} \psi_{im} \; ln[\phi(\theta_m - \beta X_i) - \phi(\theta_{m-1} - \beta X_i)] \quad (5)$$

Discussion of Results

Variables related to the pedestrian and driver characteristics, collision characteristics, and environmental conditions were examined in the model. Pedestrian and driver variables included age and gender. Collision characteristics included collision time, vehicle manoeuver, and point of impact. Environmental conditions include weather and lighting conditions. Model estimation also included a variety of street pattern classifications, land use types, transit supply, and demographic characteristics. The final ordered probit model is presented in Table 2. The model demonstrates a strong relationship between the explanatory variables and levels of pedestrian injury severity. Some variables included in the final specification exhibit relatively lower t-statistic but have been retained in the model, with the presumption that a larger dataset would result in statistically significant parameters.

The parameter estimation results suggest that the age and gender of pedestrians and drivers are strong factors in explaining pedestrian injury severity outcomes. Pedestrians aged 55 or older involved in a collision are more likely to suffer severe injuries compared to other age groups. Drivers aged 55 or older also have a positive relationship with injury severity levels of pedestrians. Older individuals are associated with slower perception and reaction times, physical fragility, existing medical conditions, which may contribute to a higher risk propensity. Therefore, although not a causal factor itself, age may be strongly associated with other relevant variables correlated with age. Female pedestrians and male drivers are associated with higher levels of injury severity for pedestrians.

The collision characteristic variables were also found to be significant predictors of pedestrian injury severity. Collisions occurring during the AM peak (7-9 AM) were found to be associated with lower levels of injury severity although they have a relatively low effect size and statistical significance but are noteworthy nonetheless. A positive and relatively moderate is found with collisions occurring after dark. Certainly lighting condition is directly correlated with pedestrian visibility, which primarily affects the risk of collisions, but also affects severity due to lack of evasive action by drivers, leading to greater impacts and thus injury severity. Lighting is a key element of crosswalk design. Seeing and being seen are essential conditions for safety of pedestrians. If adequate lighting is not provided, dark lighting conditions make pedestrians less visible to drivers. As expected, a negative relationship with injury severity is found when weather conditions are clear. Collisions occurring when a vehicle is travelling straight positively influences the probability of a more

TABLE 3 Parameter Estimation Results from Ordered Probit Model for Pedestrian Injury Severity

	coefficient	t-stat
Personal characteristics		
Female pedestrian	0.050008	0.696
Pedestrian aged 55 or older	0.457676	4.903
Male driver	0.179456	2.502
Driver aged 55 or older	-0.16441	-2.046
Collision characteristics		
AM occurrence (7-9AM)	-0.12888	-1.08
Dark lighting conditions	0.194758	2.425
Weather (clear)	-0.17268	-2.382
Vehicle traveling straight	0.171467	2.294
Left bumper impact	0.130628	1.259
Built environment characteristics		
Sloped road	0.199652	2.15
Intersection	-0.17085	-2.235
Average dwelling value (log)	-0.02977	-1.784
Average children per household	0.248078	1.832
Participation rate	-0.00713	-2.072
Median shelter cost	0.000229	1.892
KM of sidewalk	-0.00028	-1.626
KM of bus route	0.000361	2.157
Building area (sq. ft.)	-0.00046	-1.647
Number of GM stores	0.02112	1.201
Number of transit stops	0.01757	2.407
Street pattern (grid)	0.199308	2.149
Threshold parameters		
Mu(1)	.89009982	21.744
Mu(2)	2.52774352	40.622
Mu(3)	3.45813009	28.671
Constant	1.31527702	4.182
Pseudo R-squared	.0363095	
Number of observations	963	

severe injury to the pedestrian. The pedestrians' location of impact with the vehicle has an influence on the pedestrians' injury likelihood. Specifically, a collision where the pedestrian is struck with the vehicles left front bumper is associated with a higher injury risk.

Model estimation also offers some interesting insights into the role of the built environment on pedestrian injury outcomes. A variety of street pattern classifications, land use types, transit supply, and demographic characteristics were examined in the model. The majority of built environment characteristics exhibit lower effect size and statistical significance which is likely attributed to interaction with the other explanatory variables. Pedestrians involved in collisions within lower income neighbourhoods, represented by the average dwelling value variable, have a higher risk of severe injuries compared to higher income neighbourhoods. This may be attributed to more frequent speeding, increased crime, unpleasant walking environments, and riskier behaviour associated with lower income neighbourhoods. Neighbourhoods with higher averages of children per household are found to be associated with higher levels of pedestrian injury severity. Although not supported by the personal characteristic age variable (pedestrians aged 55 and older), this may attributed to the disadvantage children have as pedestrians as they have lower overall physical, cognitive, visual, and auditory development. Neighbourhoods with higher shelter costs are associated with lower levels of pedestrian injury severity. Neighbourhoods that are more affluent are associated with better quality street lighting, roadway markings, and traffic calming measures, which provide a safer environment for pedestrians.

Areas with more kilometers of sidewalk, represented by the km of sidewalk within 250m of the collision location variable, are found to be associated with lower levels of injury severity. This finding is intuitive as sidewalks provide a grade separated facility for walking that is generally considered safer for pedestrians. Conversely, areas with more kilometers of bus route are found to be associated with higher levels of pedestrian injury severity. Buses are an apparent point of conflict for pedestrians. It is likely that pedestrian and other road users may interact with buses in the roadway when crossing the street. This finding may also be explained by the increased pedestrian activity associated with areas having transit service. This finding is also supported by the number of transit stops variable which can be explained with similar reasoning. Interestingly, the building density variable (building area sq. ft.) is found to be associated with lower levels of pedestrian injury severity. This implies that denser areas are safer for pedestrians. Collision locations surrounded by higher numbers of GM stores are found to be associated with higher levels of injury severity. These locations are typically associated with higher volumes of pedestrians and vehicles which may lead to increased interaction and therefore collision incidence and severity. Finally, the grid street pattern is found to be a significant predicator of higher pedestrian injury severity levels. The grid street pattern is characterized by many intersections which may be conflict areas for pedestrians and other road users.

Several other variables were tested during model estimation but those hypotheses could not be confirmed due to lack of reasonable statistical significance. For example, some built environment variables such as residential and commercial density yielded counter-intuitive results which may be due to correlations with other built environment variables.

Conclusions

Pedestrians are particularly vulnerable road users within the urban environment. Many studies have examined the factors contributing to the frequency and severity of crashes, but limited research has examined the influence of the built environment. This paper presents the findings of an ordered probit model that examines pedestrian injury severity levels with a focus on built environment characteristics. In this study, built environment contributing factors included land use types, road network connectivity, transit supply, and demographic characteristics. These effects on injury severity were examined together with other variables including pedestrian and driver characteristics, collision characteristics, and environmental conditions.

Several important empirical findings have emerged. Time of day as well as weather conditions were found to be significant in explaining injury severity of pedestrians. The analysis also suggests that vehicle interaction, road design, and pedestrian action and location are important variables influencing pedestrian injury severity. Additionally, we found built environment characteristics including land use type, presence of activity centers, and demographic attributes to influence injury severity outcomes.

Due to the collision reporting criteria in Nova Scotia, collisions resulting in no or minor injury are likely to be unrepresented which may result in a higher number of more severe injuries present in the dataset. Compared to earlier studies in other jurisdictions, our study employs a relatively small sample size. Moreover, our study represents data from a five-year period, which means our study could not incorporate temporal variability in the model. In future studies, time-variation indicative variables will be investigated to examine the effect on injury severity. An additional limitation may exist due to the modeling framework chosen for this study. Recent research has identified the traditional ordered response model to impose a restrictive assumption on the impact of exogenous variables by constraining their impact to be the same for all alternatives. Moving forward, pedestrian injury severity will be examined using an unordered response model to allow the impact of exogenous variables to vary across the injury severity levels.

A number of contributions have emerged from this study. Earlier research has focused in a limited extent on the built environment contributing factors. This study contributes in understanding how street pattern, roadway design, land use, and neighbour characteristics influence pedestrian injury severity levels. Moreover, the contributions of our study are timely given the increased awareness and emphasis on the use of active modes of transportation in HRM, the province, and the across jurisdictions. Our study can inform the direction of policy interventions for pedestrian safety. For example, one takeaway is the need to focus on education and awareness programs for older pedestrians and drivers alike. Another may be to increase the time allowed for crossing the street at signalized intersections where there is a concentration of senior pedestrians.

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