A Spatial Analysis of Pedestrian Injury in the City of Toronto

by

Emily Grisé

A thesis submitted in conformity with the requirements for the degree of Master of Arts
Department of Geography and Planning
University of Toronto

© Copyright by Emily Grisé 2015
A Spatial Analysis of Pedestrian Injury in the City of Toronto

Emily Grisé

Master of Arts

Department of Geography and Planning
University of Toronto

2015

Abstract

The City of Toronto experienced a ten-year high in pedestrian fatalities last year and has the highest pedestrian collision rate of Canadian cities. Understanding the geography of pedestrian motor vehicle collisions (PMVCs) can provide evidence to inform policy and planning targeting increased walking while reducing pedestrian injury risk. This thesis explores spatial patterns of PMVCs in the City of Toronto, with a specific focus on two particularly vulnerable road users; children and seniors. Distinct spatial patterns of PMVCs and injuries by type and age are found. This finding is further investigated by exploring the relationship between an attempt to measure equity across neighbourhoods in Toronto and pedestrian injury risk. The results suggest age-based differences in the relationship between neighbourhood equity indicators and PMVCs. A higher PMVC and injury risk for children was observed in neighbourhoods with poorer equity outcomes, while no significant relationship with equity outcomes was observed for seniors.
Acknowledgments

I would like to first thank my supervisor Ron Buliung, for his continued guidance, patience and overall support over the course of completing this thesis and over the course of the two years of my Masters. I especially have appreciated all of the opportunities you encouraged me to take, in particular to present my research at many conferences over the past year. I am confident that you have done a great job to prepare me for what is next in my academic career.

Secondly, I would like to acknowledge the support of my friends and family over the course of my academic studies. I greatly appreciate the confidence you have in me, and the encouragement and help I received to continue to be a professional student. Lastly, I would like to acknowledge the PGB crew, who helped keep me (somewhat) sane over the writing of this thesis, I can only hope to have such great classmates in the future!
# Table of Contents

Acknowledgments........................................................................................................ iii

Table of Contents.......................................................................................................... iv

List of Tables ................................................................................................................ vi

List of Figures ................................................................................................................ vii

1 INTRODUCTION........................................................................................................... 1

1.1 The Vulnerable among the Vulnerable Road users ..................................................... 3

1.2 Policy and pedestrian injury in Toronto .................................................................... 4

   1.2.1 How is equity defined and evaluated in pedestrian planning? ......................... 5

   1.2.2 How is pedestrian planning and safety incorporated into city transportation
       planning and policy? ................................................................................................. 7

   1.2.3 How do these policies and institutions consider children and seniors in road
       safety planning? ....................................................................................................... 12

   1.2.4 Policy Conclusions ............................................................................................ 13

1.3 Thesis Objectives and Structure .............................................................................. 14

2 LITERATURE REVIEW ............................................................................................... 15

2.1 Factors associated with child and senior pedestrian injury ..................................... 15

   2.1.1 Child pedestrian injury ...................................................................................... 15

   2.1.2 Senior pedestrian injury .................................................................................... 20

2.2 Physical Determinants of Pedestrian Injury ............................................................ 25

2.3 Summary and Conclusions ....................................................................................... 31

3 EXPLORING SPATIAL PATTERNS OF PEDESTRIAN INJURY BY AGE AND
   SEVERITY .................................................................................................................... 34

3.1 Introduction ................................................................................................................ 34

3.2 Data ........................................................................................................................... 35

3.3 Methods ..................................................................................................................... 37

   3.3.1 Indirect Standardization ...................................................................................... 37

   3.3.2 Spatial Empirical Bayes Rate Smoothing ............................................................ 45

   3.3.3 Cluster Analysis ................................................................................................. 47
<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.3.4</td>
<td>Methods Limitations</td>
<td>48</td>
</tr>
<tr>
<td>3.4</td>
<td>Results</td>
<td>50</td>
</tr>
<tr>
<td>3.5</td>
<td>Discussion</td>
<td>54</td>
</tr>
<tr>
<td>3.6</td>
<td>Conclusions</td>
<td>58</td>
</tr>
<tr>
<td>4</td>
<td>EXPLORING THE RELATIONSHIP BETWEEN NEIGHBOURHOOD EQUITY AND CHILD AND SENIOR PEDESTRIAN INJURY</td>
<td>60</td>
</tr>
<tr>
<td>4.1</td>
<td>Introduction</td>
<td>60</td>
</tr>
<tr>
<td>4.2</td>
<td>Data and Methods</td>
<td>63</td>
</tr>
<tr>
<td>4.2.1</td>
<td>Methods Limitations</td>
<td>66</td>
</tr>
<tr>
<td>4.3</td>
<td>Results</td>
<td>66</td>
</tr>
<tr>
<td>4.3.1</td>
<td>Correlation Results</td>
<td>68</td>
</tr>
<tr>
<td>4.3.2</td>
<td>Descriptive Analysis of Rail Corridor Case Study</td>
<td>72</td>
</tr>
<tr>
<td>4.4</td>
<td>Discussion</td>
<td>75</td>
</tr>
<tr>
<td>4.5</td>
<td>Conclusions</td>
<td>80</td>
</tr>
<tr>
<td>5</td>
<td>CONCLUSION</td>
<td>82</td>
</tr>
<tr>
<td>5.1</td>
<td>Summary and Synthesis of Main Findings</td>
<td>83</td>
</tr>
<tr>
<td>5.1.1</td>
<td>Exploring Spatial Patterns of Pedestrian Injury by Age and Severity Analysis Results</td>
<td>83</td>
</tr>
<tr>
<td>5.1.2</td>
<td>Relationship Between Neighbourhood Equity Indicators and Pedestrian Injury Analysis Results</td>
<td>84</td>
</tr>
<tr>
<td>5.2</td>
<td>Policy Implications</td>
<td>86</td>
</tr>
<tr>
<td>5.3</td>
<td>Areas of Future Research</td>
<td>89</td>
</tr>
<tr>
<td>References</td>
<td></td>
<td>91</td>
</tr>
</tbody>
</table>
List of Tables

Table 3.1 Descriptive statistics of PMVCs and injury events by age category and spatial region ........................................................................................................................................... 41

Table 3.2 City of Toronto PMVCs and severe injury rates per 100,000 population .................. 41

Table 3.3 Indirect Standardization for children and seniors population sub-sets ..................... 45

Table 4.1 Neighbourhood Equity indicators including descriptions and data source ............. 64

Table 4.2 Correlation results of children’s standardized PMVCs and severe injury ratios and Neighbourhood Equity Indicators ......................................................................................................................... 69

Table 4.3 Correlation results of senior’s standardized PMVCs and severe injury ratios and Neighbourhood Equity Indicators ................................................................................................................................. 70

Table 4.4 Children’s Standardized Collision Ratios for each neighbourhood and overall equity score of neighbourhoods categorized as north and south (see Figure 4.3) ............... 74

Table 4.5 Average indicator values for the south and north neighbourhoods adjacent to the West Toronto Rail Corridor ........................................................................................................................... 74
List of Figures

**Figure 2.1** Typical PSO signal configuration, where the green lines represent pedestrian movements, figure source: Kattan et al., 2009 .............................................. 27

**Figure 2.2** Image of a Toronto pedestrian countdown signal, displaying the duration of time remaining for pedestrians to cross (5 seconds), figure source: Blackwell, 2012 ................. 28

**Figure 2.4** Photo of an active split phase signal in New York City, figure source: Chen et al., 2014 ............................................................. 29

**Figure 3.1** Map of Toronto with the former Municipality borders, and the classification of downtown and inner suburbs ................................................................. 36

**Figure 3.2** Outline of main research methods .......................................................... 37

**Figure 3.3** Map of counts of PMVCs observed for children ........................................ 39

**Figure 3.4** Map of counts of severe injuries observed for children .............................. 39

**Figure 3.5** Map of counts of PMVCs observed for seniors ........................................ 40

**Figure 3.6** Map of counts of severe injuries observed for seniors .............................. 40

**Figure 3.7** Map of children’s standardized collision ratios ......................................... 43

**Figure 3.8** Map of children’s standardized morbidity ratios .................................... 43

**Figure 3.9** Map of senior’s standardized collision ratios ........................................... 44

**Figure 3.10** Map of senior’s standardized morbidity ratios ........................................ 44

**Figure 3.11** Local Moran’s I cluster map results of children’s standardized collision ratios ...... 51

**Figure 3.12** Local Moran’s I cluster map results of children’s standardized morbidity ratios .... 52

**Figure 3.13** Local Moran’s I cluster map results of senior’s standardized collision ratios .... 53

**Figure 3.14** Local Moran’s I cluster map results of senior’s standardized morbidity ratios ...... 54

**Figure 4.1** Overlay of Neighbourhood Equity Index Scores and children’s standardized collision and morbidity ratio high-high clusters ........................................ 67

**Figure 4.2** Overlay of Neighbourhood Equity Index Scores and senior’s standardized collision and morbidity ratio high-high clusters ........................................ 68

**Figure 4.3** Identifier map of neighbourhoods around the West Toronto Rail Corridor .......... 73
1 INTRODUCTION

Pedestrians are among the most vulnerable road users. Pedestrians, bicyclists and motorcycle riders are considered vulnerable road users (VRUs) as a result of their vulnerability due to their lack of protection if struck by a vehicle. Globally, more than 270,000 pedestrian deaths occur annually, 22% of the total 1.24 million road traffic deaths (World Health Organization [WHO], 2013). Furthermore, research by the WHO (2013) indicates that males, both children and adults, make up a greater proportion of pedestrian deaths and injuries than others. In developed countries, older pedestrians are at greatest risk, while in low and middle-income countries, children and young adults are most often affected. In 2010, 13% of all fatalities by road users in Canada were pedestrians (Statistics Canada, 2011). Canadian urban regions account for 75% of pedestrian fatalities, with 60% of these fatalities involving a road crossing (Transport Canada, 2010).

There are extraordinary differences in the number and proportion of pedestrian fatalities by age and gender, and differences in circumstances and pedestrian actions prior to a collision. Transport Canada (2010) reported that seniors had the greatest risk of being pedestrian fatalities; 35% of pedestrians killed were seniors but seniors only accounted for 13% of the Canadian population. Pedestrians under the age of 16 years were more likely to have run into the street prior to a collision or to be hit following vehicle egress. Young adults aged 20-24 years were most likely to be struck while walking along the road or walking on the road. Furthermore, 40% of fatally injured pedestrians had been drinking but were not necessarily intoxicated.

The City of Toronto, Canada, currently has the highest pedestrian motor-vehicle collision (PMVC) rate per 100,000 people of all Canadian cities (Toronto Public Health, 2012a). Toronto pedestrians represent 52% of all fatalities and 11% of all injuries from motor vehicle collisions, despite the relatively low walking commuter mode share of 7% (Toronto Public Health, 2012a). In an average year in Toronto, 58% of PMVCs occur on major arterial roads; 47% at intersections, and in over 75% of these collisions pedestrians had the right-of-way. In 30% of

1 Commuter mode share underrepresents a significant portion of walking trips, such as leisure, shopping, physical activity, non-motorized trip links
PMVCs pedestrians were crossing with the right-of-way and then hit by a turning vehicle (resulting in 10 fatalities in 2009 alone) (Toronto Public Health, 2012a).

Pedestrian collisions, like other road traffic crashes, should not be tolerated and accepted as inevitable as they are predictable and preventable (UN Road Safety Collaboration, 2014). The key risk factors of PMVCs are well documented, and include: driver behavior, particularly in terms of speeding and drinking and driving; infrastructure, such as a lack of dedicated facilities for pedestrians such as sidewalks, raised crosswalks and medians; and vehicle design in terms of shape, size, and materials (UN Road Safety Collaboration, 2014). These key risk factors represent a shift away from the road-user approach to road safety, which was based on the premise that individual road-users are solely responsible when crashes occur. Under that model, road safety interventions were primarily aimed at persuading road-users to adopt error-free behaviour (Larsson, Dekker, & Tingvall, 2010). Alternatively, road safety professionals have more recently undertaken an approach that adapts to the psychological and physical conditions and potential limitations of all road users; pedestrians, motorists, cyclists, etc. Consequently, developed countries have seen a decline in pedestrian injury incidence and mortality, however this decline has not been uniform across the population (Yiannakoulas & Scott, 2013). It is uncertain if the decline in injury is attributable to increased safety in the road environment or less walking. Socioeconomic disadvantage has a strong association with pedestrian injury risk (Collins & Kearns, 2005), which is most likely attributable to disparities in the safety and quality of the walking environment and differential exposure to traffic hazards as a result of dependency on walking and transit as primary modes of transportation. As a result, equity objectives should be incorporated into pedestrian plans and policies, in order to ensure that the decline in injury incidence and mortality is uniform across all population groups.

This introductory chapter begins by identifying two particularly vulnerable population groups among pedestrians, children and seniors, who are focus of this thesis. This is followed by an overview and discussion of how equity is defined and evaluated in pedestrian planning. This will be followed by a discussion of policy documents specific to the City of Toronto, from a variety of government divisions; in order to develop an understanding of how pedestrian planning and safety is currently incorporated in city transportation planning and policy and how policies specifically consider children and seniors. The final section of this chapter outlines the main research objectives and structure of the remaining thesis chapters.
1.1 The Vulnerable among the Vulnerable Road users

Road traffic injury is the single largest cause of years of life lost (17%) in children and youth in Canada (Institute for Health Metrics and Evaluation, 2013). Within this category, child and youth pedestrian injury accounts for 25% of total injuries. In Ontario in 2010, older pedestrians (65+ years of age) accounted for 36% of pedestrian fatalities despite their representation in the population (about 13.2%) (Office of the Chief Coroner for Ontario, 2012). This is particularly concerning given Canada’s aging population (Employment and Social Development Canada, 2014). Child and senior pedestrian injury and death should receive greater attention in research, in public health and transport policy, and in public discourse on transportation and city building.

Traffic speed is a critical predictor of pedestrian injury severity. Children, however, are vulnerable in ways typically different from adults. For example, because of their short stature, a vehicle can directly strike a child’s head or vital organs resulting in a more severe injury outcome regardless of speed (Rothman, Slater, Meaney, & Howard, 2010). Similarly, seniors are at greater risk of severe injury and fatality when struck by motor vehicles due to increased frailty and decreased ability to recover (Oxley, Fildes, Ihsen, Charlton, & Day, 1997). Therefore, while speed remains a critical risk factor for PMVCs and fatality (Peden, 2004), emphasis must simultaneously be placed on reducing potential conflicts with vehicles, particularly in areas where children and seniors are concentrated, at both the home and destination ends of trips, and routes along the way.

Road networks have largely been designed for the use of motorized traffic at the expense of vulnerable road users. Road design should aim to be more inclusive and provide safe mobility for all. Infrastructure design and standards based on young fit males are unsuitable in an aging and a mobility diverse society (OECD, 2011). As a response to a North American legacy of arguably exclusionary road design, the 8-80 Cities initiative is based on the philosophy that if you create a city that is safe and accessible for an 8 year old and for an 80 year old, you will create a successful city for everyone. 8-80 Cities encourages sustainable and healthy lifestyles for everyone, regardless of age, gender, ability, ethnicity or economic background, by creating people-oriented destinations (8-80 Cities, 2015). A key approach promoted by 8-80 Cities is the
retrofit of streets toward a complete streets design. Complete Streets is a concept that prioritizes road design to facilitate the safe mobility of all ages, abilities and modes of travel principally by reallocating portions of the motor vehicle right-of-way to other modes, i.e., bike lanes, sidewalks, crosswalks and transit lanes. Countries with a good child safety record tend also to have a good overall traffic safety record characterized by having a well-established and integrated approach to road safety (OECD, 2004). Given the vulnerability of children and seniors in the road environment, road safety policy should include specific strategies and targets for improving child and elderly pedestrian safety; the injury and death of children and seniors in Toronto, resulting from PMVCs, is the focus of this thesis.

1.2 Policy and pedestrian injury in Toronto

Transportation and public health policy, planning and services have largely existed separate from one another institutionally, despite the connectedness between transport and health processes (Toronto Public Health, 2012a). As an example, consider how it is now widely recognized that automobile-oriented transportation is closely linked with Canadian’s low levels of daily physical activity (Transport Canada, 2011). Safe walking opportunities can reduce inequalities by enabling individuals without motor vehicles to more easily access goods and services (Toronto Public Health, 2012a). A Toronto based study found that 74% of residents preferred living in walkable and transit-supportive neighbourhoods (Toronto Public Health, 2012b). However, Toronto’s most walkable neighbourhoods and better served by transit tend to be least affordable for those with low incomes (Toronto Public Health, 2012a). Policies that target increased neighbourhood walking rates, particularly in neighbourhoods with less favourable walking conditions, if planned poorly, could associate with greater risk of PMVCs from both residential and non-residential (drive-through) traffic. Therefore, the safety risk piece should simultaneously be considered in the context of encouraging increased walking, in addition to the inclusion of equity in pedestrian planning and policy efforts to reduce inequalities.

To improve the walkability and safety for pedestrians in an urban region, alliances must be formed between various sectors of city government, including transportation and city planning, public health, environment and economic development. This section reviews a variety
of current transportation policy plans concerning the City of Toronto from a range of divisions including: Toronto’s City Planning Division, Toronto Public Health, Metrolinx, City of Toronto Transportation Services, and the Toronto Transit Commission (TTC). Evaluation of the policy documents will be organized around the following discussions: (1) how is equity defined and evaluated in pedestrian planning; (2) how are pedestrian planning and safety currently incorporated into city transportation planning and policy and; (3) how do policies consider children and seniors in road safety planning.

1.2.1 How is equity defined and evaluated in pedestrian planning?

One way to conceptualize equity is to consider the distribution of impacts (benefits and costs) and whether that distribution is considered fair and appropriate (Litman, 2015). There are three types of equity on which transportation analyses may be based: horizontal, vertical, and intergenerational equity (Litman, 2015). Horizontal equity refers to the equal distribution of resources among individuals considered equal in ability and need. Vertical equity is concerned with the distribution of impacts between individuals that differ by income or social class, and follows a progressive means of planning (transportation affordability, impacts on low-income communities, or service quality in lower-income communities). Vertical equity also considers how the transportation system is able to meet the needs of travelers with mobility impairments. In the case of vertical equity, the division of benefits should be directed, in greater proportion, to those with the greatest potential need (Litman, 2015), whereas horizontal equity requires that users bear the costs of their transport facilities and services. Furthermore, vertical equity principles work to ensure that disadvantaged groups do not bear excessive external costs (pollution, accident risk, financial costs, etc.). The final type of equity, intergenerational equity, ensures that impacts on future generations are considered in decision-making.

To evaluate equity within pedestrian planning, it is important to first consider how persons who are in need, or more in need, may be identified. Subsequently, the provision of walking infrastructure should be examined, to identify those people who do not have sufficient access to safe and quality walking infrastructure but may require it, these individuals may be referred to as transport disadvantaged (Murray & Davis, 2001). There are a number of factors that contribute to the situation of having a transport disadvantage, ranging from age prohibitive factors; under the age of 16 years or unable or unwilling to drive as a senior citizen; income constraints, new immigrants who are unlicensed, or various disabilities preventing individuals
from driving. However, need is only one of two factors that contribute to transport disadvantage; the second is inadequate transportation services in relation to need (Murray & Davis, 2001). An assessment of this could be either infrastructure related (i.e. total length of sidewalk, intersection density, width of sidewalks or quality of pedestrian infrastructure) or collision risk. Relating back to the types of equity that transportation analyses may be based, vertical equity goals could aim to improve walking conditions and safety to the transport disadvantaged or to specific geographic areas with high proportions of transport disadvantaged individuals (such as seniors or children) and a lack of supportive infrastructure. Conversely, horizontal equity goals could aim to make walking more attractive and safer across the entire city.

Evaluating how favourable a city is for pedestrians is difficult. A commonly used measure would be mode shares of pedestrian trips. This measure may be indicative of a favourable walking environment for pedestrians, or it could simply be a reflection of a population that cannot afford to own cars or use transit. Furthermore, even if walking mode share is high, pedestrians may feel insecure or unsafe, and there may be a high level of PMVCs and fatalities. This presents a challenge for transportation policy and decision-making, to fully capture the multiple dimensions of the situation for pedestrians (Manaugh, Badami, & El-Geneidy, 2015). Therefore, not distinguishing between people who walk because their neighbourhood is amenable to walk and those who simply do walk because they lack access to a vehicle or other means of mobility, might miss key issues of social equity ( Manaugh et al., 2015 ).

According to Toronto Public Health (2012a), it appears that walking does not effectively reduce inequalities in Toronto, which is in large part a result of the dramatic differences between walkability downtown in comparison to the inner suburbs. Toronto’s most walkable neighbourhoods tend to be least affordable for those with low incomes, and second, a high proportion of low-income families live in high-rise neighbourhoods in Toronto’s inner suburbs, where development patterns do not fit the typical ideas about walkability. Furthermore, evidence of high collision rates at intersections in Toronto’s inner suburbs appear to be contributing to the inequity in walking in Toronto. Overall, the links between health, equity, and active transportation have not been studied widely, and even if they had been, it remains important to situate research within the geographical domain where interventions are being considered (Public Health, 2012a).
With a view to developing improved understanding about neighbourhood level differences in equity in order to guide targeted investments in community infrastructure where most urgently needed, *Urban HEART @Toronto* is a tool that helps measure equity across Toronto’s neighbourhoods (CRICH, 2014). *Urban HEART @Toronto is measured* across the following five policy domains: Economic Opportunities, Social Development, Healthy Lives, Participation in Decision-making and Physical Environment and Infrastructure. The neighbourhood equity index provides a quantitative assessment of neighbourhood wellbeing and describes how neighbourhoods in Toronto are faring relative to others (Social Policy Analysis and Research, 2014). A conceptual and empirical limitation of this tool is that is does not attempt to incorporate pedestrian injury, although surely pedestrian safety risk should be of concern within the discussion of the geography of equity across our cities and regions. In other words, the tool emphasizes and values walkability but does not explicitly examine safety risks, or neighbourhood inequalities with regard to risk and health outcomes related to competition between motorized and non-motorized modes of transportation.

1.2.2 How is pedestrian planning and safety incorporated into city transportation planning and policy?

Here, policies in the City of Toronto, the study area of this thesis, are used as an example of how pedestrian planning and safety is incorporated into transportation planning from the following municipal government divisions: City Planning Division, the TTC, Toronto Public Health and Transportation Services; followed by the Provincial government, through the division of Metrolinx. Toronto’s Transportation Services is the City division responsible for all aspects of Toronto’s transportation network, including road and sidewalk repair and maintenance, road right-of-way regulation, snow clearing and salting, traffic signals and traffic safety, pedestrian and cycling programs and developing public spaces. The City of Toronto has jurisdiction over all arterial roads, local roads and laneways, as well as municipal expressways within the boundaries of the City. The Ministry of Transportation of Ontario (MTO) has jurisdiction over provincial highways (400-series highways and the Queen Elizabeth Way) within the boundaries of the City of Toronto. Additionally, under the Highway Traffic Act, the MTO currently sets the default maximum speed limits in Ontario municipalities, without the need to post signage. However, a municipality has the right to pass by-laws to set a different speed limit on a road segment within its jurisdiction, but must be accompanied by the applicable signage (Buckley,
While Transportation Services is primarily responsible for transportation planning in Toronto, various other government institutions contribute to transportation planning and policy as an integral part of creating a sustainable and successful city.

**City of Toronto Planning Division**

The Toronto Official Plan was released in 2010, and was developed with the vision of creating an attractive and safe city, and a city where people of all ages and abilities can enjoy a high quality of life. The Official Plan recognizes that in order to build a more livable and sustainable urban region, growth in the city must be structured with policies that integrate transportation and land use. Therefore, achieving a more intense, mixed-use pattern of development will simultaneously encourage and facilitate the need for better planning for pedestrians and cyclists. Furthermore, the entire transportation system must be designed to meet the travel needs of all Toronto residents, including people with disabilities and seniors or those without access to a car.

Toronto’s population is currently 2.6 million and is forecasted to surpass 3 million by 2031 (City of Toronto, 2010). As a result, the City Planning Division is committed to managing city growth in a way that will not have a negative impact on the safety of the streets. In this regard, pedestrian planning strategies are incorporated largely through existing City Planning and review processes, including the following two processes (City of Toronto, n.d. -a). The first of which is the Transit Oriented Development Review process which is conducted by the TTC, to review City of Toronto development applications to assess the quality of pedestrian-transit connections, including waiting areas at stops, walkway distances between bus stops and developments, and entrance connections to subway stations. The second is conducted by City Planning and Transportation Services, during the review of new development applications, to assess various pedestrian improvements, such as new pedestrian linkages within the site and also connections to surrounding areas, direct connections to transit facilities and streetscape improvements.

**Toronto Transit Commission**

The TTC has taken a proactive approach to safety. This effort has in part been warranted by recent fatal collisions involving TTC buses and streetcars and pedestrians. More specifically, between 2010 and 2014, there were 262 collisions including 8 fatalities as a result of bus
collisions with pedestrians, and 153 collisions including 6 pedestrian fatalities as a result of streetcar collisions with pedestrians (Kalinowski, 2014). Regardless of culpability or whether these fatalities were preventable, TTC management views any fatality as unacceptable and is committed to improving operational safety (TTC, 2015). Actions being taken to improve pedestrian safety performance include: speed audits, research to identify industry best practices, a review of the location of bus stops throughout the city and the addition of pedestrian crossovers or pedestrian refugee islands to facilitate safe road crossing behaviour. The final main consideration by the TTC is to review “hotspot” locations for vehicle and pedestrian accidents to identify potential interventions to reduce these dangerous conflicts.

**Toronto Public Health**

In October 2011, Toronto Public Health released the Healthy Toronto by Design series of reports that synthesize evidence of the health benefits associated with active modes of transportation, and how Toronto can benefit from adopting a Complete Streets design that prioritizes moving people over moving cars. Road modifications that are adopted to create a Complete Streets design include: minimizing road widths (both total number of lanes and a reduction in the lane width), traffic calming measures, improving street connectivity, enhanced design elements of intersections and mid-block crossings (traffic controls/signals, curb radii, zebra crossings, Pedestrian crossovers), and improving pedestrian space (e.g. sidewalks, landscaping, lighting, street furniture, transit stops). These physical interventions are intended to reduce speeds of motor vehicles, increase the safety and the perception of safety for non-motorized users of the street and to promote increased pedestrian, cycle and transit usage (Toronto Public Health, 2014).

Additionally, as an effort to empirically monitor pedestrian safety and measure the success of implemented safety programs or interventions, the City of Toronto, like many other cities in North America, has recognized the importance of improving the availability and quality of data on walking (Toronto Public Health, 2012a). Toronto Public Health is committed to continued collaboration with the transportation, planning and other municipal departments to collectively set targets of pedestrian safety and execute coordinated action on active transportation.

**Transportation Services Division**
In 2013, Transportation Services conducted an in-depth study of pedestrian collisions at signalized intersections, to review safety performance and to identify problem areas to prioritize projects and interventions. This study was a follow-up to a 2011 study conducted by Global News where it was reported that intersections predominantly located downtown and along subway lines that experience high pedestrian volumes had the lowest collision rates, and intersections in Toronto’s inner suburbs that experience lower pedestrian volumes produced higher pedestrian collision rates (Cain, 2011 ). Subsequently, Transportation Services conducted a review of the methodology of this study identifying several shortcomings including: failure to account for vehicle volume at intersections, and the exclusion of intersections with low pedestrian counts.

In an updated study using signalized intersection collision data from 2007 – 2011 Toronto Police Services records, a collision rate method was used to account for the effect of pedestrian and vehicle traffic volume on collision occurrence. Using this method, a list of 100 priority-signalized intersections was made. Only one intersection was similarly reported by the Global News priority intersection list. Subsequently a review of collision data to identify trends in collision types was conducted. The most common pedestrian collision type was a left-turning vehicle striking a pedestrian crossing with the right-of-way (47%) and speed appeared to have been a contributing factor in 42% of incidents at the priority locations. However, limitations to this study remain; this study was limited to signalized intersections (which only captures 47% of PMVCs in an average year in Toronto); age was not considered in this study and the study did not discern between all PMVCs and PMVCs inducing fatalities or severe injuries.

An action plan to improve the safety performance of the priority intersections identified in the report titled City Initiatives for Reducing Pedestrian Collisions and Improving Traffic Safety, was developed to include immediate actions, as well as long-term approaches. However, there are many ongoing initiatives to increase pedestrian safety and encourage walking, including the following. An evaluation of traffic signals, including leading pedestrian intervals and longer pedestrian walk times. To increase the visibility of pedestrians to drivers, including zebra striped pedestrian crossings and pedestrian crossovers (the push-button activated lights suspended over the roadway that flash during a pedestrian crossing). Interventions to reduce potential conflicts with drivers, including red light cameras, pedestrian priority crossings (exclusive pedestrian crossing phase at Pedestrian Scramble Intersections) and no right turn on
red regulations where appropriate. Finally, the adoption of the Traffic Calming Policy in 2002, to control speeds in residential areas and improve safety for non-motorized users.

Transportation Services initiated the Traffic Calming Policy, which was adopted by City Council in 2002. As defined by the Institute of Transportation Engineers (ITE): “traffic calming is the combination of mainly physical measures to reduce the negative effects of motor vehicle use, alter driver behaviour, and improve conditions for non-motorized street users” (Lockwood, 1997, p. 22). The Traffic Calming Policy aims to achieve an equitable distribution of resources available for installing traffic measures among areas of the City and outlines the criteria for traffic calming. The provision of traffic calming measures is only considered on local or collector roads, and requires residential and political support, as well as careful consideration of traffic conditions and safety impacts. A ranking process is used to prioritize traffic calming requests, using a point system, which considers speed, traffic volume, number of preventable collisions (a collision that is considered preventable through the use of traffic calming measures) and pedestrian and bicycling factors (pedestrian generators, e.g. park, school, seniors centre, recreation centre). Currently, in the City of Toronto, only streets with traffic calming devices have posted 30km/h speed limits. However, requests are being made to lower the posted speed limit to 30 km/h in the absence of traffic calming measures. The Coroner’s report on pedestrian fatalities in 2010 advocated for the Province of Ontario to lower the default speed limit of Ontario roads from 50 km/h to 40 km/h. A reduction in the default speed limit could be a positive step forward in managing speeds and keeping communities safe, however this change may have a significant impact to the City and requires further research and analysis (Buckley, 2015).

**Metrolinx**

Metrolinx, which is an agency of the Government of Ontario, was created in 2006 to improve the coordination and integration of all modes of transportation in the Greater Toronto and Hamilton Area (GTHA). In 2008, the Metrolinx Board delivered *The Big Move*, as a long-term multi-modal transportation plan to revitalize communities in the GTHA into places where residents can choose transit, walking or cycling to fulfill daily activities, and where a greater share of children walk to school again. *The Big Move* prioritizes the need to develop a transportation system that will accommodate everyone, regardless of age, means or ability. There are two main goals of
The Big Move that target safe walking in the GTHA: (1) active and healthy lifestyles, (2) safe and secure mobility. To promote active and healthy lifestyles, neighbourhoods and cities should be designed in a way that makes walking and cycling attractive and realistic choices for all, including children and seniors. The objective of this goal is to increase the mode share of walking and cycling. Developing urban regions that foster safe and secure mobility, will ideally encourage parents to facilitate the independent mobility of their children, through means of walking, cycling or public transit. The objectives of this goal include: a reduction of casualties and injuries on all transportation modes; improved real and perceived traveller safety especially for women, children, and seniors; and improved safety for cyclists and pedestrians. In order to achieve these goals and objectives, priority actions have been identified, which include (however this not an exhaustive list): (1) to conduct research to promote best practices to integrate walking and cycling in road design, (2) undertake Active Transportation Master Plans, (3) complete walking and cycling networks, (4) policies to require sidewalks on all new regional and local roads, and (5) to establish a pedestrian-focused region where priority is given to transit, pedestrian and bicycle access over all other modes, and to consider connections for pedestrians around transit stations.

1.2.3 How do these policies and institutions consider children and seniors in road safety planning?

Toronto Public Health (2012a) identified elderly pedestrians as the most likely age group to be killed in collisions with motor-vehicles. Furthermore, children and residents from low-income neighbourhoods are also identified as particularly at risk of injury when walking and cycling. Planning interventions directed towards these vulnerable pedestrian groups include assigning greater priority and consideration of pedestrians in street design, including pavement markings to increase visibility at pedestrian road crossings, and pedestrian priority signalization at intersections. This investment is categorized under Health and Safety Projects, which represents 3.3% of the 10-Year (2013 – 2022) Capital Plan Project Budget (Transportation Services, 2013).

Toronto’s Transportation Services Division has recently adopted policy to conduct a “road diet” on Toronto’s streets. This consists of an evaluation of the current design of streets, including the total number of lanes and lane width; in an effort to reduce vehicle speeds, to
increase the safety of non-motorized road users and to minimize crossing distances, which is especially important for seniors and pedestrians with disabilities (Toronto Public Health, 2014). Furthermore, in areas with a high population of seniors, crossing times at intersections must be assessed and adapted to safe allowable crossing times. Roadway modifications that improve the safety and walkability of the senior population could ultimately benefit all road users.

A recent pedestrian safety initiative of the Transportation Services involves participating in the development of the City’s Seniors Strategy, to consider the needs of older adult pedestrians. Through consultation with seniors the following suggestions were made: regular sidewalk inspection, snow clearing assistance programs for seniors and standards for snow clearing, signal improvements at intersections, curb ramps for those using wheelchairs or scooters, and wide, uncluttered sidewalks. Additionally, the report suggested the development of pedestrian-demand mapping for vulnerable pedestrians such as seniors. Demand mapping reflects the different amounts of pedestrian activity that are anticipated in different parts of the city, to allow the City to focus investments in locations that will have the biggest impact on pedestrian convenience and safety, or the selection of and prioritization of a range of pedestrian improvements such as sidewalks, curb ramps and crosswalks.

The Big Move envisions the revitalization of communities where residents not only choose active modes of transportation such as walking and cycling, but also where residents can feel safe doing so (Metrolinx, 2008). A goal of the Big Move is to create healthy and active lifestyles, specifically where walking will be an attractive and realistic choice for children and seniors. The following objectives target children and seniors: improved accessibility for seniors, children and individuals with special needs and at all income levels; and improved real and perceived traveller safety, especially for women, children and seniors. While these goals and objectives are critical for improving walking in the Greater Toronto Area, they are rather vague and there are no measures in terms of which impacts are to be assessed.

1.2.4 Policy Conclusions

Active transportation has many potential benefits which include: improved public health outcomes, environmental benefits and positive impacts on social cohesion and equality issues (Transport Canada, 2011). However, while evaluating current policy initiatives to increase active transportation, we must carefully evaluate pedestrian injury, to ensure that increased walking
does not have detrimental effects on pedestrian safety. In the policy documents considered above, the safety and accessibility of children and senior pedestrians are acknowledged as a priority to transportation planning. However, there appears to be a lack of directed and collaborative (i.e., cutting across institutional silos) interventions or policies that target child or senior injury risk. Rather the recommended interventions or pedestrian programs mainly appear to target a normative “type” of pedestrian. Furthermore, there is currently little understanding of the extent to which pedestrian injury and collision events are geographically concentrated in the city, or how collision patterns may vary by age across the city. Incorporating geographic knowledge about the geographic characteristics of PMVCs and injury is a necessary component of effective environmental intervention programs (Yiannakoulias, Rowe, Svenson, Schopflocher, Kelly, & Voaklander, 2003).

1.3 Thesis Objectives and Structure

This thesis examines child and senior pedestrian safety risk in the City of Toronto, using a spatial analytical approach. Additionally, it appears that differences in walkability in Toronto have contributed to inequalities in the walking environment, however little is known about the interaction between measures of Toronto’s neighbourhood equity and pedestrian injury and collision risk of children and seniors. In this way, this thesis contributes to knowledge gaps and policy limitations outlined in this introductory chapter. The thesis includes a review of the literature on pedestrian injury, with a focus on children and seniors, and two empirical studies. The first study looks at the geography of PVMCs in the City of Toronto, by age and severity. The second study examines the intersection between pedestrian injury and neighbourhood equity/inequality. There are five chapters in this thesis. The introduction has provided background information on pedestrian injury from a global to a local context, the policy context of pedestrian injury and planning in the City of Toronto, and outlined the objectives of this research. This is followed by a review of the literature in Chapter 2. Chapter 3 presents and discusses the results of the spatial analysis of PMVCs and injuries. Chapter 4 introduces the selected Neighbourhood Equity Scores used in this thesis and their correlation with children and senior’s PMVCs patterns found in Chapter 3. Finally, Chapter 5 provides the conclusions of this research and recommendations for City Planning, along with areas of future research.
2 LITERATURE REVIEW

This chapter reviews the literature on pedestrian injury, specifically focusing on studies that have examined age-specific social and environmental determinants of pedestrian injury risk, and how urban development patterns and features in the built environment contribute to the risk of pedestrian motor-vehicle collision and injury. There are three main sections of this review: Section 2.1 provides a review of research into factors associated with child and senior pedestrian injury. Section 2.2 discusses the interaction between the built environment and pedestrian motor-vehicle collision frequency and severity, and commonly identified physical determinants of pedestrian injury and subsequent injury prevention implications. Section 2.4 provides a summary of the main findings of the literature review.

2.1 Factors associated with child and senior pedestrian injury

Walking requires a variety of cognitive skills, including visual examination, gap judgment, reaction time and understanding or at least anticipating the behaviour of other road users. At different ages, variation in these abilities may be critical to understanding and explaining injury risk. Furthermore, pedestrian motor-vehicle collisions are complex, and consist of a range of different mechanisms and circumstances acting together that contribute to injury risk, with variation by age (Dunbar, Holland, & Maylor, 2004). Children and seniors are amongst the most vulnerable pedestrians; planning and policy should accordingly strive to produce a safe environment for children to grow up, and that promotes safe aging. In the remainder of this review, the cognitive and perceived risks associated with being a pedestrian and the unique characteristics and locational patterns associated with pedestrian injury within an urban environment, specific to children and seniors are outlined, reported, and discussed.

2.1.1 Child pedestrian injury

Children often use streets differently than any age group; streets are not only for travel in childhood, they may be used as an outdoor play space. Despite decline in the burden of child
pedestrian injury, some have argued that the decrease is mainly attributable to children’s declining walking rates, which reduces traffic exposure (Roberts, 1993). Children should be encouraged to participate in the use of active modes of transportation such as walking and cycling. However, traffic safety risk often motivates parents to instead drive their children, which in turn contributes to the increased risk of injury to others, induced by traffic (Collins & Kearns, 2005).

Children follow their own unique developmental pattern prior to reaching adulthood, which puts them at risk for different pedestrian behaviours and crash characteristics, such as dashing between parked cars or mid-block darting (Koopmans, Friedman, Kwon, & Sheehan, 2015). However, children cannot be expected to comprehend all aspects of the built environment and react to stimuli in the same way as adults (OECD, 2004). As a result, traffic engineers and urban planners have a responsibility to design road systems that carefully consider children’s mobility needs, travel behaviour and differences in their perceptual and reactive capabilities, in order to maximise their safety and mobility.

Previous geographical and epidemiological research on child pedestrian motor-vehicle collisions (PMVCs) has reported widely on the locational patterns and determinants of injury risk. Most child pedestrian injury occurs close to home (Ha & Thill, 2011; Joly, Foggin, & Pless, 1991; Lightstone, Dhillon, Peek-asa, & Kraus, 2001) particularly on non-arterial, neighbourhood roads (Rothman, Slater, Meaney, & Howard, 2010). Child PMVCs are also more common during mid-block crossings, producing more severe injuries (Koopmans et al., 2015; Rothman, Howard, Camden, & Macarthur, 2012), however as children age, they are more likely to be involved in PMVCs at intersections (Koopmans et al., 2015). Temporal patterns have also been explored; child PMVCs are more common during daylight hours and PMVCs peak during summer months, but road and weather conditions appear to have little statistically significant effect (DiMaggio & Durkin, 2002).

In a Toronto study by Rothman et al. (2010), the frequency of severe PMVC outcomes on neighbourhood roads and major arterial roads was investigated. The authors found that severe injuries involving children were more common on neighbourhood roads, and that the proportion of severe injury on neighbourhood roads decreased with increasing age of children. As a result, neighbourhoods that have high populations of children are expected to experience a greater risk.
of child pedestrian injury occurring on neighbourhood roads. The authors suggested that the lack of adult supervision on small, neighbourhood roads may be contributing to this greater risk, as it is more likely that when children are exposed to traffic on major roads in their travels, such as to or from school, they are more closely supervised by a caregiver or a crossing guard. Although, the authors emphasize that supervision of children in the road environment does not necessarily guarantee safety. Attributing children’s injury to “lack of supervision” is difficult to reliably assess without considering the relationship and proximity of supervisors to the child at the time of the collision (Wills, et al., 1997). For example, level of supervision can vary from supervising a child from inside a window while the child is playing outside, compared to holding a child’s hand while crossing the street. The presence of supervision does not guarantee safety from motor-vehicles; however one-on-one supervision seems to deter impulsive behaviours. While for children in groups, supervised or not, rates of impulsive behaviour were higher in the presence of peers, suggesting that supervision may be less effective when peers are present (Wills, et al., 1997). However, shouldn’t the planning and design goal lean toward the production of places for unsupervised play in childhood? Supervision can’t possibly be the only solution.

Ha and Thill (2011) conducted a density analysis of collisions at intersections and mid-block locations and found that young pedestrians (aged 1-15 years) were more often injured at mid-block locations. The circumstances prior to mid-block collisions probably involve children playing or socializing in their own neighbourhood and perhaps then darting into the street. Adults are more often injured at intersections, which is potentially more often the result of adults walking to a destination further from home. However, the study conducted by Ha and Thill (2011) did not distinguish between different types of intersections, rather the study methodology defined an intersection as the junction of two or more roadways. This is problematic, as it does not provide any information of the efficacy of signalized intersections for producing a safe walking environment or potential risks incurred by different age groups at intersection types.

Traffic speed is another key predictor of pedestrian injury severity. However, children are uniquely vulnerable when struck by automobiles because of their short stature. A vehicle can directly strike a child’s head or vital organs resulting in a more severe injury outcome regardless of speed. Whereas, the windshield and its frame are the main source of head injuries in PMVCs involving adults, which can cause severe brain injuries and lead to lifelong disability or death (Yao, Yang, & Otte, 2008). In a study of age-based PMVCs, it was found that children under 5
years had the lowest average injury incidence but the highest average case-fatality rate when compared to older children (Koopmans et al., 2015). Furthermore, for children 5 – 19 years of age, injury incidence was higher than adults but fatality incidence was lower, suggesting that older children sustain less fatal injuries than adults (Koopmans et al., 2015).

Previous Canadian studies have shown that children in lower income neighbourhoods have higher rates of pedestrian collisions and mortality (Birken, Parkin, To, & Macarthur, 2006; Oliver & Kohen, 2009). This finding has been the focus of much research, yet, little is known about the mechanisms by which social differences between areas and between individuals interact in determining traffic injury risks (Laflamme & Diderichsen, 2000). Social differences in traffic injury risks in children appear to be best supported by the differential exposure of children to traffic, as opposed to children’s propensity to behave in any particular manner (Laflamme & Diderichsen, 2000). Christie (1995) found that children from lower socioeconomic groups are more exposed to traffic compared with higher socioeconomic groups, especially in the context of using streets for recreation, which is often unsupervised by adults. Working simultaneously with greater exposure to vehicle traffic, poorer neighbourhoods tend to have comparatively unsafe walking environments, by virtue of factors such as high traffic volumes and speeds (Gunier, Hertz, Von Behren, & Reynolds, 2003; Haynes, Reading, & Gale, 2003; Morency, Gauvin, Plante, Fournier, & Morency, 2012; Oliver & Kohen, 2009). These studies suggest that poverty does not produce pedestrian injuries; exposure to vehicle traffic does (Haddon, 1973; Morency et al., 2012).

A significant portion of child’s independent mobility likely occurs during school travel. Children are typically injured in the morning and in the mid-afternoon (Calhoun, King, & Rousculp, 1998), which for many children coincides with periods of travel to and from school (Yiannakoulas, Smoyer-Tomic, Hodgson, Spady, Rowe, & Voaklander, 2002). As a result, parents may try to reduce perceived safety risks by minimizing their child’s exposure to traffic often by driving them to school. Again, class plays a role, parents with no car or single-parent families are likely to find it more difficult to transport their children to and from school by car or otherwise (Roberts & Norton, 1994). Children’s increased exposure to vehicle traffic is likely to reflect social, political, and economic differences and constraints among families, rather than differences in parental perceptions of danger to children as pedestrians (Roberts & Norton, 1994).
The higher traffic volumes of many North American lower-income central-city neighbourhoods is in part a result of influxes of non-local vehicles accessing city centres from higher income areas (Yiannakoulias & Scott, 2013). This is a concern for child pedestrian safety, as the risk of collisions was found to be higher in neighbourhoods with higher density of flow-through traffic (Yiannakoulias & Scott, 2013). This higher collision risk may be a result of varying behaviour as a non-local driver, such as a greater focus while driving on reaching their destination than the route, or flow-through drivers may have less attachment to the neighbourhoods they pass through compared to their home (Yiannakoulias & Scott, 2013). Similar evidence of the effect of non-local traffic on child injury risk was found by Desapriya, Sones, Ramanzin, Weinstein, Scime, and Pike (2011), where the largest proportion of drivers (36.4%) involved in children’s pedestrian fatalities in British Columbia, were not local to the neighbourhood (lived more than 10 kilometers away). Yiannakoulias and Scott (2013) suggests that School Boards could consider adjusting current school bus policies, which provide bus services based on distance between home and school, not on the relative safety of different pedestrian commutes. Adjusting school bus policies to consider children’s pedestrian safety may be most appropriate in neighbourhoods with unfavourable walking conditions for children, particularly where there are high proportions of low income families. However, this policy solution ignores the more central problem of potential inequalities in the safety and quality of the road environment, and the need to adopt more pedestrian friendly road designs. Especially since these children would still be facing poor walking conditions while making walking trips for purposes other than school travel. Furthermore, reducing children’s active school travel and exposure to traffic, by either being driven to school by their parents or taking a school bus, may instill in them a desire to drive or be driven as, “it is through such generational processes that automobility has both evolved and become culturally locked in” (Buliung, Larsen, Hess, Faulkner, Fusco, & Rothman, 2015, p. 99).

Many features of the built environment are associated with children walking. Walkability is a term that is widely used, however poorly defined (Southworth, 2005). Southworth (2005) defined walkability as “the extent to which the built environment supports and encourages walking by providing for pedestrian comfort and safety…” (p. 248). Walkability can be measured by various indicators, such as distance to destinations, connectivity of the street network or linkage with other modes of transport. However the measurement of walkability and
interventions to promote walking should simultaneously consider pedestrian injury rates to optimize health outcomes of active transportation (Rothman, Buliung, Macarthur, To, & Howard, 2014). Rothman et al. (2014) conducted a systematic review of built environment correlates of safe walking specific to children, and found that traffic calming, which included roundabouts or speed humps, and proximity to playgrounds or recreation areas/parks resulted in less injury and higher walking rates. Conversely, built environment correlates that were associated with higher walking rates, but higher injury rates included: higher road density, number of crosswalks, increased pedestrian volume and population density, and number of schools, land use mix and proximity to neighbourhood facilities. These features, however, are likely indicative of locations where there is greater child pedestrian activity and as a result greater exposure to traffic. As a result, recommended neighbourhood features that either slow down traffic (e.g. traffic calming), separate children in space from traffic (e.g. playgrounds) or separate children in time (e.g. exclusive traffic-light phasing) were found to increase children’s pedestrian safety (Rothman et al., 2014).

2.1.2 Senior pedestrian injury

The 2010 Ontario Pedestrian Death Review reports that seniors account for a disproportionate share of fatalities, while seniors represent 36% of fatalities they account for 13.2% of the population in 2007 (Office of the Chief Coroner for Ontario, 2012). This is particularly concerning given the anticipated demographic shift of the global population over the age of 60 (National Institute on Aging, 2014). In Canada, seniors are the fastest-growing age group; the proportion of people over age 65 is projected to reach 22% by 2030, compared with 15% in 2013 (Statistics Canada, 2014). In a review of pedestrian fatalities that occurred in Ontario in 2010, 63% of pedestrians killed at intersections were 65 years and older (Office of the Chief Coroner for Ontario, 2012). Furthermore, 10% of seniors involved in pedestrian fatalities were using assistive devices (e.g. canes, walkers, crutches, wheelchairs, etc.). The growing senior population is expected to place new and increasing demands on Canada’s transport systems. Future transport systems and services will play an essential role in supporting independent living and healthy aging (OECD, 2011). Supportive walking environments are particularly important for the elderly population, as the percentage of people with a driver’s license begins to decline after the age of 59, thus reducing alternative transportation options to the private vehicle.
Elderly pedestrians are particularly vulnerable because they are at a greater risk of severe injury and fatality when struck by motor vehicles due to increased frailty and decreased ability to recover (Oxley et al., 1997). Vehicle speed is a critical predictor of the severity of injury sustained after a collision, however pedestrians over the age of 65 experience higher injury rates than younger people at all speeds (Leaf & Preusser, 1999). The proportion of pedestrian injuries that are fatal increases rapidly with age, from less than 2% for those aged 20-50 years, to more than 9% for those aged 80 and over (Dunbar et al., 2004). Therefore, even if the number of PMVCs is similar to younger adults, older pedestrians would be over-represented in fatality records. Furthermore, the psychological consequences of PMVCs for older pedestrians have not yet been studied, however it can be expected to be serious, possibly making the injured more anxious about future travel, as well as potentially leading to conditions such as depression or post-traumatic stress disorder (Dunbar et al., 2004). The psychological consequences, however, following a PMVC, may be characteristic of pedestrians of all ages.

Pedestrian accidents involving seniors have typical features. The most commonly identified location for senior pedestrian accidents is at wide street crossings (Zeeger, Stutts, Huang, Zhou, & Rodgman, 1993) and at intersections rather than at midblock (Zeeger, Seiderman, Lagerwey, Cynecki, Ronkin, & Schneider, 2002). Seniors are more likely to use signalized intersections than young pedestrians when they cross streets (Lightstone et al., 2001; Zeeger et al., 2002). This observation can be explained in part by the preference of older pedestrians (70 years and older), who stated that crossing at signalized intersections makes them feel safer, and that they feel it is dangerous to cross the road where these facilities are missing (Bernhoft & Carstensen, 2008). Furthermore, PMVCs involving older pedestrians are commonly related to the times and places that older people most frequently walk. They are more common during the day/daylight (Bernhoft & Carstensen, 2008; Zeeger et al., 1993); on weekdays and in winter (Zeeger et al., 1993) and close to home (Dunbar et al., 2004) generally on regular trips or at shopping malls or recreational centres (Oxley, Corben, Fildes, & O'Hare, 2004). Additionally, Oxley et al. (1997) found that older pedestrians were more likely than younger pedestrians to be involved in a collision with vehicles at locations or under circumstances categorized as “other”, such as in parking lots, collisions with vehicles turning into driveways, or collisions with vehicles reversing.

Dunbar et al. (2004) identified various effects of aging and potential consequences on
older people’s ability to safely navigate the road environment, which include: vision, hearing, reduced physical mobility, and reaction times. Loss of vision and hearing are important considerations for older pedestrians; their ability to detect and identify moving objects decreases, and hearing problems can make it harder to detect vehicles or other hazards, especially in darkness. A decline in depth perception and perception of vehicle motion with age makes it more difficult to estimate the distance and speed of approaching vehicles. Reduced physical mobility that makes walking outdoors difficult was reported by about 50% of men and 70% of women over the age of 80 in a National Travel Survey conducted in the United Kingdom (2000). In addition to slower walking speeds of older pedestrians, reduced ability to make head and neck movements that could affect looking behaviour are also potentially a problem. Finally, as reaction time slows with age, the ability to divide or switch attention decreases, and the ability to change speed or direction quickly to avoid hazards decreases.

Age-related changes in vision, perception and reaction times result in greater difficulty in making decisions about safe road-crossing behaviour. Bernhoft and Carstensen (2008) compared pedestrian behaviour of older adults (70 years and over) and adults (40 – 49 years of age), and found that the need to be safe, the lack of trust in their abilities and the respect for the law are probably part of the reason that older road users more often engage in safe crossing behaviour at designated facilities. However, the authors found that older adults with poor health cross the road irrespective of crossing facilities to avoid a detour or to divert from their destination. This is particularly problematic as previous research on elderly crossing behaviour has found that when crossing two-way roads seniors exhibited dangerous crossing behaviour as a result of incorrectly estimating the arrival time of approaching vehicles and underestimating their walking speeds (Oxley et al., 1997; Oxley, Ihsen, Fildes, Charlton, & Day, 2005).

Using a simulated road-crossing environment, Oxley et al. (2005) found that pedestrians of all ages appear to make road-crossing decisions based primarily on the distance of the oncoming vehicle, and less so on the estimated time of arrival. For younger pedestrians, while this is an unsafe strategy, they were generally able to make safe crossing decisions, however, older pedestrians appeared to have difficulties choosing a sufficiently large gap to compensate for their decline in walking speed. Practical implications for road safety countermeasures based on these findings, include: vehicle speed restrictions to provide both older pedestrians and drivers additional time to react in the case of a conflict, and the development of behavioural and
training programs aimed at older pedestrians to assist their awareness of declining abilities and adoption of safe road-crossing practices (Oxley et al., 2005). Furthermore, drivers have a responsibility to be aware of pedestrians and safely navigate through an intersection at appropriate speeds, as the time required to detect a pedestrian, decelerate and come to a complete stop is frequently underestimated (Federal Highway Administration, 2013).

In addition to a reduction in vehicle speeds, the literature identifies the following interventions for senior’s safety in the road environment: the addition of more traffic islands, and greater allowance for crossing time. Oxley et al. (1997) found that the addition of a traffic island appeared to increase the safety of seniors while crossing as it reduced vehicle speeds and allowed pedestrians to cross in two stages. Traffic islands simplify the road crossing, to one direction of traffic at a time, while decreasing the cognitive and physiological demands of crossing the road (Oxley et al., 2004). Furthermore, traffic islands were found to improve decision making for selecting traffic gaps to cross safely in seniors (Oxley et al., 1997), however would likely improve the crossing behaviour and safety of all pedestrians.

Previous research has found that the default allocated crossing time at signalized intersections is insufficient for the elderly (Langlois, Keyl, Guralnik, Foley, Marottoli, & Wallace, 1997; Oxley et al., 1997). Specifically, Langlois et al. (1997) evaluated older pedestrian’s ability to cross the street, and found that fewer than 1% of adults aged 72 years and over had a normal walking speed sufficient to cross the street in the typically allocated amount of time at signalized intersections. This is not only because of slower walking speeds, but also the additional time for seniors to perceive and react upon light signals as well as traffic (Oxley et al., 1997). A potential solution to this problem is a Pedestrian User-Friendly Intelligent Crossing System (PUFFIN), which has been adopted in the United Kingdom. A PUFFIN utilizes sensors to detect the presence of pedestrians waiting to cross, and to track pedestrians as they are crossing the road to adjust the length of the pedestrian phase to match walking speeds (Davies, 1999). Acknowledging and understanding age-related changes contributes to a better understanding of the challenges older pedestrians could face in the road environment, and should be considered when implementing countermeasures.

Older drivers have recently been studied in various projects, however older pedestrians have historically been a low priority issue for traffic safety researchers (Bernhoft & Carstensen,
While the literature appears to be rather consistent on the physical determinants of senior pedestrian injury, there appears to be limited studies that have specifically focused on social determinants of senior’s injury rates. Much of the literature on social determinants of pedestrian injury is focused on children (Morency et al., 2012). Furthermore, research into the relationship between socioeconomic status and health inequalities in older populations remains limited in comparison to children and middle-aged people (Grundy & Holt, 2001). This is likely due in part to the difficulties associated with measuring the socioeconomic status of seniors, for reasons such as the difficulty in collecting comprehensive and accurate data on income for seniors (Grundy & Holt, 2001). Additionally, drawing inferences regarding the socioeconomic status of people living in more deprived areas may be misleading for seniors, as area-based indicators such as unemployment rates, are not always accurate indicators for seniors (Grundy & Holt, 2001). However, a study in Wales on unintentional injuries, found higher rates of injuries in more deprived communities for all younger age groups. For older people (75 years and over), only pedestrian injuries and assault related injuries showed a substantial socioeconomic gradient (Lyons, Jones, Deacon, & Heaven, 2003). However, the authors provided no insight into potentially why this observation was found. Grant, Edwards, Sveistrup, Andrew and Egan (2010) examined the role of neighbourhood socioeconomic status (SES) and urban form characteristics of senior’s walking experiences in Ottawa, Canada. The study found in lower SES neighbourhoods a lack of pedestrian infrastructure, greater distances between destinations, high vehicle volume and a higher proportion of PMVCs. These factors combined to produce a poor perception of the walking environment. However, in high SES neighbourhoods more amendable walking conditions were perceived, as a result of safety features such as traffic calmed streets, extensive walking paths and park spaces. Regrettably the author’s study did not measure objective safety risks, and how they vary by neighbourhood SES. These findings appear consistent with research that found that poorer neighbourhoods tend to have comparatively unsafe walking environments (Haynes et al., 2003; Gunier et al., 2003; Morency et al., 2012; Oliver & Kohen, 2009). Little is known about the interaction between the physical environment and social risk factors contributing to injury risk, or how the perception of unsafe walking environments affect the behaviour of seniors, or the decision to walk versus choose other modes of transport.
2.2 Physical Determinants of Pedestrian Injury

This section provides an overview of frequently documented features found to have some statistical association with pedestrian motor-vehicle collisions in an urban environment. These include: the interaction between the built environment and pedestrian motor-vehicle collision frequency and severity, presence of transit features, types of signal-controlled intersections, and the negative effects of personal electronic device usage on both driver and pedestrian behaviour.

In order to assess how the built environment potentially affects crash frequency and crash severity, the evaluation of development patterns and roadway designs is critical. Consideration of these factors is inspired by a commonly used conceptual framework linking the between the built environment and pedestrian collision occurrence and the mediating risk exposure determinants, as supported by several previous studies (Clifton, Burnier, & Akar, 2009; Elvik, 2009; Ewing & Dumbaugh, 2009; Harwood, et al., 2008; Miranda-Moreno, Morency, & El-Geneidy, 2011; Ukkusuri, Miranda-Moreno, Ramadurai, & Isa-Tavarez, 2012; Weir, Weintraub, Humphreys, Seto, & Bhatia, 2009). Under this framework the built environment affects both crash frequency and severity through the mediators of traffic volume and traffic speed. Development patterns have an important impact primarily through the traffic volumes they generate and attract, and secondly through the speeds which they encourage or permit (Ewing & Dumbaugh, 2009). Road network characteristics (such as number of lanes, speed limits, etc.) impact safety primarily through the traffic speeds they allow, and secondarily through the traffic volumes they accommodate. Traffic volume is the primary determinant of crash frequency, while traffic speed is the primary determinant of crash severity (Ewing & Dumbaugh, 2009).

Wide, straight roads with gentle turns are more accommodating of driver errors; however, they allow for very high traffic speeds, which is particularly dangerous when the right-of-way is shared with other road users such as pedestrians and cyclists (Ewing & Dumbaugh, 2009; Garder, 2004). Moreover, the maximum number of lanes crossed by a pedestrian in any crossing maneuver at a signalized intersection is positively associated to both total and fatal pedestrian crashes (Hardwood et al., 2008; Ukkusuri et al., 2012). This is a concern for some seniors

---

2 The following studies support this conceptual framework, however each reports unique instances of the framework and variables included in empirical models.
because slower walking speeds increase exposure to vehicle traffic. However, it is expected that slower traffic speeds induced by congestion in an urban downtown could produce fewer fatal crashes (Ewing & Dumbaugh, 2009).

Two primary determinants of pedestrian injury are vehicle volume and pedestrian volume (Lee & Abdel-Aty, 2005; Hardwood et al., 2008; Miranda-Moreno et al., 2011; Weir et al., 2009). Pedestrian and traffic volume have been identified as the main determinants of PMVC frequency, while road network design and the speeds which roads allow are the main contributing factors associated with injury severity (Miranda-Moreno et al., 2011). As a result, a reduction in traffic volume would be associated with great improvements in pedestrian safety (Miranda-Moreno et al., 2011), and ideally a mode shift in favour of active modes of transportation. Additionally, an increase in the number of pedestrians may contribute to the “safety in numbers” effect (Jacobsen, 2003; Leden, 2002) that is likely associated with an adjustment in motorists’ behaviour in the presence of higher numbers of more obviously present people walking.

The presence of transit features (i.e. subway stations, bus and streetcar stops and transit signal priority technology) at an intersection is a characteristic of the built environment that is frequently investigated with regard to PMVCs. There are two primary reasons for this: first, there is potentially an increase in pedestrian risk-taking behaviour, such as running to catch a bus, or a streetcar in the centre lane of traffic (Cheung, Shalaby, Persaud, & Hadayeghi, 2008) or jaywalking at signalized intersections in response to longer wait times for pedestrians as a result of extra green-time allocated to transit vehicles through transit signal priority (Shahla, Shalaby, Persaud, & Hadayeghi, 2009). Second, proximity to transit features results in an increase in pedestrian activity and consequently a greater likelihood of crashes (Miranda-Moreno et al., 2011; Ukkusuri et al., 2012). For example, Clifton et al. (2009) found that transit access (as measured by number of bus stops within a quarter mile buffer) had a significant association with crashes resulting in injury but not a significant influence on crashes resulting in death.

Intersections create locations where streams of traffic converge, and are thus locations where conflicts between roadway users may occur (Dumbaugh & Li, 2010). The recognition of traffic conflicts at intersections has led planners and engineers to develop various countermeasures through traffic signalization. Examples of these traffic signalizations include,
allocation of right-of-way to specific traffic movements (i.e. split phase timing); to reduce the number of conflicts between materially differentiable road users (i.e. pedestrian scramble operations); or to increase the information available at intersections to pedestrians to behave more safely (i.e. pedestrian countdown signals (PCS)). Pedestrian scramble operations (PSO), also referred to as Barnes Dance, is an exclusive phase added to the regular two-phase signal timing. During the third signal phase, vehicle traffic is halted in all directions allowing exclusive pedestrian crossing laterally and diagonally (see Figure 2.1). Two main benefits of PSO are that during the exclusive pedestrian crossing conflicts are eliminated between pedestrians and turning vehicles, and the distances that pedestrians need to cross are reduced (if they need to cross in both directions). In Calgary, Kattan, Acharjee, and Tay (2009) studied the efficacy of one PSO for its ability to reduce pedestrian-vehicle conflicts and its effect on pedestrian violations, at a high pedestrian volume downtown intersection. They found that PSO implementation resulted in a reduction in the number of pedestrian-vehicle conflicts occurring at an intersection, but an increase in pedestrian violations (i.e. pedestrian noncompliance with the “Don’t Walk” phase). Similarly, Chen, Chen, and Ewing (2014) studied the effect of PSO in New York City using pedestrian injury data, and found that PSO is effective in reducing pedestrian crashes, although PSO implementation is most appropriate in busy downtown locations where there can be rapid accumulation of pedestrians.

![Figure 2.1 Typical PSO signal configuration, where the green lines represent pedestrian movements, figure source: Kattan et al., 2009](image)

The addition of pedestrian countdown signals (PCS), which display the remaining time for pedestrians to safely cross the road before the light changes (as shown in Figure 2.2), has become very popular in North America. PCS implementation has prompted research into their
efficacy as safety countermeasures for both pedestrians and drivers, and the findings have largely been inconsistent. Findings have ranged from evidence of increasing aggressive driver behaviour and subsequently more accidents (Kapoor & Magesan, 2014), to better pedestrian behaviour (Lipovac, Vujanic, Maric, & Nesic, 2013) and a significant decline in the mean number of collisions at intersections. The largest benefits are typically noted at high crash and high volume intersections (Pulugurtha, Desai, & Pulugurtha, 2010). Most recently, Richmond et al. (2013) concluded that the installation of PCS throughout the City of Toronto resulted in an increase in PMVC rates post-PCS installation in some settings.

Figure 2.2 Image of a Toronto pedestrian countdown signal, displaying the duration of time remaining for pedestrians to cross (5 seconds), figure source: Blackwell, 2012

Split phase timing was initially invented and implemented by the New York City Department of Transportation. This signal configuration allows pedestrians with a “walking person” display to cross while the potential turning traffic is held, and then turning vehicles have an exclusive signal, while through movement proceeds as normal (see Figure 2.3 and 2.4). The downside of this signal operation is that it reduces the pedestrian crossing time and the time allowed for turning vehicles, which can be most problematic for slower walking pedestrians and can generate longer vehicle queues at high traffic volume intersections. Therefore, the use of split phase timing is favoured with high pedestrian volumes, wide crossings, and relatively low traffic demand. However, installation of split-phase timing was found to be effective in reducing pedestrian crashes in New York City (Chen et al., 2014).
Chen et al. (2014) suggested that the selection of a specific signalized intersection countermeasure at a location is highly dependent on the characteristics of the location and the traffic problem at hand. Intersections are very complex traffic environments, and there are many contributing factors that may explain why an intersection performs well from a safety perspective or what countermeasure may improve the safety of all road users. Additionally, there is potential that countermeasures could compromise the safety of motorists, for example by increasing the cycle length for pedestrian crossing which is associated with a longer wait time for motorists, which may directly increase speeding and crash risk (Chen et al., 2014).

In general, there is some consensus that giving pedestrians more time to cross is a good
idea, particularly in areas with a high children and/or senior population (Federal Highway Administration, 2013). However the downside is that opposing vehicles and pedestrians must wait longer, potentially producing a longer queue during high traffic periods. Additionally, the longer waiting time may provoke pedestrians waiting to cross to do so against the signal (Chen et al., 2014), since research has found that pedestrians are willing to wait only 30 seconds to cross, and after that will begin to look for opportunities to cross, regardless of the walk indication (Federal Highway Administration, 2013).

Distracted driving over the past five years has become one of the most high profile, talked-about issues in road safety today (Robertson, 2011). Although more traditional sources of driver distraction remain, such as talking to passengers, eating, drinking etc., the current focus of the distracted driving issue is centered on the use of personal electronic devices (Strayer, Drews, & Crouch, 2006). Cell phones in particular allow drivers to take up an attempt to multitask, such as send and receive email, surf the Internet or communicate via text or voice call. However, these multitasking activities may be substantially more distracting than the more traditional driver distractions, because they are cognitively engaging, and has been shown to impair driver performance (Strayer et al., 2006). Strayer et al. (2006) estimated that drivers using a cell phone could fail to see up to 50% of information in the road environment after controlling for driving conditions and time on task. Impairments associated with cell phone use while driving were found to be as common as those associated with drunk driving (Strayer et al., 2006). Consequently, distracted driving penalties in the Province of Ontario, Canada, for example, are now among the toughest in the world (Csanady, 2015). The Canadian government has largely targeted the use of hand-held phone use while driving, however research has shown that hands free cell phone use while driving also negatively impacts driver performance, as the main problem is cognitive distraction, not the physical use of the phone (Caird, Willness, Steel, & Scialfa, 2008). However, the widespread use of personal electronic devices not only negatively affects driver’s behaviour and performance, but also reduces situational awareness and increases unsafe behaviour in pedestrians (Nasar, Hecht, & Wener, 2008), likely putting pedestrians at increased risk for accidents (Nasar et al., 2008; Schwebel, Stravrinos, Byington, Davis, O'Neal, & de Jong, 2012; Stravrinos, Byington, & Schwebel, 2009).
2.3 Summary and Conclusions

The environmental and social risk factors pedestrians face in an urban environment can make walking a complex task, especially when crossing the road. Walking also requires a variety of cognitive skills, including a visual examination, gap judgment, reaction time and understanding or anticipating the behaviour of other road users. Children and seniors have unique physiological and cognitive PMVC risk factors when compared with older youth and adults. A child’s short stature exposes the head or vital organs to vehicles, resulting in a more severe injury outcome regardless of speed. Whereas, a senior’s increased frailty, results in a decreased ability to recover following an accident. Therefore, while speed remains a critical factor of the severity of injury following an accident, emphasis must simultaneously be placed on reducing potential conflicts with vehicles, particularly in areas where there is a high presence of children and seniors. This emphasizes the need to consider neighbourhood factors, such as accessibility to green space and parks, trails and recreational space to play. Elderly and youth in large cities seem to benefit the most from the presence of green spaces in their living environment than any other group (Commission for Architecture and the Built Environment, 2010). Furthermore, since children and seniors are most likely to be struck by a motor vehicle close to home, residential neighbourhood factors potentially play a significant role in understanding and attenuating safety risks to limit injury.

Risk factors have also been shown to vary between children and seniors. Child PMVCs more commonly occur during a mid-block crossing, and are more frequent on non-arterial, neighbourhood roads. This is due in part to differences in experience, knowledge and behaviour in the road environment. For example, when children are with peers, higher rates of impulsive behaviour have been found while seniors are more likely to be involved in PMVCs while crossing at an intersection, particularly at wide street crossings. There are several explanations to account for the heightened crash risk for older pedestrians at intersections. First, older pedestrians often require additional time to walk the same distance as younger pedestrians, so when crossing the street are exposed to vehicle traffic for longer periods of time. Second, their reduced physical mobility and perceptual and cognitive functions, may affect their judgment and ability to safely cross streets. As a result of the divergence in risk factors between children and seniors, age-related differences in the geography of injury are expected given age-related
differences in activity patterns and physical and cognitive abilities, and characteristic correlates of injury that contribute to injury risk by age.

The literature surrounding determinants of pedestrian injury and prevention strategies consistently identifies the underlying importance of a reduction in vehicle speeds and vehicle volume. There is irrefutable evidence that a reduction in vehicle speed allows for more reaction time of both drivers and pedestrians, and in the event of a pedestrian motor-vehicle collision reduces the likelihood of the collision inducing severe injury or fatality. Reducing vehicle speeds will increase the safety of all road users: pedestrians, cyclists, and motor vehicles users alike. One omnibus approach for transforming road or street design is known as complete streets. A Complete Street design incorporates various roadway elements that reduce vehicle speeds to increase safety for all road users, and for all ages and abilities (Laplante & McCann, 2008). There are many road modifications within the complete streets design that are particularly beneficial to the child and senior populations, which include: improved sidewalks, street furniture, higher frequency of safe spaces to cross, and reduced crossing distances and traffic speeds. Adoption of the complete streets design creates more equitable roadways, as a greater a greater proportion of the right-of-way is shared with pedestrians and cyclists, and speeds are controlled to be more considerate of vulnerable road users. However, Laplante and McCann (2008) advise that the complete streets concept “focuses not just on individual roads but on changing the decision-making and design process so that all users are routinely considered during the planning, designing, building and operating of all roadways” (p. 24). Thus, complete streets is more of a fundamental shift away from the auto-centric design of urban and in particular suburban roadways. Whereas, more immediate interventions to reduce child and senior collision risk, include the addition of traffic islands, higher pedestrian priority at signalized intersections, and more supportive pedestrian infrastructure (such as zebra crossings or traffic calming devices) around neighbourhood facilities that generate pedestrian activity such as transit features, recreation facilities, schools etc.

While road modifications to increase pedestrian safety are critical (e.g., see Complete Streets), policy and planning must acknowledge that there is an important intersection between physical and social correlates of injury. This is most evident in the literature for children, as research has identified that children of lower socioeconomic status walk in greater proportions, and poorer neighbourhoods tend to have comparatively unsafe walking environments. However,
there is an apparent gap in the literature around senior’s social determinants of injury, and the relationship between neighbourhood factors and senior’s walking behaviour and injury rates. The intersection between physical and social determinants of injury is where equity considerations should be integrated into pedestrian planning, to identify both geographic areas and populations that are at higher risk of injury. Walking may help reduce inequities, as it is an affordable mode of transport that has many additional benefits, such as health and economic. However, if populations that are most reliant on walking and public transit reside in neighbourhoods that are least walkable, these populations are potentially experiencing greater objective risk of injury from motor vehicles. This suggests the development of research plans that identify geographic locations of high injury risk, and where there are high proportions of vulnerable populations, to develop interventions accordingly. Therefore, this thesis will first use a geographical approach to explore patterns of injury by age and type, to visualize the spatial patterns of injury and the level to which collision and injury events are either distributed randomly or clustered in specific areas. Following the evaluation of these patterns, analysis will be conducted to evaluate how collision and injury rates are related to indicators of neighbourhood equity. This research is intended to contribute to the academic literature as well as shape future policy work on pedestrian planning and the current injury problem in Toronto.
3 EXPLORING SPATIAL PATTERNS OF PEDESTRIAN INJURY BY AGE AND SEVERITY

The previous chapters of this thesis have provided background information on the pedestrian injury problem in the City of Toronto, discussed current policies that are in place to create a safer walking environment particularly for children and seniors in the City of Toronto, and stated the main objectives of this thesis. The literature review chapter examined research into the physical and social determinants of child and senior pedestrian. Research into current policy regarding pedestrian safety in Toronto and the literature review indicate that more work is needed to look at the geography of injury and in particular, how the geography of injury and its correlates vary by age and severity. This chapter presents the first empirical analysis of this thesis with an exploration of the spatial patterns of pedestrian motor vehicle collisions (PMVCs) by age and severity in the City of Toronto. The chapter is organized into six sections. Section 3.1 provides a brief introduction to the chapter and states the research questions and objectives. Section 3.2 describes the empirical data used in this research, followed by an outline of research methods in Section 3.3. In section 3.4 the empirical results are presented. The chapter concludes with a discussion of research findings, policy and planning implications and conclusions in sections 3.5 and 3.6 respectively.

3.1 Introduction

In 2009, Toronto City Council adopted the Walking Strategy as an approach to consider built environment modifications to foster pedestrian well-being and safety. However, there are significant challenges that may limit some Toronto neighbourhoods from becoming more walkable, including a legacy of auto-oriented development within its newer neighbourhoods and at the key points of access into, out of, and across the city (City of Toronto, 2009). Broadly, two distinct patterns of development have shaped the City of Toronto; neighbourhoods characterized by compact and mixed land uses, primarily located in the downtown core; and Toronto’s inner suburbs, which are typically characterized by segregated land-use patterns, composed of low development residential subdivisions and apartment towers located on arterial roads.
Urban development patterns impact safety primarily through the traffic volumes they generate, and secondarily through the speeds permitted and/or encouraged (Ewing & Dumbaugh, 2009). Traffic volume and pedestrian volume are the primary determinants of crash frequency, while traffic speeds are the primary determinants of crash severity (Ewing & Dumbaugh, 2009). It is expected that high-density, high-volume traffic environments, characteristic of Toronto’s downtown, experience a higher frequency of PMVCs in general, however slower traffic speeds induced by congestion in the downtown core could produce fewer fatal crashes (Ewing & Dumbaugh, 2009). Exploratory spatial analysis of PMVCs and injury by severity may reveal unique geographic patterns throughout a city or region, and places suitable for further study and possible intervention. The purpose of this chapter is to explore spatial patterns of PMVCs, with a focus on age-based differences in the geography of PMVCs and injury in Toronto. The chapter is constructed around the following research questions: (i) to what extent do collision and injury events cluster across the City of Toronto, (ii) where are the locations of clusters of high injury events located in Toronto, and (iii) do children and seniors exhibit similar spatial patterns of injury?

3.2 Data

Data on weekday motor vehicle collisions involving pedestrians that occurred in Toronto, between January 1, 2000 and December 31, 2011 were obtained from Motor Vehicle Collision Reports filed by the Toronto Police Services. This study examines weekday pedestrian injury events only due to differences between weekday and weekend activity patterns. Age was categorized according to Statistics Canada’s Life Cycle Groupings (Statistics Canada, 2007): Children (0 - 14 years), Youth (15 - 24 years), Adults (25 - 64 years) and Seniors (65 years and over). PMVCs were examined by age category given expected age-related differences in activity patterns, places of residence, and physical and cognitive abilities. Injury events were categorized as either occurring downtown or in the inner suburbs. For this study, downtown refers to the original City of Toronto (prior to amalgamation in 1998), and the inner suburbs include the suburban regions adjacent to or surrounding the downtown, as shown in Figure 3.1.
Injury severity is recorded by Toronto police officers using five categories (Ministry of Transportation, 2007): no injury; minimal injury: i.e., scrapes and bruises but no hospital visit; minor injury: hospital visit, treated in the emergency room but not admitted; major injury: requiring hospital admission; and fatal: person killed immediately or within 30 days of the collision. In this chapter, injury severity is examined by comparing the spatial pattern of all PMVCs to ‘severe’ injury events (defined as major or fatal injuries). Aggregation of major and fatal injuries was informed by previous research indicating that the study of fatalities and major injuries results in the identification of locations distinguishable from places where minor injuries typically occur (San Francisco Department of Public Health, 2005; Sciortino, Vassar, Radetsky, & Knudson, 2005).

**Figure 3.1** Map of Toronto with the former Municipality borders, and the classification of downtown and inner suburbs
3.3 Methods

There are three main steps to the data analysis presented in this chapter (Figure 3.2). Indirect standardization (Section 3.3.1) is used to account for heterogeneity in the population at risk, and to identify CTs where there are either greater or fewer collisions or injuries observed in the study population than expected. Spatial Empirical Bayes smoothing (section 3.3.2) is conducted to stabilize local standardized ratios and consider spatial dependence, by accounting for collisions or injuries occurring in surrounding CTs. Finally, cluster analysis (Section 3.3.3) is conducted to determine whether there is evidence of global spatial autocorrelation, and the local cluster results are mapped to display the spatial pattern of PMVCs and injury events for children and seniors in Toronto.

Figure 3.2 Outline of main research methods

3.3.1 Indirect Standardization

Indirect age-standardized rates are estimated to account for heterogeneity in the population at risk. Rates were estimated for two age-groups: children and seniors. The selection of these populations as the focus of this analysis was guided from the evaluation of current transportation policy plans in the City of Toronto. It appears that despite prioritizing the safety and accessibility
of children and senior’s mobility, the recommended interventions into the built environment mainly target a homogenous population. However, the literature review on risk factors that contribute to pedestrian injury revealed that children and seniors experience unique risk factors and exhibit distinct locational patterns of injury. Spatial analysis methods can be used to identify locations of potentially high risk, followed by age-based interventions into the built environment to prevent further injuries. Residential population data from the 2006 Canadian Census were used to account for variation in children and senior’s populations across Toronto. Census tracts (CTs) were chosen for this study for two reasons. First, CTs in Toronto (n = 528) are small areas, with generally homogenous environmental and urban design features, with a population between 2,500 and 8,000 persons. Second, and for the particular populations in this study, weekday collisions are likely to occur closer to home in the CT in which a child lives (Joly, Foggin, & Pless, 1991), while for seniors PMVCs tend to occur on regular trips, generally occurring close to home (Oxley et al., 2004).

Collision events were initially geocoded to the City of Toronto centreline street network, using the latitude and longitude coordinates of each PMVC event. In order to conduct the analysis at the CT level, point injury event data were aggregated using a series of spatial joins. The number of PMVCs and severe injury events that occurred in each CT for each age group was determined. Descriptive statistics of the number of PMVCs and severe injury events by age category and the number of PMVCs that occurred in either downtown or the inner suburbs is shown in Table 3.1, and the rates of PMVCs and severe injury per 100,000 population by age group is shown in Table 3.2. Senior’s severe injury rate is almost twice as high as the other population groups. Figures 3.3 – 3.6 present maps of child and senior PMVC and severe injury incidents per CT over the study period.
**Figure 3.3** Map of counts of PMVCs observed for children

**Figure 3.4** Map of counts of severe injuries observed for children
Figure 3.5 Map of counts of PMVCs observed for seniors

Figure 3.6 Map of counts of severe injuries observed for seniors
Indirectly standardized age-specific rates are calculated for the standard population (the City of Toronto) and applied to the study population (each census tract) to determine the expected number of events. Using the age-specific rates, the observed number of events in the study population is divided by the expected number of events to determine the standardized collision/morbidity ratio. Standardized collision ratios (all PMVC events) and standardized morbidity ratios (SMR) (all severe events) indicate a relative excess (values greater than 1) or deficit (values between 0 and 1) in the actual number of collisions or injuries observed in the study population on the basis of the rates observed for the standard population.

**Table 3.1** Descriptive statistics of PMVCs and injury events by age category and spatial region

<table>
<thead>
<tr>
<th>Age Category</th>
<th>City</th>
<th>Downtown</th>
<th>Inner Suburbs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Children</td>
<td>PMVCs</td>
<td>2401</td>
<td>668</td>
</tr>
<tr>
<td></td>
<td>Severe Injuries</td>
<td>191</td>
<td>46</td>
</tr>
<tr>
<td>Youth</td>
<td>PMVCs</td>
<td>3803</td>
<td>1241</td>
</tr>
<tr>
<td></td>
<td>Severe Injuries</td>
<td>260</td>
<td>73</td>
</tr>
<tr>
<td>Adults</td>
<td>PMVCs</td>
<td>11798</td>
<td>4842</td>
</tr>
<tr>
<td></td>
<td>Severe Injuries</td>
<td>1135</td>
<td>431</td>
</tr>
<tr>
<td>Seniors</td>
<td>PMVCs</td>
<td>2709</td>
<td>975</td>
</tr>
<tr>
<td></td>
<td>Severe Injuries</td>
<td>556</td>
<td>181</td>
</tr>
<tr>
<td>Total</td>
<td>PMVCs</td>
<td>20711</td>
<td>7726</td>
</tr>
<tr>
<td></td>
<td>Severe Injuries</td>
<td>2142</td>
<td>731</td>
</tr>
</tbody>
</table>

**Table 3.2** City of Toronto PMVCs and severe injury rates per 100,000 population

<table>
<thead>
<tr>
<th>Age Groups</th>
<th>PMVCs</th>
<th>Severe</th>
<th>Population</th>
<th>PMVC Rate per 100,000</th>
<th>Severe Injury Rate Per 100,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Under 4</td>
<td>418</td>
<td>27</td>
<td>134625</td>
<td>310.49</td>
<td>20.06</td>
</tr>
<tr>
<td>5 - 9</td>
<td>660</td>
<td>57</td>
<td>133335</td>
<td>494.99</td>
<td>42.75</td>
</tr>
<tr>
<td>10 - 14</td>
<td>1334</td>
<td>108</td>
<td>140725</td>
<td>947.95</td>
<td>76.75</td>
</tr>
<tr>
<td><strong>Children</strong></td>
<td><strong>2412</strong></td>
<td><strong>192</strong></td>
<td><strong>408685</strong></td>
<td><strong>590.19</strong></td>
<td><strong>46.98</strong></td>
</tr>
<tr>
<td>15 - 19</td>
<td>1853</td>
<td>115</td>
<td>145690</td>
<td>1271.88</td>
<td>78.93</td>
</tr>
<tr>
<td>20 - 24</td>
<td>2004</td>
<td>148</td>
<td>171715</td>
<td>1167.05</td>
<td>86.19</td>
</tr>
<tr>
<td><strong>Youth</strong></td>
<td><strong>3857</strong></td>
<td><strong>263</strong></td>
<td><strong>317405</strong></td>
<td><strong>1215.17</strong></td>
<td><strong>82.86</strong></td>
</tr>
<tr>
<td>25 - 29</td>
<td>1895</td>
<td>143</td>
<td>189490</td>
<td>1000.05</td>
<td>75.47</td>
</tr>
<tr>
<td>30 - 34</td>
<td>1694</td>
<td>145</td>
<td>194855</td>
<td>869.36</td>
<td>74.41</td>
</tr>
<tr>
<td>35 - 39</td>
<td>1644</td>
<td>143</td>
<td>202305</td>
<td>812.63</td>
<td>70.69</td>
</tr>
<tr>
<td>40 - 44</td>
<td>1695</td>
<td>161</td>
<td>211780</td>
<td>800.36</td>
<td>76.02</td>
</tr>
<tr>
<td>45 - 49</td>
<td>1580</td>
<td>162</td>
<td>193155</td>
<td>818.00</td>
<td>83.87</td>
</tr>
<tr>
<td>50 - 54</td>
<td>1319</td>
<td>148</td>
<td>167625</td>
<td>786.88</td>
<td>88.29</td>
</tr>
</tbody>
</table>
This method was derived using the following equation from Bains (2009):

\[
\text{Standardized collision/morbidity ratio} = \frac{\sum e_i}{\sum P_i E_i} - \frac{\text{Observed number of events}}{\text{Expected number of events}}
\]

where \( e \) is the total number of observed PMVCs or severe injury events in each CT, \( P_i \) is the number of persons in the standard population in age group \( i \), \( E_i \) is the total observed number of events in the standard population for age group \( i \) and \( p_i \) is the population of age group \( i \) in the CT. See Table 3.3 for the age groups used and a sample calculation of one CT. The results of the standardized collision and morbidity ratios are presented in Figures 3.7 - 3.10.

An outlier analysis of the standardized ratios was conducted by identifying standardized collision/morbidity ratios that were three standard deviations above or below the mean ratio estimated for the study area. These values were removed from subsequent analysis. These outlier CTs experienced multiple collision events but are not primarily residential areas, they had low residential population counts resulting in exaggerated estimates of the standardized collision or morbidity ratios. These outlier CTs were mapped separately for contextual information of potential physical features, amenities or health and social services that attract walking trips for children and seniors where the walking environment is not supportive of these population groups and warrants further attention. In other words, the presence of collisions in the absence of a large residential population may be indicative of PMVC concentration at trip destinations.

<table>
<thead>
<tr>
<th>Age Group</th>
<th>Total</th>
<th>Seniors</th>
<th>Total</th>
<th>Adults</th>
<th>Total</th>
<th>Seniors</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>55 - 59</td>
<td>1153</td>
<td>139</td>
<td>147500</td>
<td>781.69</td>
<td>94.24</td>
<td></td>
<td></td>
</tr>
<tr>
<td>60 - 64</td>
<td>930</td>
<td>106</td>
<td>109030</td>
<td>852.98</td>
<td>97.22</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Adults</strong></td>
<td><strong>11910</strong></td>
<td><strong>1147</strong></td>
<td><strong>1415740</strong></td>
<td><strong>841.26</strong></td>
<td><strong>81.02</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>65 - 69</td>
<td>713</td>
<td>103</td>
<td>93470</td>
<td>762.81</td>
<td>110.20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>70 - 74</td>
<td>663</td>
<td>120</td>
<td>84995</td>
<td>780.05</td>
<td>141.18</td>
<td></td>
<td></td>
</tr>
<tr>
<td>75 - 79</td>
<td>615</td>
<td>139</td>
<td>74710</td>
<td>823.18</td>
<td>186.05</td>
<td></td>
<td></td>
</tr>
<tr>
<td>80 - 84</td>
<td>459</td>
<td>110</td>
<td>56385</td>
<td>814.05</td>
<td>195.09</td>
<td></td>
<td></td>
</tr>
<tr>
<td>85 Plus</td>
<td>281</td>
<td>87</td>
<td>42995</td>
<td>653.56</td>
<td>202.35</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Seniors</strong></td>
<td><strong>2731</strong></td>
<td><strong>559</strong></td>
<td><strong>352555</strong></td>
<td><strong>774.63</strong></td>
<td><strong>158.56</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>20910</strong></td>
<td><strong>2161</strong></td>
<td><strong>2494385</strong></td>
<td><strong>838.28</strong></td>
<td><strong>86.63</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Population is based on 2006 Canadian Census*
Figure 3.7 Map of children’s standardized collision ratios

Figure 3.8 Map of children’s standardized morbidity ratios
Figure 3.9 Map of senior’s standardized collision ratios

Figure 3.10 Map of senior’s standardized morbidity ratios
Table 3.3 Indirect Standardization for children and seniors population sub-sets

<table>
<thead>
<tr>
<th>Age Groups</th>
<th>Events</th>
<th>Population</th>
<th>Rate</th>
<th>Study Population (CT 5350004)</th>
<th>Events observed</th>
<th>Events Expected</th>
<th>SR by age</th>
</tr>
</thead>
<tbody>
<tr>
<td>Under 4</td>
<td>418</td>
<td>134625</td>
<td>0.003</td>
<td>Population</td>
<td>325</td>
<td>1</td>
<td>1.009</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.991</td>
</tr>
<tr>
<td>5 - 9</td>
<td>660</td>
<td>133335</td>
<td>0.005</td>
<td></td>
<td>295</td>
<td>4</td>
<td>1.460</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2.739</td>
</tr>
<tr>
<td>10 - 14</td>
<td>1334</td>
<td>140725</td>
<td>0.009</td>
<td></td>
<td>295</td>
<td>1</td>
<td>2.796</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.358</td>
</tr>
<tr>
<td>Total</td>
<td>2412</td>
<td>408685</td>
<td>0.018</td>
<td></td>
<td>915</td>
<td>6</td>
<td>5.266</td>
</tr>
</tbody>
</table>

CT Standardized Collision Ratio 6/5.266 1.139*

*Higher than expected number of collisions

<table>
<thead>
<tr>
<th>Age Groups</th>
<th>Events</th>
<th>Population</th>
<th>Rate</th>
<th>Study Population (CT 5350004)</th>
<th>Events observed</th>
<th>Events Expected</th>
<th>SR by age</th>
</tr>
</thead>
<tbody>
<tr>
<td>65 - 69</td>
<td>713</td>
<td>93470</td>
<td>0.008</td>
<td></td>
<td>195</td>
<td>2</td>
<td>1.487</td>
</tr>
<tr>
<td>70 - 74</td>
<td>663</td>
<td>84995</td>
<td>0.008</td>
<td></td>
<td>145</td>
<td>0</td>
<td>1.131</td>
</tr>
<tr>
<td>75 - 79</td>
<td>615</td>
<td>74710</td>
<td>0.008</td>
<td></td>
<td>120</td>
<td>3</td>
<td>0.988</td>
</tr>
<tr>
<td>80 - 84</td>
<td>459</td>
<td>56385</td>
<td>0.008</td>
<td></td>
<td>105</td>
<td>1</td>
<td>0.855</td>
</tr>
<tr>
<td>85 Plus</td>
<td>281</td>
<td>42995</td>
<td>0.007</td>
<td></td>
<td>80</td>
<td>0</td>
<td>0.523</td>
</tr>
<tr>
<td>Total</td>
<td>2731</td>
<td>352555</td>
<td>0.038</td>
<td></td>
<td>645</td>
<td>6</td>
<td>4.984</td>
</tr>
</tbody>
</table>

CT Standardized Collision Ratio 6/4.984 1.204*

*Higher than expected number of collisions

3.3.2 Spatial Empirical Bayes Rate Smoothing

CTs were chosen as the study area to limit aggregation of PMVC events. CT boundaries are delineated along permanent and easily recognizable physical features, such as the road network. As a result, many collision events occurred at the intersection of multiple CT boundaries. Therefore, spatial (or local) Empirical Bayes (EB) smoothing is used to stabilize local standardized rates by “borrowing” information from surrounding zones (Waller & Gotway, 2004), and to reduce the uncertainty possibly associated with allocating events along CT borders to member CTs. The spatial EB smoother corrects for variance instability, which is associated with rates that have a smaller than expected number of events or a small population. Local EB smoothing maintains variability across the study area, as mean ratio estimates are determined from neighbouring CT values rather than the overall mean ratio estimate, which is used in the standard Empirical Bayes smoothing method (Waller & Gotway, 2004).
There are two main advantages and disadvantages to smoothing rate data. The advantages are: first, smoothing helps stabilize rates based on small numbers at the desired level of spatial disaggregation; and secondly it reduces noise caused by different population sizes used in the calculation of rates. The ultimate gain is the increased ability to discern more clearly systematic patterns in the spatial variation of underlying risk (Kafadar, 1996; Waller & Gotway, 2004). Furthermore, when estimating risk in a single zone, it is important to consider spatial dependence, by accounting for the collective relationship of surrounding zones and the high probability that underlying patterns of PMVCs or injury may cross zone boundaries (Carrington, Ralphs, Mitchell, Heady, & Rahman, 2007). Spatially smoothed estimates are more appropriate for the judgment of geographic variation than estimates that do not consider spatial dependence (Veugelers & Hornibrook, 2002). Carrington et al. (2007) identifies two disadvantages associated with smoothing data. The first is that it introduces correlation from neighbouring values. Second, potential concern arises from differences between the smoothed and raw values, as users can be concerned about using the statistically adjusted numbers.

The spatial EB smoothing was conducted using GeoDa (Version 1.6.7). The first step to smoothing the rates was to create a spatial weights matrix. A spatial weights matrix is used to conceptualize the neighbourhood structure between zones of a study area, to assess the extent of similarity between locations and values, which is the absence or presence of spatial autocorrelation. Broadly, there are two categories of defining neighbours: distance and contiguity. Contiguity-based neighbour definitions consider neighbours as sharing a border or vertices. Distance-based neighbour definitions consider neighbours that are a user-specified threshold distance away. For this thesis, a distance-based neighbour definition was used: k nearest neighbours. For this method, the user specifies the number (k) of neighbours surrounding a zone. It is computed as the distance between a CT’s centroid and the number of nearest neighbouring centroids. This method was chosen, as it is often applied when areas have different sizes to ensure that every location has the same number of neighbours, independent of how large the neighbouring regions are (GeoDa Centre, 2015). Once the spatial weights matrix was created for the study area, the local EB smoother rates were calculated, using the observed number of events and the expected number of events.
3.3.3 Cluster Analysis

Using the smoothed rates, global and local indicators of spatial association were evaluated using a Moran’s I statistic (Anselin, 1995). Global cluster analysis provides a measure of the overall ‘global’ spatial clustering of standardized collision/morbidity ratios across the study area, and local cluster analysis provides a measure of spatial clustering of each sub-region or zone within a study area. The global Moran’s I statistic ranges from -1 (negative autocorrelation) to +1 (positive spatial autocorrelation) and 0 implies absence of spatial autocorrelation (random distribution). The global Moran’s I statistic was used to test the hypothesis that high standardized collision and morbidity ratios are clustered in specific regions across the city, rather than organized randomly. Rejection of the null hypothesis (no spatial autocorrelation) implies a non-random spatial pattern, which for this study implies that the smoothed standardized ratios of PMVCs and injury events are closer to the values of its neighbours than to the average of the study area.

Local indicators of spatial association (LISA) are evaluated to identify where the PMVC and injury events are clustering. The LISA statistic must satisfy the following two requirements (Anselin, 1995): the LISA value for each CT indicates the extent of significant spatial clustering of similar values around that observation. Secondly, the sum of the local cluster index for each CT in the study area is proportional to the global indicator of spatial association for the study area. The local Moran’s I statistic was used in this study. Significance is tested using the Monte Carlo permutation approach (Pouliou & Elliott, 2009), where the p-values are based on 999 permutations under a constant risk hypothesis. The chosen significance threshold for the LISA clusters in this study was a p-value less than 0.05. The cluster analysis was conducted using GeoDa Software (Version 1.6.7).

The local Moran’s I results are mapped to explore the spatial pattern of PMVCs and injury events. The resulting LISA cluster map consists of a spatial typology consisting of five categories for each region (Pouliou & Elliott, 2009): (i) high-high indicates clustering of high values of standardized collision/morbidity ratios (positive spatial autocorrelation); (ii) low-high indicates that low values are adjacent to high values of standardized ratios; (iii) low-low indicates clustering of low values of standardized ratios; (iv) high-low indicates that high values
are adjacent to areas of low values and; (v) not significant indicates that there is no spatial autocorrelation.

3.3.4 Methods Limitations

Pedestrian exposure to injury risk factors is recognized as one of the least understood and most important areas of research for pedestrian planners (Clifton & Kreamer-Fults, 2007; NHTSA, 2000). There is no single best measure of pedestrian exposure and it is important that the chosen exposure measure best matches the needs and purposes of the study (Greene-Roesel, Diogenes, & Ragland, 2010). Pedestrian exposure can be approximated at the micro level, such as pedestrian and vehicle volume at an intersection (Lee & Abdel-Aty, 2005) or surrounding a school zone (Clifton & Kreamer-Fults, 2007), or the macro level, such as pedestrian trips made (Pucher & Renne, 2003). However, in the absence of available exposure data at the macro level that is appropriate for the child and senior populations, a population-based exposure method is used.

The main strengths of using population data to measure pedestrian exposure are that it is widely available and relatively easy to understand, it adjusts for differences in the underlying resident population of an area and provides a crude adjustment for the amount of vehicle traffic on the streets (Greene-Roesel, Diogenes, & Ragland, 2010). However, population data does not provide information about the number of pedestrians in the area at the time of injury, or the amount of time or distance travelled by residents in or from an area. This makes it more difficult to determine whether areas of the city with low risk of injury indicates a highly walkable and safe environment or simply low walking rates. Therefore, in addition to population data it is recommended that a more robust measure of pedestrian demand, such as pedestrian activity (Miranda-Moreno et al., 2011) be considered, however, these data, particularly for non-work travel are not available at the population level for Toronto.

With regard to police reported collision data, there are two main limitations often cited in the literature. The first of which is underreporting of incidence, which has the potential to produce biased estimates as the data available only involves individuals in either collisions reported to the police or who received treatment in a hospital (Roberts, Vingilis, Wilk, & Seeley, 2008). Argan et al. (1990) conducted a study in San Diego County, California, that compared police reports to a hospital monitoring system to identify limitations of police statistic databases
for the investigation of pedestrian and bicycle collisions with motor vehicles. It was found that police under-reported the number of injured pedestrians by at least 20%. Sciortino et al. (2005) reported a similar result, where police collision reports underestimated the number of injured pedestrians by 21% in San Francisco.

The second limitation associated with the use of police report data is that the operational definition of injuries can be imprecise (Roberts, Vingilis, Wilk, & Seeley, 2008). A reporting officer uses best judgment to record injury severity following a PMVC, rather than by a medical professional following an examination. Furthermore, the frequency of delayed injuries, injuries that develop or become more severe after the initial collision, is unknown. Police collision reports remain a comprehensive resource for geographic information, and are an indispensable source of data (Argan, Castillo, & Winn, 1990), however some suggest that surveillance efforts should include greater linkages with hospital data to increase case ascertainment and to produce better assessment of health outcomes (Sciortino, Vassar, Radetsky, & Knudson, 2005).

Aggregation of PMVCs to the census tract level appeared to be the optimal spatial unit of study for the selected populations, mainly since the literature suggests PMVCs involving children and seniors are likely to occur close to home. However, aggregation does present challenges for the interpretation of results, due to a lack of detail of the spatial pattern of PMVCs within each CT and the modifiable areal unit problem. In the process of aggregation of point data, information is lost with regard to the possible level of spatial autocorrelation of PMVCs within each CT. However, the purpose of this study was to examine spatial patterns of PMVCs at the city-wide level while accounting for the residential populations of each CT.

Inconsistent findings among different potential aggregation approaches may be related to the modifiable areal unit problem, which is a measurement issue that includes scale or zoning effects (Openshaw, 1984). In this study, the scale effect may be a result of the varying size of the census tracts, particularly between downtown and the inner suburbs. Census tracts increase in size toward the inner suburbs and potentially increase in road km per census tract. While this may affect the relative collision risk as a function of the length of roadway per CT, however the use of residential population as a crude adjustment of pedestrian activity is likely to control for differences in scale. Finally, zoning effects may arise from the selection of possible zone boundaries, such as the use of traffic analysis zones rather than CTs, when analytical results are
sensitive to how space is partitioned (Mitra & Buliung, 2012). Future research to explore the scale and zoning effects of similar point data may be beneficial to further understanding the effect of aggregation methods.

A final limitation of this study that is recommended for future research of this sort, is to conduct a sensitivity analysis of the global and local Moran’s I results, in order to determine the persistence of global spatial autocorrelation and clustering. While the specification of parameters for the correlation analysis was based on thinking about the process under investigation in the presence of the data describing it, further analysis could explore the sensitivity of the cluster results to decisions made during estimation.

### 3.4 Results

The standardized collision ratios and SMRs indicate spatial variation in injury intensity across the City of Toronto. Results of the global Moran’s I analysis are as follows: children’s standardized collision ratio was 0.489, children’s SMR was 0.603, senior’s standardized collision ratio was 0.335 and senior’s SMR was 0.274 indicating significant \((p<0.001)\) positive spatial autocorrelation. To determine where the clusters are located, the local Moran’s I cluster maps are shown below for children and seniors (Figures 3.11 – 3.14), showing evidence of statistically significant clustering \((p<0.05)\). These figures display distinct patterns of collisions/injuries between the child and elderly populations. The classification scheme of the local Moran’s I results is as follows:

- **High-high** indicates clustering of high values of standardized collision/morbidity ratios (positive spatial autocorrelation)
- **Low-high** indicates that low values are adjacent to high values of standardized ratios
- **Low-low** indicates clustering of low values of standardized ratios
- **High-low** indicates that high values are adjacent to areas of low values and
- **Not significant** indicates that there is no spatial autocorrelation
High standardized collision ratios for children appear to be concentrated towards central downtown Toronto and toward the north-western neighbourhoods of the city (Figure 3.11). This clustering pattern is predominantly located along the east side of the West Toronto Rail Corridor. Examining children’s SMR clusters (Figure 3.12) reveals a greater level of dispersion of high values of injury, primarily distributed within the periphery of the inner suburbs. Additionally, there is a significant clustering pattern of high SMR values in the south-east end of Toronto.

High standardized collision ratios for seniors are concentrated in the downtown core, specifically the central business district (CBD) (Figure 3.13). However, the cluster analysis of high SMR values (Figure 3.14) reveals the addition of clusters outside the CBD, in the periphery of the inner suburbs and similar to children, along the West Toronto Rail Corridor. The outlier analysis of senior’s standardized collision/morbidity ratios resulted in the removal of two adjacent CTs that had very low senior populations, but experienced a high number of collisions.
and injuries. Two of these CTs were located in the CBD, and experienced 39 PMVCs and 8 of which were severe injuries. Toronto’s major hospitals are located within these CTs, which would attract a significant amount of walking trips for seniors. This result provides further evidence of the concentration of CTs located in the CBD with higher than expected numbers of PMVCs and injuries involving the senior population.

**Figure 3.12** Local Moran’s I cluster map results of children’s standardized morbidity ratios
Figure 3.13 Local Moran’s I cluster map results of senior’s standardized collision ratios
3.5 Discussion

High standardized collision ratios for children appear to be concentrated towards central downtown Toronto and toward the north-western neighbourhoods of the city. This clustering pattern is predominantly located along the east side of the West Toronto Rail Corridor. However, there is a greater level of dispersion of high SMR clusters, primarily distributed within the periphery of the inner suburbs. The apparent clustering of high SMRs in the periphery of the downtown core and towards the inner suburbs are likely indicative of concentrations of high child populations, where children are walking in greater proportions than in the downtown.

The cluster analysis of PMVCs involving seniors reveals that high standardized collision ratios are highly concentrated in the downtown core, specifically the central business district (CBD). However, the cluster analysis of high SMR values reveals the addition of clusters outside
the CBD, in the periphery of the inner suburbs and similar to children, along the West Toronto Rail Corridor. The cluster of high SMRs in the CBD, is potentially a result of amenities or health and social services located downtown that attract walking trips for seniors where the walking environment is not supportive of elderly pedestrians. Additionally, the frequency of PMVCs in the CTs where many of Toronto’s major hospitals are located, warrants further study in order to determine what features of the built environment may contribute to a higher than expected number of collisions, and what can be done to prevent injuries. Specifically, as these are not residential locations, the presence of transit facilities likely contributes to greater pedestrian volume, and potentially requires greater safety considerations for pedestrian connections to or from their various destinations.

The cluster of severe injuries involving seniors found in the CBD indicates that while development patterns and road metrics in the downtown core may promote higher rates of walking or a more walkable neighbourhood, the frequency of severe injuries suggests that the walking environment may not be as supportive of elderly pedestrians. This result warrants further investigation into the circumstances immediately prior to the occurrence of PMVCs with seniors, particularly in the CBD. As the literature review of this thesis suggests, seniors could be engaging in dangerous pedestrian behaviours such as mid block crossings, or while crossing at a signalized intersection they could be stranded in the intersection as a result of having insufficient time to cross or struck by drivers making risky turns. Future research of this sort would likely be most successful if conducted using a mixed methods approach where seniors share their walking experiences and identify how mobility for the elderly population can be enhanced in ways that are both safe and practical. This approach will ideally develop a deeper understanding of issues associated with constructing safe walking environments and policy recommendations to improve walkability for the senior population, which is expected to improve walking conditions for all residents.

The results indicate geographical variation in PMVCs and injury by type and age. Interventions should acknowledge population based geographical differences in PMVCs and injury. The global Moran’s I results indicate statistical evidence of clustering of PMVCs and injuries for children and seniors in Toronto. Children’s standardized collision and morbidity ratios exhibit the strongest level of spatial autocorrelation, particularly for the SMR results. The development of prevention programs and health-related policies that account for the spatial and
population heterogeneity of PMVC and injury risk may be an effective approach to attenuate the injury risk. For example, features that either slow down traffic (e.g. traffic calming), separate children in space from traffic (e.g. playgrounds) or separate children in time (e.g. exclusive traffic-light phasing) are found to be associated with increased walking and decreased pedestrian injury risk (Rothman, Buliung, Macarthur, To, & Howard, 2014).

The results indicate differences in PMVCs and injury by age but also across Toronto’s urban to inner suburban divide. Fatal and major injury events involving children and seniors appear to be more concentrated toward and within Toronto’s inner suburbs. This result is consistent with a study of various counties across the United States that found that urban sprawl is a significant risk factor for traffic fatalities, especially for pedestrians (Ewing, Schieber, & Zeeger, 2003). The key characteristics used by Ewing et al. (2003) to measure urban sprawl included: the rigid separation of homes, shops and workplaces, as well as the lack of distinct thriving activity centres such as strong downtowns or suburban town centres. Furthermore, vehicle speed may contribute to the increased risk of fatalities between the inner suburbs and the downtown core. Sprawling areas tend to have wide, long streets that encourage excessive speed, which directly increases the chance of being killed when struck by a vehicle (Ewing et al., 2003). It appears likely that the high prevalence of severe injuries found in Toronto’s inner suburbs are indicative of injury risks associated with urban sprawl, as described by Ewing et al. (2003). Policies in support of the development of mixed land-use planning in Toronto’s inner suburbs may increase the walkability of neighbourhoods, however the differential roadway characteristics are likely contributing to the higher prevalence of severe injuries in the inner suburbs. Policies and roadway modifications that target the high vehicle speeds, volumes, road-widths, and signal timing, in the inner suburbs, particularly surrounding residential areas and various neighbourhood amenities, must be emphasized to the City of Toronto. Countermeasures, such as a reduction in the width of traffic lanes, a reduction in the number of lanes and replacing that space with bicycle lanes or wider sidewalks, or traffic calming measures are recommended. Additionally, such interventions should be prioritized during reconstruction projects of existing roads in the inner suburbs, by ensuring that careful consideration of pedestrians, particularly children and seniors, are made. In other words, Toronto’s “road diet” program, should carefully consider what is happening in the inner suburbs.

The City of Toronto is often referred to as a “city of neighbourhoods”, where each
neighbourhood provides differential access to physical infrastructure and social and community services. Aside from roadway design differences between the downtown and inner suburbs, there are clear patterns of wealth and poverty between Toronto’s inner suburbs and its downtown neighbourhoods (Hulchanski, 2010). Many of Toronto’s downtown neighbourhoods, particularly those that are highly walkable and offer good transit access, have largely been gentrified, and are now home to affluent households (Hulchanski, 2010) Overall, the 2001 median household income in downtown Toronto was $54,696 compared to $49,259 in the inner suburbs (The Neptis Foundation, 2007). However, the prevalence of persons in households below the low income cut off level in 2005 was 30% in the inner suburbs, compared to 14% in central parts of Toronto (Hulchanski, 2010). As a result, one can speculate a potential association between PMVCs and economically disadvantaged neighbourhoods, as found in previous research (Morency et al., 2012). The concentration of severe injury events for children in the inner suburbs is consistent with studies that have found that children from lower income families cross more roads, encounter higher vehicle volume and have a higher risk of injury (Morency et al., 2012). This relationship is potentially indicative of the physical environment and infrastructure within neighbourhoods, suggesting a lack of green space or recreational space to play (Collins & Kearns, 2005; Safe Kids Canada, 2008) that facilitate active, healthy lifestyles and safe spaces for children to play.

Residential communities neighbouring the West Toronto Rail Corridor, where a predominant clustering pattern of PMVCs and injuries was detected, are of lower socioeconomic status, and are potentially vulnerable to health impacts associated with diesel exhaust emissions (City of Toronto Medical Officer of Health, 2009). Particularly for children, there appears to be a relationship between clusters of high PMVCs along the West Toronto Rail Corridor and CTs where there is a high proportion of children living below the low-income cut-off (City of Toronto, n.d.-b). This warrants further attention as it is unclear whether this relationship is attributable to features of the road environment in these neighbourhoods, or if there are other processes contributing to greater PMVC risk. Neighbourhoods adjacent to the West Toronto Rail Corridor and the high prevalence of PMVCs and injuries will be discussed further in the next chapter, where the relationship between neighbourhood equity and pedestrian injury risk is explored.
These findings support previous studies that emphasized the potential for age-based guidance for pedestrian safety interventions into the built environment, for example near schools or playgrounds (Koopmans, Friedman, Kwon, & Sheehan, 2015). However, while this study did reveal places of high risk suitable for further study and possible intervention, the global clustering results indicate that PMVCs and injuries involving seniors are more dispersed across the City of Toronto than children. This result is particularly interesting, since the high level of clustering of children’s PMVCs and severe injuries provides evidence of spatial inequalities of child pedestrian injuries across the City of Toronto. How these inequalities relate to various factors associated with neighbourhood wellbeing will be explored in the following chapter. Efforts to develop injury prevention strategies for seniors and children must be directed accordingly. Age-based environmental modifications are recommended in areas that experienced high collision and injury risk. However, the level of dispersion of PMVCs and injuries involving seniors suggests the importance of adopting planning and policy decisions that are more considerate of the physical and cognitive difficulties seniors face as a pedestrian in an urban environment.

3.6 Conclusions

This chapter has presented the findings of an exploratory geographical analysis of pedestrian motor vehicle collisions of two particularly vulnerable populations, children and seniors. Age related differences in the geography of PMVCs and injury were expected given differences in activity patterns and physical and cognitive abilities by age. The severity of injury was studied across the City of Toronto’s, urban and inner suburban neighborhoods, as a result of differences in development patterns and roadway network attributes. This chapter was guided by the following research questions: (i) to what extent do collision and injury events cluster across the City of Toronto, (ii) where are the locations of clusters of high injury events located in Toronto, and (iii) do children and seniors exhibit similar spatial patterns of injury?

The standardized collision and morbidity ratios reveal positive spatial autocorrelation and indicate geographical variation in injury intensity by age group. PMVCs involving seniors are highly concentrated in the downtown core, specifically in the Central Business District, where
there are many amenities or health and social services that attract walking trips for seniors. The walking environment of these downtown neighbourhoods requires further research on how changes to the built environment could foster increased pedestrian safety and wellbeing for the growing senior population. However, to address the growing senior population, future research would likely be most successful if conducted using a mixed methods approach, to gain a greater perspective on what effective and realistic interventions and policies would enhance the mobility of the elderly population in an urban environment. PMVCs involving children appear to be concentrated towards central downtown Toronto and toward the located predominantly along the east side of the West Toronto Rail Corridor. However, severe injury events involving children and seniors are more concentrated toward and within Toronto’s inner suburbs. This finding suggests that additional attention is required, on the policy and planning front, to inner suburban pedestrian safety. Intervention planning and implementation should acknowledge spatial differences in pedestrian motor-vehicle collisions by age and severity. Findings regarding population-based and geographical diversity in PMVCs and injury severity inform a planning and policy setting in Toronto that presently appears to target a normative “type” of pedestrian. There is currently little evidence of demographic or geographical segmentation in the policy and planning response to the PMVC and injury problem in Toronto.
In the previous chapter of this thesis spatial patterns of child and senior pedestrian motor vehicle collisions were evaluated by level of severity. The standardized collision ratios and SMRs indicated spatial variation in injury intensity across Toronto, and distinct patterns of collisions/injuries between the child and elderly populations emerged. Examining PMVCs by level of severity revealed that major and fatal injury events were found to be more concentrated toward and within Toronto’s inner suburbs. In the final study included in this thesis, the relationship between child and senior PMVCs and injury rates and various indicators of neighbourhood equity is explored. This piece begins to address the following research question: do neighbourhoods facing more inequitable outcomes have higher rates of PMVCs and injuries involving children and seniors?

The chapter is organized as follows, Section 4.1 introduces the concept of equity and its relationship to pedestrian injury, and states the research objectives. Section 4.2 describes in detail the formulation of the Neighbourhood Equity tool and the methods used to evaluate its relationship with child and senior PMVCs and injuries. Section 4.3 provides the results of the analysis, which is followed by a discussion of results in Section 4.4, and conclusions are presented in Section 4.5.

4.1 Introduction

Developed countries have seen a decline in pedestrian injury incidence and mortality, however this decline has not been uniform across the population (Yiannakoulas & Scott, 2013). Socioeconomic disadvantage has a strong association with pedestrian injury risk, and there are social inequalities in the effectiveness of prevention programs (Collins & Kearns, 2005). Neighbourhood factors may have an effect on pedestrian injury risk alongside individuals and families since, “injuries occur in a place as well as to a person” (Haynes et al., 2003, p. 626).
The injury risk factors associated with living in a disadvantaged neighbourhood may include: environmental/physical, such as dangerous streets or lack of supportive walking infrastructure; social or cultural in nature, such as attitudes and practices related to supervision, independence, and appropriate play activities (Haynes et al., 2003); or related to economic opportunities, such as low car ownership. Walking provides an affordable, basic mode of transport, producing places that are walkable may help achieve social and economic equity goals and objectives (Litman, 2014). But what precisely is equity, and particularly, what do we mean by equity when we use the concept in a transport planning context?

One broad definition is that equity refers to the distribution of benefits and costs, and whether that distribution is considered fair and appropriate (Litman, 2015). There are three types of equity on which transportation analyses may be based: horizontal, vertical and intergenerational equity (Litman, 2015). Horizontal equity refers to the equal distribution of resources among individuals considered equal in ability and need. Vertical equity is concerned with the distribution of impacts between individuals that differ by income or social class, and follows a progressive means of planning. Vertical equity also considers how the transportation system is able to meet the needs of travelers with mobility impairments. Furthermore, vertical equity principles work to ensure that disadvantaged groups do not bear excessive external costs (pollution, accident risk, financial costs, etc.). The final type of equity, intergenerational equity, ensures that impacts on future generations are considered in decision-making. Vertical equity goals aim to improve walking conditions and safety to the transport disadvantaged (economically, socially or physically disadvantaged) or to specific geographic areas with high proportions of transport disadvantaged individuals and a lack of supportive infrastructure, whereas horizontal equity goals aim to make walking more attractive and safe across the entire city. This chapter studies the relationship between an attempt to measure equity across neighbourhoods in Toronto and pedestrian injury risk, with a specific focus on some of our most vulnerable road users – children and seniors. Much of the literature on social determinants of pedestrian injury has largely focused on children (Morency et al., 2012), whereas little is known regarding how social determinants may influence senior’s pedestrian injury risk in an urban environment. Addressing this research and policy gap in the literature is particularly important, given the aging population, where in Canada seniors are the fastest-growing age category (Employment and Social Development Canada, 2014).
Toronto is often referred to as a “city of neighbourhoods”, where each neighbourhood provides different access to physical infrastructure and social and community services. In particular, there are currently significant barriers to walkability in some Toronto neighbourhoods, which are largely a result of two distinct development patterns in Toronto. The first is characterized by compact and mixed land uses, primarily located in the downtown core and the second is characteristics of Toronto’s inner suburbs, which are typically characterized by segregated land-use patterns, composed of low development residential subdivisions and apartment towers located on arterial roads. However, in addition to roadway design differences between Toronto’s downtown and inner suburbs, there is a high concentration of low-income households in the inner suburbs. Many of Toronto’s downtown neighbourhoods, particularly those that are highly walkable and offer good transit access have largely been gentrified (Hulchanski, 2010). As a result, it appears that walking does not effectively reduce inequalities in Toronto (Toronto Public Health, 2012a). Furthermore, the links between health, equity, and active transportation have not been well studied (Toronto Public Health, 2012a). As a means to measure and address inequalities among Toronto’s neighbourhoods, a Neighbourhood Equity Index (Social Policy Analysis and Research City of Toronto, 2014) has been developed to monitor wellbeing across a broad range of issues, including various indicators of the physical and built environment.

The *Urban HEART @Toronto* is a tool recently developed and used to measure equity across Toronto’s neighbourhoods (Social Policy Analysis and Research City of Toronto, 2014). The type of equity represented by the *Urban HEART @Toronto* tool is vertical equity, as this tool was developed to empirically measure how neighbourhoods are performing relative to each other, in order to prioritize investment towards neighbourhoods facing the poorest equity outcomes. The tool measures equity across the following five policy domains: Economic Opportunities, Social Development, Healthy Lives, Participation in Decision-making and Physical Environment and Infrastructure. A conceptual and empirical limitation of the tool is that it does not attempt to incorporate pedestrian injury, although surely pedestrian safety risk should be of concern within the discussion of the geography of equity across our cities and regions. In other words, the tool emphasizes and values walkability but does not explicitly examine safety risks, or neighbourhood inequalities with regard to risk and health outcomes related to competition between motorized and non-motorized modes of transportation.
The main objective of this chapter to explore the relationship between children and senior’s pedestrian injury and various indicators of neighbourhood equity that the City of Toronto has chosen from the *Urban HEART @Toronto* research initiative. Additionally, an in-depth case study is described that examines a particularly high-risk area of child pedestrian injury, located adjacent to Toronto’s Western Rail Corridor. In addition to the high pedestrian collision risk, many of these neighbourhoods are of lower socioeconomic status than the Toronto average, and are potentially vulnerable to health impacts associated with diesel exhaust emissions from the operating rail lines (City of Toronto Medical Officer of Health, 2009). If injury risk is related to neighbourhood factors, then there may be additional evidence to support demographic and geographical segmentation in the policy and planning response to children and senior’s pedestrian injury, to limit injury or intervene to attenuate safety risks within at risk neighbourhoods.

4.2 Data and Methods

In 2012, as an initiative to strengthen all neighbourhoods in Toronto and monitor their wellbeing across a broad range of issues, Toronto City Council approved the report titled Toronto Strong Neighbourhoods Strategy 2020. In this report, Neighbourhood Improvement Areas (NIAs) were selected based on which neighbourhoods were facing the most inequitable outcomes. The selection criteria of these NIAs reflects the strategy’s goal of building an equitable set of social, economic and cultural opportunities for all residents, to provide equitable outcomes for all neighbourhoods. These equitable outcomes were evaluated by developing a Neighbourhood Equity Index for each of Toronto’s 140 neighbourhoods, based on data available from the *Urban HEART @Toronto* research initiative. *Urban HEART @Toronto* is funded by the Canadian Institute of Health Research, and involves a partnership in place to bring together various sectors to solve urban health and social inequalities (Urban Heart @TORONTO, 2011). The *Urban HEART @Toronto* is an evidence-based approach to community priority-setting and investment planning, to assess urban equity across the five policy domains: economic opportunities, social and human development, physical environment and infrastructure, governance and general population health. Table 4.1 describes the Neighbourhood Equity Indicators (NEIs), and the data source for each indicator.
A composite score for each neighbourhood was derived from the 15 indicators, according to the following steps (Social Policy Analysis and Research City of Toronto, 2014). Indicator values were first standardized, to values ranging from 0 to 1 (where 1 signifies the most inequitable outcomes). Indicators were then weighted, using principle components analysis with varimax rotation. The NEI was then calculated by multiplying the standardized value and the indicator weight. This weighted score was then reversed and multiplied by 100, meaning that a value of 100 would describe a neighbourhood with the best equity outcome. Using the composite score, a benchmark score was derived that signals that the overall burden of inequities faced by a neighbourhood requires immediate action. The benchmark equity score is 42.89; 31 of 140 neighbourhoods had equity scores falling below this benchmark and were designated as Neighbourhood Improvement Areas (NIAs).

<table>
<thead>
<tr>
<th>Table 4.1 Neighbourhood Equity indicators including descriptions and data source</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Domains</strong></td>
</tr>
<tr>
<td><strong>Economic Opportunities</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>Social Development</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>Participation in Decision-Making</strong></td>
</tr>
<tr>
<td>Physical Surroundings</td>
</tr>
<tr>
<td>-----------------------</td>
</tr>
<tr>
<td>Walkability</td>
</tr>
<tr>
<td>Healthy Food Stores</td>
</tr>
<tr>
<td>Green Space</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Healthy Lives</th>
<th>Premature Mortality</th>
<th>Age-adjusted number of deaths under age of 75 per 100,000 population age under 75</th>
<th>Ontario Mortality Data 2005-2009, Ontario Ministry of Health and Long-Term Care 2005-2011 Canadian Community Health Survey</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mental Health</td>
<td>Percentage of those age 20+ reporting very good or excellent mental health</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Preventable Hospitalizations</td>
<td>Age and sex adjusted number of ambulatory care sensitive condition hospitalizations per 100,000 population</td>
<td>2009-2011 Discharge Abstracts Database, Canadian Institute for Health Information</td>
<td></td>
</tr>
<tr>
<td>Diabetes</td>
<td>Age and sex adjusted number of persons age 20 years and over with diabetes per 100 population</td>
<td>Ontario Diabetes Database, Ontario Registered Persons Database, Ontario Ministry of Health and Long-Term Care</td>
<td></td>
</tr>
</tbody>
</table>

Source: Social Policy Analysis and Research City of Toronto, 2014

To evaluate the relationship between the standardized collision/morbidity ratios and the NEIs, correlations were calculated using non-parametric Spearman rank correlations. First, the smoothed standardized collision/morbidity ratios of each Census Tract (CT) from Chapter 3 were aggregated to the neighbourhood level. The aggregation was conducted by calculating a weighted average of the smoothed ratios, which was based on the proportional area of each CT within the neighbourhood. Spearman correlations between each indicator including the overall
neighbourhood equity score and the neighbourhood standardized collision/morbidity ratios for children and seniors were calculated using $p<0.05$ as the criterion for statistical significance.

4.2.1 Methods Limitations

A limitation associated with the method used to assess the correlation of the *Urban HEART @Toronto* Equity scores and the standardized collision/injury ratios, was the aggregation of the ratios from the census tract level to the neighbourhood level. However, the use of the Toronto neighbourhood boundaries allows for the specific discussion of the health of neighbourhoods as these boundaries are consistently used by the City of Toronto and other stakeholders for reporting on social wellbeing (Social Policy Analysis and Research City of Toronto, 2014). Furthermore, the *Urban HEART @Toronto* Equity was selected to provide a broad look at equity indicators and pedestrian injury rather than limiting the analysis of this study to variables available at the Census Tract level.

It is also possible that underreporting of pedestrian motor-vehicle collisions may be more prevalent in certain population groups. Sciortino et al. (2005) found that police collision reports underestimated the number of injured pedestrians by 21%. Furthermore, pedestrians who were African American were less likely than whites to have filed a police collision report, similarly males were less likely to have filed a collision report than females (Sciortino et al., 2005). The authors speculate that the underreporting rates may be a result of reluctance of some pedestrians to summon the police to file a report when the police were not initially present at the scene of the collision. As a result, by comparing injury rates at the neighbourhood level, neighbourhoods composed of a high ethnic concentration or demographic, such as African-American in the case of Sciortino et al. (2005), could potentially appear safer than they are, as a result of under-reporting of pedestrian injuries.

4.3 Results

In order to visualize the relationship between children and senior’s standardized collision and morbidity ratios, an overlay of the location of clusters of high collisions and injury ratios
(positive spatial autocorrelation) and the overall neighbourhood equity scores is presented in Figures 4.1 and 4.2. A visual examination of these figures appears to reveal a pattern between clusters of PMVCs and injuries in neighbourhoods that have lower scores on the exogenously defined equity scale\(^3\), particularly for children. The empirical correlations of the overall equity scores and each equity indicators is presented in the following section.

Figure 4.1 Overlay of Neighbourhood Equity Index Scores and children’s standardized collision and morbidity ratio high-high clusters

\(^3\) Throughout the discussion of the NEI scores and correlation with PMVCs, the referral of lower or higher scored neighbourhoods on the equity scale is defined and discussed according to the Social Policy Analysis and Research City of Toronto (2014) terminonology of the composite score results
4.3.1 Correlation Results

Spearman correlation results ($r_s$-values) and significance values for child and senior standardized collision/morbidity ratios and the NEI scores are presented in Table 2. The correlation results indicate that neighbourhoods that scored lower for overall equity experienced greater than expected rates of PMVCs involving children ($r_s = -0.173$, $p=0.041$). Children’s severe injuries had a higher inverse relationship with overall equity scores ($r_s = -0.285$, $p=0.001$) than children’s PMVCs, which can be explained by the shift in severe injuries towards the inner suburbs where

**Figure 4.2** Overlay of Neighbourhood Equity Index Scores and senior’s standardized collision and morbidity ratio high-high clusters
overall equity scores are lower. This suggests a stronger relationship between a neighbourhood’s overall equity score and children’s severe injuries. No significant correlation was found between PMVCs and severe injuries involving seniors and overall neighbourhood equity scores. The insignificant statistical result indicates that little citywide association between senior’s collision and injury risk and equity, although the opposite effect could be present at finer scales.

Table 4.2 Correlation results of children’s standardized PMVCs and severe injury ratios and Neighbourhood Equity Indicators

<table>
<thead>
<tr>
<th>Economic Opportunities</th>
<th>r_s</th>
<th>p-value</th>
<th>Economic Opportunities</th>
<th>r_s</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Income</td>
<td>0.208</td>
<td>0.013</td>
<td>Low Income</td>
<td>0.159</td>
<td>0.061</td>
</tr>
<tr>
<td>Unemployment</td>
<td>0.066</td>
<td>0.442</td>
<td>Unemployment</td>
<td>0.111</td>
<td>0.191</td>
</tr>
<tr>
<td>Social Assistance</td>
<td>0.313</td>
<td>0.000</td>
<td>Social Assistance</td>
<td>0.332</td>
<td>0.000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Social Development</th>
<th>r_s</th>
<th>p-value</th>
<th>Social Development</th>
<th>r_s</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>High School Graduation</td>
<td>-0.402</td>
<td>0.000</td>
<td>High School Graduation</td>
<td>0.319</td>
<td>0.000</td>
</tr>
<tr>
<td>Marginalization</td>
<td>0.236</td>
<td>0.005</td>
<td>Marginalization</td>
<td>0.252</td>
<td>0.003</td>
</tr>
<tr>
<td>Post Secondary Graduation</td>
<td>-0.237</td>
<td>0.005</td>
<td>Post Secondary Graduation</td>
<td>0.347</td>
<td>0.000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Participation in Decision Making</th>
<th>r_s</th>
<th>p-value</th>
<th>Participation in Decision Making</th>
<th>r_s</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Municipal Voting Rate</td>
<td>-0.088</td>
<td>0.299</td>
<td>Municipal Voting Rate</td>
<td>0.162</td>
<td>0.055</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Physical Surroundings</th>
<th>r_s</th>
<th>p-value</th>
<th>Physical Surroundings</th>
<th>r_s</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walkability</td>
<td>0.341</td>
<td>0.000</td>
<td>Walkability</td>
<td>0.041</td>
<td>0.634</td>
</tr>
<tr>
<td>Green Space</td>
<td>-0.267</td>
<td>0.001</td>
<td>Green Space</td>
<td>0.135</td>
<td>0.113</td>
</tr>
<tr>
<td>Meeting Places</td>
<td>0.464</td>
<td>0.000</td>
<td>Meeting Places</td>
<td>0.145</td>
<td>0.087</td>
</tr>
<tr>
<td>Healthy Food Stores</td>
<td>0.443</td>
<td>0.000</td>
<td>Healthy Food Stores</td>
<td>0.054</td>
<td>0.526</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Healthy Lives</th>
<th>r_s</th>
<th>p-value</th>
<th>Healthy Lives</th>
<th>r_s</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diabetes</td>
<td>0.148</td>
<td>0.082</td>
<td>Diabetes</td>
<td>0.299</td>
<td>0.000</td>
</tr>
<tr>
<td>Premature Mortality</td>
<td>0.439</td>
<td>0.000</td>
<td>Premature Mortality</td>
<td>0.286</td>
<td>0.001</td>
</tr>
<tr>
<td>Preventable</td>
<td>0.361</td>
<td>0.000</td>
<td>Preventable</td>
<td>0.290</td>
<td>0.001</td>
</tr>
<tr>
<td>Hospitalizations</td>
<td>0.361</td>
<td>0.000</td>
<td>Hospitalizations</td>
<td>0.290</td>
<td>0.001</td>
</tr>
<tr>
<td>Mental Health</td>
<td>0.266</td>
<td>0.001</td>
<td>Mental Health</td>
<td>0.211</td>
<td>0.012</td>
</tr>
<tr>
<td>Overall Equity Score</td>
<td>-0.173</td>
<td>0.041</td>
<td>Overall Equity Score</td>
<td>-0.285</td>
<td>0.001</td>
</tr>
</tbody>
</table>
Economic Opportunities

There were no statistically significant correlations between indicators of economic opportunities and seniors’ standardized collision/morbidity ratios. However, for children, significant positive relationships were found between low income and collision ratios ($r_s = 0.208$, $p=0.013$), and social assistance and collision ($r_s = 0.313$, $p<0.001$) and morbidity ratios ($r_s = 0.332$, $p<0.001$). These results suggest that areas with a larger percentage of persons living below the after-tax low-income measure and percentage of residents who receive social assistance experienced more child PMVCs and injuries.

Table 4.3 Correlation results of senior’s standardized PMVCs and severe injury ratios and Neighbourhood Equity Indicators

<table>
<thead>
<tr>
<th>Senior PMVCs</th>
<th>$r_s$</th>
<th>p-value</th>
<th>Senior Severe Injuries</th>
<th>$r_s$</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Economic Opportunities</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unemployment</td>
<td>-0.190</td>
<td>0.024</td>
<td>Unemployment</td>
<td>-0.098</td>
<td>0.248</td>
</tr>
<tr>
<td>Low Income</td>
<td>0.089</td>
<td>0.298</td>
<td>Low Income</td>
<td>0.048</td>
<td>0.577</td>
</tr>
<tr>
<td>Social Assistance</td>
<td>0.091</td>
<td>0.285</td>
<td>Social Assistance</td>
<td>0.061</td>
<td>0.476</td>
</tr>
<tr>
<td><strong>Social Development</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High School Graduation</td>
<td>-0.160</td>
<td>0.059</td>
<td>High School Graduation</td>
<td>-0.111</td>
<td>0.190</td>
</tr>
<tr>
<td>Marginalization</td>
<td>0.012</td>
<td>0.887</td>
<td>Marginalization</td>
<td>-0.014</td>
<td>0.869</td>
</tr>
<tr>
<td>Post Secondary Graduation</td>
<td>0.081</td>
<td>0.342</td>
<td>Graduation</td>
<td>0.025</td>
<td>0.771</td>
</tr>
<tr>
<td><strong>Participation in Decision Making</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Municipal Voting Rate</td>
<td>0.007</td>
<td>0.931</td>
<td>Municipal Voting Rate</td>
<td>-0.049</td>
<td>0.567</td>
</tr>
<tr>
<td><strong>Physical Surroundings</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Walkability</td>
<td>0.541</td>
<td>0.000</td>
<td>Walkability</td>
<td>0.312</td>
<td>0.000</td>
</tr>
<tr>
<td>Green Space</td>
<td>-0.419</td>
<td>0.000</td>
<td>Green Space</td>
<td>-0.325</td>
<td>0.000</td>
</tr>
<tr>
<td>Meeting Places</td>
<td>0.509</td>
<td>0.000</td>
<td>Meeting Places</td>
<td>0.354</td>
<td>0.000</td>
</tr>
<tr>
<td>Healthy Food</td>
<td>0.593</td>
<td>0.000</td>
<td>Healthy Food</td>
<td>0.423</td>
<td>0.000</td>
</tr>
<tr>
<td><strong>Healthy Lives</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diabetes</td>
<td>-0.141</td>
<td>0.097</td>
<td>Diabetes</td>
<td>-0.093</td>
<td>0.277</td>
</tr>
<tr>
<td>Premature Mortality</td>
<td>0.195</td>
<td>0.021</td>
<td>Premature Mortality</td>
<td>0.124</td>
<td>0.144</td>
</tr>
<tr>
<td>Preventable Hospitalizations</td>
<td>0.109</td>
<td>0.202</td>
<td>Hospitalizations</td>
<td>0.054</td>
<td>0.523</td>
</tr>
<tr>
<td>Mental Health</td>
<td>-0.192</td>
<td>0.023</td>
<td>Mental Health</td>
<td>-0.098</td>
<td>0.247</td>
</tr>
<tr>
<td>Overall Equity Score</td>
<td>0.112</td>
<td>0.188</td>
<td>Overall Equity Score</td>
<td>0.073</td>
<td>0.392</td>
</tr>
</tbody>
</table>
Social Development

All indicators of social development had a significant relationship with children’s PMVCs and injury rates. Significant negative relationships were found between high school graduation and children’s collision ($r_s = -0.402, p<0.001$) and morbidity ($r_s = -0.319, p<0.001$) ratios, and post secondary graduation and children’s collision ($r_s = -0.237, p=0.005$) and morbidity ($r_s = -0.347, p<0.001$) ratios. Therefore neighbourhoods with higher high school graduation rates, and post secondary completion rates experienced fewer pedestrian collisions involving children. Marginalization had a significant positive relationship with children’s collision ($r_s = 0.236, p=0.005$) and morbidity ratios ($r_s = 0.252, p=0.003$). Therefore, neighbourhoods that ranked higher on the Ontario Marginalization Index (a composite measure of the following four dimensions: residential instability, material deprivation, ethnic concentration and dependency) experienced a higher than expected number of children’s PMVCs and injuries. There was no significant correlation with seniors PMVCs or injuries and indicators of social development.

Participation in voting

An inverse relationship between children’s SMRs and the neighbourhood municipal voting rate was observed ($r_s = -0.161, p=0.055$). Although this result was not significant at the 95% confidence level, this finding is interesting from a civil society and citizenship perspective, indicating that neighbourhoods with a higher voting rate experienced fewer severe injury events involving children. Participation in municipal politics through voting is an important way to experience the politics of change, and people who vote are more likely to be active in their community, to talk to their neighbours and to volunteer (Nakhaie, 2006). The inverse relationship between neighbourhood voting rate and pedestrian injury is potentially suggestive of the importance of community involvement, such as through participating in municipal politics, to promote neighbourhood environmental change. There was no significant correlation with senior’s PMVCs or injuries and the municipal voting rate.

Physical Surroundings

Significant positive relationships were found between walkability and children’s standardized collision ratios ($r_s = 0.341, p<0.001$), and senior’s standardized collision and morbidity ratios ($r_s = 0.541, p<0.001$ and $r_s = 0.312, p<0.001$). Significant positive relationships were found between
community places for meeting and children’s standardized collision ratios ($r_s = 0.464, p<0.001$) and senior’s collision and morbidity ratios ($r_s = 0.509, p<0.001$ and $r_s = 0.354, p<0.001$). Access to healthy food stores had a significant positive relationship with children’s standardized collision ratios ($r_s = 0.443, p<0.001$) and senior’s collision and morbidity ratios ($r_s = 0.593, p<0.001$ and $r_s = 0.423, p<0.001$). In contrast, the measure of green space resulted in a significant inverse relationship with children’s collisions ($r_s = -0.267, p=0.001$) and senior’s collision ($r_s = -0.419, p<0.001$) and morbidity ratios ($r_s = -0.325, p<0.001$). These findings suggest that neighbourhoods with greater walkability and with higher accessibility to healthy food stores and community places for meeting experience higher than expected PMVCs and injury events for children and seniors. Neighbourhoods with greater access to green space experience lower rates of PMVCs and injuries.

**Healthy Lives**

Significant positive relationships were found between: diabetes and children’s morbidity ratios ($r_s = 0.299, p<0.001$); premature mortality and children’s collision ($r_s = 0.439, p<0.001$) and morbidity ratios ($r_s = 0.286, p<0.001$); and preventable hospitalizations and children’s collision ($r_s = 0.361, p<0.001$) and morbidity ratios ($r_s = 0.290, p=0.001$). However, significant inverse relationships between mental health and children’s collision ($r_s = -0.266, p=0.001$) and morbidity ratios ($r_s = -0.285, p=0.012$) were observed. For seniors, premature mortality had a significant positive correlation with collisions ($r_s = 0.195, p=0.021$) and mental health had a significant inverse relationship ($r_s = -0.192, p=0.023$). Note that the mental health indicator is measured as the percentage of the population over the age of twenty reporting very good or excellent mental health, which indicates that neighbourhoods with lower reported mental health experience higher rates of children’s and senior’s PMVCs. In the following section a closer study is presented of data located around the Toronto Western Rail Corridor, an area that emerges from this study as a geographical focal point for the injury of children (Figures 4.1, 4.2).

### 4.3.2 Descriptive Analysis of Rail Corridor Case Study

This case study focused on the West Toronto rail corridor because this is an area where the exploratory analysis of this thesis revealed some spatial coincidence between injury and
neighbourhoods that have lower scores on the equity scale. Each of the neighbourhoods selected had significant clusters of high children’s standardized collision ratios. The study was further divided by neighbourhoods located north of St Clair Ave and in the inner suburbs and neighbourhoods located south of St. Clair Ave and located downtown, as shown in Figure 4.3. The categorization of north and south neighbourhoods was conducted primarily for two reasons. First, to compare inner suburban neighbourhoods (north) and older neighbourhoods (south) that can be quite different in terms of development patterns and aspects of transport system design, demand, and supply. The majority of the residential developments in the northern neighbourhoods are comprised of high-rise apartment buildings, where walkability is lower on average in inner suburban neighbourhoods. The second reason for this categorization was as a result of the significant difference between the overall equity scores of the neighbourhoods, all of the northern neighbourhoods had an overall equity score below the neighbourhood equity benchmark score, which is 42.89.

Figure 4.3 Identifier map of neighbourhoods around the West Toronto Rail Corridor
Table 4.4 presents the children’s standardized collision ration, and the overall equity score of the selected neighbourhoods. Table 4.5 presents the average of each indicator value for the north and south neighbourhoods. It is evident that these neighbourhoods are facing inequitable outcomes in all domains except the physical environment and infrastructure domain. There is a sharp decrease in the average walkability score between the south and north neighbourhoods. However, in the south neighbourhoods where walkability is higher, the majority of neighbourhoods have very poor accessibility to green space, which is an important, and potentially protective, environmental feature particularly for the elderly and youth (Commission for Architecture and the Built Environment, 2010).

**Table 4.4** Children’s Standardized Collision Ratios for each neighbourhood and overall equity score of neighbourhoods categorized as north and south (see Figure 4.3)

<table>
<thead>
<tr>
<th>Neighbourhood</th>
<th>PMVCs Standardized Ratio</th>
<th>Overall Equity Score</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>South Neighbourhoods</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>83 Dufferin Grove</td>
<td>2.12</td>
<td>66.79</td>
</tr>
<tr>
<td>84 Little Portugal</td>
<td>1.96</td>
<td>60.04</td>
</tr>
<tr>
<td>86 Roncesvalles</td>
<td>1.26</td>
<td>64.95</td>
</tr>
<tr>
<td>91 Weston-Pellam Park</td>
<td>2.00</td>
<td>40.47*</td>
</tr>
<tr>
<td>93 Dovercourt-Wallace Emerson-Junction</td>
<td>1.58</td>
<td>57.09</td>
</tr>
<tr>
<td><strong>North Neighbourhoods</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>110 Keelesdale-Eglinton West</td>
<td>2.73</td>
<td>40.14*</td>
</tr>
<tr>
<td>111 Rockcliffe-Smythe</td>
<td>1.14</td>
<td>33.86*</td>
</tr>
<tr>
<td>112 Beechborough-Greenbrook</td>
<td>2.54</td>
<td>26.54*</td>
</tr>
<tr>
<td>113 Weston</td>
<td>1.95</td>
<td>35.99*</td>
</tr>
<tr>
<td>115 Mount Dennis</td>
<td>1.58</td>
<td>26.39*</td>
</tr>
</tbody>
</table>

*Below Benchmark

**Table 4.5** Average indicator values for the south and north neighbourhoods adjacent to the West Toronto Rail Corridor

<table>
<thead>
<tr>
<th>Indicator</th>
<th>South</th>
<th>North</th>
<th>Benchmark</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unemployment</td>
<td>7.84%</td>
<td><strong>11.50%</strong></td>
<td>11.30%</td>
</tr>
<tr>
<td>Low Income</td>
<td>21.48%</td>
<td>25.72%</td>
<td>28.10%</td>
</tr>
<tr>
<td>Social Assistance</td>
<td>11.92%</td>
<td><strong>19.76%</strong></td>
<td>15.10%</td>
</tr>
<tr>
<td>High School Graduation</td>
<td>1.6</td>
<td>1</td>
<td>Low</td>
</tr>
<tr>
<td>Marginalization</td>
<td>2.48</td>
<td><strong>2.96</strong></td>
<td>2.9</td>
</tr>
<tr>
<td>Post Secondary Completion</td>
<td><strong>60.7</strong></td>
<td>46.54</td>
<td>62.10%</td>
</tr>
<tr>
<td>Municipal Voting Rate</td>
<td>44.28</td>
<td><strong>40.28</strong></td>
<td>41.40%</td>
</tr>
<tr>
<td>Community places for meeting</td>
<td>28.5</td>
<td>15.62</td>
<td>8.56</td>
</tr>
</tbody>
</table>
Walkability   86.4   64.8   59.48  
Healthy Food Stores  9.766   3.736   1.36  
Green Space  20.8   60.48   23.03  
Premature Mortality  246.28   272.78   271.4  
Mental Health  68.1   70.1   64.30%  
Preventable Hospitalizations  319.82   297.78   292.6  
Diabetes  9.14   11.52   10.2  

4.4 Discussion

The significant positive relationship between children’s standardized collision/morbidity ratios and NEI of economic opportunities (low income and social assistance) is consistent with previous Canadian studies that have shown that children in lower income households have higher rates of pedestrian collisions and mortality (Birken, Parkin, To, & Macarthur, 2006; Oliver & Kohen, 2009). Understanding whether this relationship is attributable to features of the road environment, or if there are other processes contributing to greater PMVC risk has been the objective of extensive research. Social differences in traffic injury risk in children appears to be best explained by the differential exposure of children to various hazards, as opposed to children’s propensity to behave in any particular way (Laflamme & Diderichsen, 2000). Working simultaneously with greater exposure to vehicle traffic, poorer neighbourhoods tend to have comparatively unsafe walking environments, by virtue of factors such as high traffic volumes and speeds (Gunier et al., 2003; Haynes et al., 2003; Morency et al., 2012). Thus providing evidence that poverty does not produce pedestrian injuries; exposure to vehicle traffic does (Haddon, 1973; Morency et al., 2012).

There is a considerable body of literature identifying social inequalities of pedestrian injury, however much less has been researched about the social distribution of traffic safety interventions (Jones, Lyons, John, & Palmer, 2005). Commonly used interventions, or road safety infrastructure modifications, include traffic calming devices, crosswalks, or the employment of crossing guards. Furthermore, strategy and policy documents on the distribution of countermeasures are insufficient to ensure that effective countermeasures are implemented (Christie, Towner, Cairns, & Ward, 2004). In the United Kingdom, traffic calming measures are distributed according to deprivation, and as a result, may reduce inequalities in child pedestrian injury rates (Jones et al, 2005). However, in Montreal, Canada, safety of the environment for
pedestrians and cyclists was found to be associated with greater neighborhood affluence (Gauvin, et al., 2005). A similar evaluation of the provision of road safety infrastructure modifications in Toronto would be beneficial to determine whether there is an equitable distribution of such measures to improve safety.

The correlation results between NEIs and senior’s collision/morbidity ratios indicate that the physical surroundings have the strongest correlation to senior’s pedestrian injury, rather than social and economic factors. Neighbourhood factors are an important consideration for senior’s walking patterns and rates, since this group tends to spend more time in local environments (King, 2001). The literature appears to be consistent with the physical determinants and risk factors seniors face in the built environment. Seniors are overrepresented in collisions at intersections, which is in part attributed to various effects of aging including reduced physical mobility and perceptual and cognitive functions, which affect their judgment and ability to safely cross streets (Oxley et al., 2004). However, there appears to be limited studies that have specifically focused on social determinants of senior’s injury rates. Furthermore, research into the relationship between socioeconomic status and health inequalities in older populations remains limited in comparison to children and middle-aged adults (Grundy & Holt, 2001). This is likely due in part to the difficulties associated with measuring the socioeconomic status of seniors, for reasons such as the difficulty in collecting comprehensive and accurate data on income for seniors (Grundy & Holt, 2001). Additionally, drawing inferences regarding the socioeconomic status of people living in more deprived areas may be misleading for seniors, as area-based indicators such as unemployment rates, are not always accurate indicators for seniors (Grundy & Holt, 2001). As a result, the use of household or individual based measures may reveal a relationship between collision risk and economic indicators not captured in this study. Perception of pedestrian injury risk for seniors may affect their level of engagement in walking trips for transportation or physical activity. Economic differences may exist between seniors who perceive high levels of traffic danger and therefore seek to avoid exposure through the use of personal auto modes of transport, such as a driver or taxi, and those who are otherwise dependent on walking and public transit (walking en route to transit facilities). Therefore, it is suspected that economic indicators remain a factor in senior’s collision risk, however this hypothesis requires further research.
Walkability, community places for meeting and healthy food were associated with higher rates of child and senior injury. Accessibility to healthy food stores or community meeting places (i.e. libraries, recreation facilities, etc.) was measured as the average number of places within a short walking trip (approximately 800 meters or 10 minutes). Previous studies on the influence of the built environment on walking in older adults found that accessibility of utilitarian destinations, similar to the destinations measured in community places for meeting equity indicator, are positively associated with walking trips (Michael, Beard, Choi, Farquhar, & Carlson, 2006). Also, parents may allow children to walk to libraries or recreation facilities independently if they are nearby and easily accomplished by walking. As a result, it is expected that these neighbourhood facilities increase children’s and senior’s exposure to traffic, and generate pedestrian activity, which is positively associated with traffic accidents (Miranda-Moreno et al., 2011). This potentially indicates the need for improved walking infrastructure around these neighbourhood destinations, perhaps beyond school zones, which is a common child-centred traffic safety intervention. Green space was the only indicator that was inversely correlated with injury. Green space is likely most protective for children who would otherwise use streets as an outdoor play space. Given the various factors that place children at risk for injury in the road environment, such as their risk-taking behaviour, or their smaller size and reduced ability to make safe decision in the road environment (WHO, 2008), green space provides children with a safe place to play that is separated from vehicle traffic. However, parental concerns about safety, from traffic while walking to a park and strangers, appear to play a critical role in limiting or determining children’s play opportunities within neighbourhood green space (Valentine & McKendrick, 1997). Similarly, increased accessibility to green space for seniors provides a safe place separated from traffic to enjoy, walk around in, sit and socialize. However, the addition of green space is not a complete solution in itself, rather the surrounding traffic environment should simultaneously be considered in order to ensure that pedestrian safety is not compromised by the increased pedestrian activity around green space.

The results of the analysis of the neighbourhoods adjacent to the Toronto Western Rail Corridor indicate that social determinants have a clear relationship with child PMVCs. There appears to be an important interaction between the social and built environment and the high child injury rates observed. Previous research in Toronto found that low-income neighbourhoods were more likely to be hot-spots of where children are walking to school (Mitra, Buliung, &
Faulkner, 2010). Parental perceptions of traffic risk are important influences of whether or not children walk to school (Beck & Greenspan, 2008; Wen, Fry, Rissel, Dirks, Balafas, & Merom, 2008). However, parents’ ability to reduce risk in this way may be related to various social class gradients. As found previously, parents in lower socioeconomic areas shared the same concerns about their child’s safety as those in more privileged neighbourhoods, however they often lacked the time, skills or resources to promote change (Collins & Kearns, 2005). The higher rates of children’s collision risk observed in neighbourhoods that have lower scores on the equity scale requires careful planning and policy interventions that work to attenuate the high injury risk to these vulnerable populations. However, this approach should encourage and continue to promote walking, which may contribute to the safety in numbers effect (Jacobsen, 2003) associated with high walking rates.

Previous research has shown that factors of the road environment, such as traffic and pedestrian volume, explain a significant portion of inequalities in pedestrian injury (Morency et al., 2012). Therefore, interventions that either slow down traffic or improve the safety and interaction of pedestrians and vehicles at busy roads such as the use of crossing guards or exclusive crossing signals may help reduce inequalities in injury risk. Reducing vehicle traffic volume, particularly on major roads, through adopting a complete streets design, may be particularly effective in these inner suburban neighbourhoods. A complete streets design adopts road modifications that are considerate of non-motorized modes of transport; however most importantly creates people-oriented streets. The concept of complete streets extends beyond retrofitting individual roads, to changing the decision-making and design process of roads, so that all users are considered during the planning, design and building of roadways (Laplante & McCann, 2008). Despite the potential resistance by motorized vehicle drivers, these policies and interventions have the potential to address neighbourhood inequalities with regard to safe walking environments and an inequitable distribution of PMVCs and injuries.

In more marginalized neighbourhoods in Toronto, higher rates of children’s collisions and injuries were observed. Marginalization is the process by which individuals and groups are systematically prevented from fully participating in society (Centre for Research on Inner City Health, 2012). In the equity index of this study, marginalization was measured using the Ontario Marginalization Index (ON-Marg). The ON-Marg is a composite measure of four dimensions of marginalization: residential instability, material deprivation, dependency and ethnic
concentration. Silverman et al. (2013) explored the relationship between the ON-Marg Index and
cyclist and pedestrian collisions that occurred at Toronto intersections, and found that ethnic
congestion and residential instability increased the odds of pedestrian collisions occurring at
intersections. The authors speculated that a relationship between ethnic concentration and
pedestrian collisions was related to the presence of a higher child population in those areas,
decreased familiarity with local road rules or differences in cultural norms. Alternatively, the
authors suggested that populations of high ethnic concentration may have a higher tendency to
live in areas with poorer road safety infrastructure, which may coincide with low income. The
higher collision rates in neighbourhoods with high residential instability, may be explained by
many residents strategically residing close to work, and therefore walking, or using public transit
more frequently to get to work (Silverman et al., 2013). However, in this study, the composite
measure of marginalization was evaluated and age was considered. The higher injury rates
observed in more marginalized neighbourhoods suggests that there is potentially a lack of
neighbourhood involvement in local politics and community issues, particularly as a result of
factors related to residential instability. Neighbourhood associations play a critical role in
creating walkable places and often work in conjunction with a variety of local stakeholders (i.e.
tenant organizations, local businesses and schools) (Grant, Edwards, Sveistrup, Andrew, & Egan,
2010). However, homeowners are more likely to participate in neighbourhood associations than
individuals who rent (Rossi & Weber, 1996). Since higher socio-economic status
neighbourhoods have greater levels of home ownership (Galster, 2003) this creates a
discrepancy, where neighbourhoods with lower proportions of homeowners result in smaller
neighbourhood associations. This can be a disadvantage, as there is evidence that larger groups
are more effective politically (Glickman & Servon, 1998), or in wealthier neighbourhoods,
associations can potentially generate more financial resources.

In the City of Toronto, many environmental modifications or physical interventions in the
built environment require residential and local political support. As a result, residents should be
educated on their role of recommending physical interventions, such as the installation of traffic
calming measures, reduced speed limits or a request for a crossing guard. The approval of these
recommendations is made by the City of Toronto or Toronto Police Services and has
requirements in place of what type of road these changes are appropriate for, however the initial
role of the community in supporting and recommending these interventions is of utmost
importance. Therefore, encouraging the development of neighbourhood associations and linking associations across similar neighbourhoods could give resident’s a powerful voice in local affairs and the ability to bring about neighbourhood change. Furthermore, these neighbourhood associations should be linked to organizations or individuals who they can partner with in educating each other about local pedestrian issues and the policies and procedures necessary to produce neighbourhood level environmental change.

4.5 Conclusions

This chapter investigated whether there was a relationship between observed PMVCs and injury clusters and a recent attempt to measure equity across Toronto’s neighbourhoods. The Urban HEART @Toronto tool was developed to empirically measure how neighbourhoods are performing relative to each other, in order to prioritize investment towards neighbourhoods facing the poorest equity outcomes. While the tool measures walkability across neighbourhoods, it fails to explicitly examine safety risks, or neighbourhood inequalities with regard to pedestrian injury risk.

Variation in the relationship between neighbourhood equity indicators and the standardized collision and morbidity ratios were detected between children seniors. A higher PMVC and injury risk for children was observed in neighbourhoods that scored lower on the equity measure, while no significant relationship with equity outcomes was observed for seniors. It is recommended that pedestrian planning and policy decisions be made to reduce social inequalities of children’s pedestrian injury observed in the City of Toronto, by examining whether there is an equitable distribution of safety countermeasures, and by instating policies that consider and attenuate social inequalities during the planning process. Furthermore, it is recommended that local councillors work with neighbourhood-based groups to educate residents of the processes involved in requesting safety countermeasures and facilitating change to create more walkable neighbourhoods.

This study provides an original contribution to the literature, by studying the relationship between pedestrian injury and various indicators of neighbourhood equity, and focusing on an under-studied population in this field, seniors. Contrary to studies that consistently observe social inequalities in child pedestrian injury risk, the study findings reveal that senior’s injury risk has
little relation to overall equity outcomes. Senior’s PMVC and injury risk is significantly correlated with indicators of the built environment, such as neighbourhood accessibility to meeting places and walkability. This potentially indicates where seniors are walking more frequently and the need for improved walking infrastructure around these neighbourhood destinations, such as provision of higher priority to pedestrians at intersections, speed reductions, and traffic islands to facilitate wide street crossings.
5 CONCLUSION

Inadequate transportation systems can contribute to social exclusion or marginalization; constraints that prevent people from participating actively in society; particularly for people who live in an automobile dependent neighbourhood and are either physically disabled, low income or unable to own or drive a car (Litman, 2003). Approximately 20% of Canadian households do not own a car; another 10% cannot drive because of a disability, while a further 10% simply do not have the income to support car ownership (Litman, 2003). In addition, approximately 40% of the average Canadian’s life is spent either as a senior citizen or as a child without a driver’s license (Transport Canada, 2011). These individuals are transport disadvantaged; investing in pedestrian projects and creating environments that are conducive to walking can potentially improve mobility for these individuals. This will help ensure that services and activities are accessible to all members of society, regardless of income or physical disability. This is an important step in increasing the equity of a community’s transportation system and the mobility of all Canadians. Particularly with a rapidly aging population, investments in active transportation today could help ensure greater mobility for tomorrow’s growing number of seniors (Transport Canada, 2011).

Along with the health benefits and potential equity benefits achievable through walking, are the risks imposed by vehicle traffic on pedestrians in the road environment. Pedestrian motor-vehicle collisions are complex, and age-related differences in activity patterns and physical and cognitive abilities likely result in unique geographic patterns of injury risk across regions and cities. In the introductory chapter of this thesis, a review of policy documents from a variety of government divisions was conducted with a view to surveying pedestrian planning in the City of Toronto. It appears that while the safety and mobility of children and seniors is considered in planning documents, the recommended interventions or programs mainly appear to target a normative “type” of pedestrian. Additionally, there appears to be a lack of geographical segmentation in which to intervene and alleviate pedestrian injury and collision risk in Toronto. This thesis used a spatial analytical approach to investigate pedestrian motor-vehicle collisions involving children and seniors, to determine whether investigating injury events by age and injury type reveals unique patterns to address the policy limitations in the City of Toronto. The main purpose of this thesis was to explore spatial patterns of PMVCs, with a focus on age-based...
differences in the geography of PMVCs and injury in Toronto and to explore the relationship between PMVC and injury rates and various indicators of neighbourhood equity. This concluding chapter summarizes the main findings of this thesis. This is followed by the policy implications drawn from this research and recommendations specific to addressing the PMVC and injury problem in the City of Toronto, as well as the main contributions of this thesis. The final section of this chapter provides a description of potential future research in the field of pedestrian injury.

5.1 Summary and Synthesis of Main Findings

This thesis was based on the following three research objectives: (i) to explore spatial patterns of PMVCs for children and seniors; (ii) to determine whether evaluating PMVCs by level of injury reveals unique geographic patterns throughout the city; and (iii) to determine whether equity outcomes are correlated with children and senior’s PMVCs and injuries. This section presents the main findings from the two analytical chapters, followed by a synthesis of the key results of this thesis.

5.1.1 Exploring Spatial Patterns of Pedestrian Injury by Age and Severity Analysis Results

This study explored spatial patterns of PMVCs, with a focus on age-based differences in the geography of PMVCs and injury in Toronto. Specifically, the following research questions were addressed: (i) to what extent do collision and injury events cluster across the City of Toronto, (ii) where are the locations of clusters of high injury events located in Toronto; and (iii) do children and seniors exhibit similar spatial patterns of injury? The results indicated geographical variation in injury intensity by age group. Statistical evidence of positive spatial autocorrelation was found for children and seniors standardized collision and morbidity ratios, indicating evidence of clustering. However, while a higher level of clustering was observed for severe injuries involving children than PMVCs in general, a lower level of clustering was observed for severe injuries involving seniors than PMVCs in general. This result has important policy implications, as it provides evidence to support targeted intervention approach in these high-risk areas, particularly for children.
High standardized collision ratios for children appear to be concentrated towards central downtown Toronto and toward the north-western neighbourhoods of the city, with a predominant clustering pattern along the east side of the West Toronto Rail Corridor. However, by isolating major and fatal injuries, the clustering pattern revealed that children’s severe injury events are more concentrated toward and within Toronto’s inner suburbs, which is likely indicative of concentrations of high child populations.

PMVCs involving seniors were found to be highly concentrated in the downtown core, specifically in the Central Business District. However, major and fatal injuries involving seniors were more dispersed, and revealed additional high injury risk areas in the periphery of the inner suburbs, and similar to children, along the West Toronto Rail Corridor. For seniors, the cluster of high PMVCs and injuries in the CBD indicates that while development patterns in the downtown may promote higher rates of walking, the high prevalence of injury in the CBD suggests that the walking environment is potentially not as supportive of elderly pedestrians. Furthermore, the level of dispersion of senior’s PMVCs indicates that a citywide approach to senior pedestrian safety may be more effective.

The spatial patterns found in this chapter indicate differences in PMVCs and injury by age but also across Toronto’s urban to inner suburban divide. Fatal and major injury events involving children and seniors appear to be more concentrated toward and within Toronto’s inner suburbs. Vehicle speed may contribute to the increased risk of fatalities between the inner suburbs and the downtown core. This finding provides evidence of the importance of countermeasures, such as a reduction in the width of traffic lanes, temporal separation of pedestrians and vehicles through adjustments to traffic control signals, reducing the number of lanes and replacing that space with bicycle lanes or wider sidewalks, or traffic calming measures. Furthermore, the clustering patterns found in this analysis indicate that there is an inequitable spatial distribution of pedestrian collision and injury risk, particularly for children.

5.1.2 Relationship Between Neighbourhood Equity Indicators and Pedestrian Injury Analysis Results

In order to further investigate the clustering patterns of between children and senior’s standardized collision and injury ratios, the main objective of this study was to explore the relationship between the collision/injury ratios and various indicators of neighbourhood equity.
that City of Toronto has chosen from the Urban HEART @Toronto research initiative. This chapter answered the following research questions: (i) do neighbourhoods that scored lowest on the exogenously defined equity scale bear a greater burden of children and senior’s PMVCs than neighbourhoods that scored higher; and (ii) how do the neighbourhood equity indicators correlate to children and seniors collision/injury ratios? The results suggest that neighbourhoods that have lower scores on the equity measure experienced higher than expected rates of collisions and severe injuries involving children. The correlation was stronger for severe injuries, indicating that proportionally more severe injuries occur in neighbourhoods with lower scores on the equity scale than PMVCs. As a higher risk of severe injuries involving children was observed in the inner suburbs, where neighbourhoods are ranked lower on the equity scores. This finding reinforces the need to address pedestrian safety in Toronto’s inner suburban neighbourhoods, and develop policies that reduce inequalities in child injury risk.

However, there was no significant correlation found between senior’s PMVCs and injuries and overall neighbourhood equity outcomes. The correlation results between NEIs and senior’s collision/morbidity ratios indicated that the physical surroundings have the strongest relationship with pedestrian crashes, rather than social or economic indicators. This finding suggests that the surrounding neighbourhood environment is particularly important for senior’s physical mobility and likely is predictive of older adults walking rates, thus increasing the risk of PMVCs and injury.

The indicators of neighbourhood equity from the physical environment had interesting correlations with children and senior’s pedestrian safety. The presence of green space was negatively correlated with injury, while, walkability, community places for meeting and healthy food access were positively correlated with PMVCs and injuries. Neighbourhood accessibility to green space appears to be particularly important for children and seniors, as it provides a safe place away from vehicle traffic for both groups to enjoy, play, sit and walk around in. However, the accessibility of community places for meeting and healthy food access likely act as destinations that attract walking trips, thus increasing residents’ exposure to traffic. The positive correlation between walkability and pedestrian collisions may also be a result of higher walking rates in neighbourhoods with a higher Walk Score. However excluding a measure of pedestrian injury appears to be a significant limitation of the walkability measure, as surely pedestrian safety risk should be of concern within the geography of equity across cities and regions.
The positive relationship between marginalization and children’s PMVCs and injuries (insignificant correlation with senior’s PMVCs and injury) provides a rather unique finding with important policy implications for child pedestrian injury. Neighbourhood engagement through various organizations likely plays a critical role in creating walkable places, and in the City of Toronto, many environmental modifications or physical interventions in the built environment require residential support. The higher injury rates observed in more marginalized neighbourhoods suggests that there is potentially a lack of neighbourhood involvement in local politics and community issues, particularly in neighbourhoods with high residential instability. As a result, educating residents on their role of recommending physical interventions or traffic safety modifications and encouraging the development of neighbourhood associations could provide residents with a powerful voice in local affairs. These neighbourhood associations should be connected with groups or individuals with an understanding of the policies and processes involved in enabling the production of neighbourhood environmental change.

The case study of neighbourhoods adjacent to the West Toronto Rail Corridor revealed a specific area of Toronto that requires immediate attention. Many of these neighbourhoods are identified as Neighbourhood Improvement Areas, and face many inequitable outcomes. However these neighbourhoods scored relatively well for indicators of the physical environment, as a result they may be overlooked in regards to transportation policy to improve pedestrian safety. These neighbourhoods are experiencing a large burden of pedestrian collision risk, and as a result of a high prevalence of low income and residents on social assistance, many residents may be particularly dependent on walking, specifically children. The pedestrian safety concerns of this neighbourhood must be conveyed to the City of Toronto, and carefully considered within plans to improve neighbourhood equity outcomes.

5.2 Policy Implications

Children and seniors are amongst the most vulnerable pedestrians; therefore planning and policy should accordingly prioritize the development of a safe environment for children to grow up, and one that promotes safe and active aging. To ensure that pedestrians of all ages feel safe and comfortable walking throughout an urban region, a vertical equity approach and measurable objectives to pedestrian planning and policy is recommended. This approach would identify populations (such as seniors or children), and geographic areas (such as those experiencing a
high PMVC risk or those with high proportions of residents dependent on walking) and target recommendations and interventions accordingly. With this approach, recommended prevention programs and health-related policies would be locally context-specific. Furthermore, pedestrian safety plans should simultaneously be incorporated into plans to improve equity outcomes in the identified Neighbourhood Improvement Areas, for example the neighbourhoods surrounding the Toronto West Rail Corridor. However, it appears that this approach may be less effective in attenuating the collision risk for seniors as a result of the low level of clustering and more random dispersion of risk across Toronto; different approaches are indicated for different constituencies. The lack of dispersion is not reflective of a low injury risk; in the City of Toronto the rate of severe injuries (per 100,000 population) involving seniors was approximately double the risk of adults. Thus, a higher priority and consideration for the elderly population is required within the pedestrian planning process to create a more accessible and walkable environment for an aging population. Furthermore, this should be a priority within the larger field of transportation planning, such as pedestrian connections with transit features, or in the design of new residential or commercial developments to provide greater pedestrian accessibility and connections.

The walkability measure of the Urban Heart equity indicator was found to have a positive association with child PMVCs and senior’s pedestrian collisions and injuries. Walkability is measured using a Walk Score, which is primarily focused on accessibility of amenity, in addition to a measure of pedestrian friendliness that considers population density and road metrics, such as intersection density (Walk Score, 2015). While Walk Score is a useful tool for measuring neighbourhood walkability on a large scale, the tool does not incorporate pedestrian injury. A homogenous measure of walkability across all population groups may be missing important safety concerns in the built environment for vulnerable populations, particularly for an aging society. While Walk Score easily captures tangible outcomes such as population density, block length and intersection density, there are intangible outcomes that are very difficult to measure such as safety perceptions and quality of the pedestrian environment. The measure of walkability used to assess neighbourhood equity should incorporate a more comprehensive set of variables including PMVCs and variables that contribute to pedestrian safety risk, such as vehicle volume and speeds. Furthermore, an assessment of walkability that considers injury rates will more effectively identify inequalities in neighbourhood walking environments across cities and
regions. In other words, a change or adaptation of the method used to assess equity is recommended, to include data on injury, with a view to enhancing evidence about neighbourhood inequalities that could be used to inform development of corrective plans, policies, and procedures.

The social inequalities found in children’s pedestrian injury risk is consistent with other Canadian studies (Birken et al., 2006; Oliver & Kohen, 2009), however, to the best of the author’s knowledge, this is a new finding in the Toronto context. Therefore, while this finding substantiates the literature on social determinants of child pedestrian injury, the inequalities in the burden of child PMVCs is novel to the injury problem in the City of Toronto. Additionally, the evidence of spatial clustering of PMVCs and injuries involving children and seniors identifies the potential for targeted interventions and policy development. It is recommended that the City of Toronto’s Transportation Services Division increase the transparency and availability of data related to current and future pedestrian safety infrastructure (such as Traffic Calming areas, Pedestrian Crossovers, Zebra crossing pavement markings, crossing guards etc.). To generate evidence to be used in intervention development, a geographically based medium that is openly available to the public, such as Open Data Toronto⁴, would allow for improved monitoring and evaluation of both the spatial and social distribution of pedestrian infrastructure. This would be informative for two reasons, first to evaluate the distribution of countermeasures, to determine if they are distributed according to deprivation (which can be assessed by the Urban Heart Equity Index), and thus would likely help reduce social inequalities in pedestrian injury. Secondly, to assess whether sufficient pedestrian safety infrastructure is allocated to the road environment in Toronto’s inner suburbs.

In order to address the concentration of severe injury events within Toronto’s inner suburbs, Transportation Services should continue to retrofit those major arterial streets with high vehicle volumes and speeds toward a more complete streets design that considers non-motorized modes of transport. A complete streets design would require the reallocation of the right-of-way (either reducing the number of traffic lanes or narrowing traffic lanes) from vehicles to non-motorized modes, such as bicycle lanes and wider sidewalks. This could produce a safer and

---

⁴ Open Data Toronto currently has a sidewalk inventory of information regarding the presence and location of sidewalks along all transportation corridors in the City of Toronto, in the form of a Shapefile
more equitable road design for all road users, and would potentially encourage greater walking rates, which may create a safety in numbers effect (Jacobsen, 2003). However, complete streets is a more long-term goal and transition in planning and design process of urban roadways, and would mostly involve a redesign of the wide arterial streets characteristic of Toronto’s inner suburbs. Therefore, the City of Toronto should also consider more immediate interventions, such as the addition of traffic islands or zebra crossings at intersections with high pedestrian volume or nearby neighbourhood facilities (such as libraries, recreation facilities etc.), various traffic calming measures to slow down traffic, and modifications to signal control and timing, such as leading pedestrian intervals.

The final recommendation drawn from the findings of this thesis is to emphasize public and neighbourhood engagement in the pedestrian planning process, particularly in neighbourhoods with a higher level of marginalization. Neighbourhood associations would allow residents to voice concerns and offer recommendations to increase pedestrian safety in their neighbourhood. These associations should be linked with groups or individuals with the experience required to facilitate neighbourhood environmental change. Additionally, local councillors should be familiar with the neighbourhood walking environment, and work closely with residents and neighbourhood-based groups to educate residents of the processes involved in requesting safety countermeasures and facilitating change to create more walkable neighbourhoods.

5.3 Areas of Future Research

The rising number of pedestrian injuries involving seniors in the City of Toronto is a growing concern. Child pedestrian injuries have generally received more attention, across various mediums such as academic research and local news. However, given the recent prevalence of senior fatalities in Toronto, in addition to the aging population, senior pedestrian injury is gaining further attention and awareness. The findings of this thesis reveal that the PMVC and injury risk of seniors is rather evenly distributed across neighbourhoods in Toronto, aside from a pattern of PMVCs and severe injuries in the central business district of Toronto. The overall equity score appeared to have little relation to the senior’s PMVC and injury risk at the
neighbourhood level. While the findings of this thesis provide insight into current knowledge and policy gaps regarding senior pedestrian injury, the results also reveal many questions that could be addressed in future research. The following research questions may help guide future research: how does living in a neighbourhood of a high elderly population affect pedestrian safety and injury risk for the elderly? What is the relationship between individual or household social and economic indicators and pedestrian injury involving seniors? How can mobility for the elderly population be enhanced in ways that are both safe and practical? How do perceptions of traffic safety influence walking behaviours or walking rates of seniors? Perceptions of a high traffic danger may act as a critical barrier to engaging in walking for transport or physical activity, which may have a range of negative impacts on the senior population. A mixed-method approach to future research in this field would likely increase the efficacy of developing a comprehensive understanding of walking experiences and challenges facing the elderly population. Investments in active transportation will help provide greater and prolonged mobility for the growing senior population. Therefore, proactive planning research must be conducted to develop strategic and effective policies to foster pedestrian safety in the urban environment, and perhaps most importantly to develop an urban environment that would make walking a realistic option for seniors.

The concentration of fatal and major injury events within Toronto’s inner suburbs, particularly for children, provides additional direction for future research. Qualitative research on perceptions of neighborhood walkability, such as a research project by Hess and Farrow (2010), may identify barriers to walking and traffic safety risks, particularly for vulnerable population groups such as children and seniors. Further qualitative research of this sort, encourages local and context-specific approaches to pedestrian safety. Ideally, improved neighbourhood walking environments will increase residents’ tendency to walk and promote social inclusion and physical activity for residents.
References


