SAFER WALKING ROUTES TO SCHOOL

SAFER WALKING ROUTES TO SCHOOL: APPLIED AND METHODOLOGICAL GEOGRAPHIES OF CHILD PEDESTRIAN INJURY

By

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A Thesis Submitted to the School of Graduate Studies in Partial Fulfilment of the Requirements for the Degree Doctor of Philosophy

McMaster University

McMaster University DOCTOR OF PHILOSOPHY (2015) Hamilton, Ontario (School of Geography and Earth Science)

TITLE: Safer Walking Routes to School: Applied and Methodological Geographies of Child Pedestrian Injury.

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PAGES: xiv, 152

Abstract

The general theme of this dissertation is understanding and enabling safe walking routes to school for children. We restrict our focus to safety issues related to the motorized-transportation environment, thereby defining safety as a function of factors that determine whether or not a child will be struck by a motor-vehicle on their journey to or from school. Our analysis is unique because it is at a small geographical scale but is representative of an entire urban environment. Working at a small geographic scale allows us to evaluate the variability in safe routes for children within our study area and apply our findings to develop a decision support tool that could be used to plan individualized routes for children in other similar urban environments. Our study area for this dissertation is Hamilton, Ontario, Canada. The findings in this dissertation contribute ideas about how features of the local road environment may and may not influence risk of collisions between child pedestrians and motor-vehicles. It also offers methodological insight for future research on pedestrian safety at small geographic scales. This dissertation demonstrates the potential reduction in the risk of child pedestrian injuries by planning safer routes to school and also introduces methods that can be used to plan safer routes for children. Our results are a reminder of the importance of understanding the interaction between environment and behaviour in research on traffic safety and offer some caution to the notion of a universal 'safe route' to school. Whether or not a particular route to school is safe will very likely be dependent both on the environment and the child's behaviour in that environment.

Acknowledgement

First and foremost, I would like to thank my Ph.D. thesis supervisor, Dr. Niko Yiannakoulias, for his unwavering guidance and support over the years. It goes without saying that this thesis would not have been possible without him. It has truly been a privilege to learn from him. Many thanks also go to my committee members – Dr. Troy Glover, Dr. Antonio Paez, and Dr. Darren Scott – and my external examiner – Dr. William Pickett – for all the time, effort, and valuable insight that they contributed. I would like to express my gratitude to the City of Hamilton, and Hamilton-Wentworth District School Board for providing the data necessary to carry out this research.

I would also like to extend my thanks to fellow grad students Matt Leyenaar, Aman Gill, Stacy Lockerbie, and Ewa Kielasinska. You will never know how essential your support has been to my successful completion of this thesis. I could always count on all of you to truly understand what I was going through and to provide the perfect advice and encouragement just when I needed it most.

Finally, I would like to thank Lisa, my parents Heather and Ian, my sister Shauna and her husband Pete, my brother Chris, his wife Trisha and their children Olivia and Landon. You all have helped shape the person I am today. Your unconditional love and support have proven to be immeasurable. Mom and Dad, thank you for not only providing me with the opportunity to pursue higher education, but also for being amazing role models. Lisa, thank you for being on my team through this lengthy process and keeping me laughing even during the most stressful of times.

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List of Abbreviations and Symbols

Active Safe Routes to School (ASRTS)

Child Activity Using Shortest Distance (CASD)

Child Activity Using Preferred Route (CAPR)

Child Pedestrian Activity Based on Child Population (CACP)

Geographic Information System (GIS)

Moving Ahead for Progress in the 21st Century (MAP-21)

Relative Risk (RR)

Route to School Decision Tool (RSDT)

Safe Routes to School (SRTS)

Socio-Economic Status (SES)

Declaration of Academic Achievement

I am the primary author of the chapters included in this “sandwich” dissertation. Chapter two has been published and the pages have been renumbered for continuity within this dissertation. This research was developed in consultation with my supervisor Dr. Nikolaos Yiannakoulias and my thesis committee. I collected and analyzed the data, and authored all chapters.

The roles of co-authors for each chapter, as well as the year the research was conducted, are documented below.

Chapter 1:
Scott Allan Bennet – authored manuscript, and revised manuscript
Dr. Nikolaos Yiannakoulias – revised manuscript

Chapter 2:
Scott Allan Bennet – design and conceptualization, data collection and analysis, authored manuscript, and revised manuscript
Dr. Nikolaos Yiannakoulias – design and conceptualization, and revised manuscript
Research conducted 2012-2014

Chapter 3:
Scott Allan Bennet – design and conceptualization, data collection and analysis, authored manuscript, revised manuscript
Dr. Nikolaos Yiannakoulias – design and conceptualization, revised manuscript
Research conducted 2012-2014

Chapter 4:

Scott Allan Bennet – design and conceptualization, data collection and analysis, authored manuscript, and revised manuscript

Dr. Nikolaos Yiannakoulias – design and conceptualization, and revised manuscript

Research conducted 2012-2014

Chapter 5:

Scott Allan Bennet – design and conceptualization, data collection and analysis, wrote python script, authored manuscript, and revised manuscript

Dr. Nikolaos Yiannakoulias – design and conceptualization, and revised manuscript

Research conducted 2012-2014

Chapter 6:

Scott Allan Bennet - authored manuscript, revised manuscript

Dr. Nikolaos Yiannakoulias – revised manuscript

Chapter 1: Introduction

In many regions of the world, children are less active than they have been in the past (Davison and Lawson, 2006). Encouraging individuals to be active at a young age is important because studies show that lifelong patterns of physical activity are established during childhood, and children who are regularly driven to and from school are less likely to appreciate the benefits of being physically active into adulthood (Tudor-Locke *et al*., 2001; Sleap and Warburton, 1993). Using active transportation modalities — such as walking — for travel to and from school offers children an opportunity to increase their physical activity as part of their daily lives (Mitra *et al.* 2010; Tudor-Locke *et al.*, 2001), as school travel constitutes approximately 26 percent of all trips made by children (McMillan, 2005). Children who use active transportation for travel to and from school are found to accumulate approximately twenty additional minutes of moderate to physical activity per day on weekdays and are more likely to meet the recommended levels of daily physical activity compared to children who travel to school by car or bus (Davison *et al*., 2008; Heelan *et al*., 2005; Alexander *et al*., 2005; Cooper *et al*., 2005; Sirard *et al*., 2005). However the number of children who actively travel to school has declined considerably since the 1960's (Macdonald, 2011).

An important reason for this decline has been parental fear of their child being injured due to features of the built environment, such as traffic volume, and road characteristics (Ridgewell *et al.*, 2009; Ahlport *et al.*, 2008; Kerr *et al.*, 2006; Gielen *et al.*, 2004). To address parental concerns about traffic safety, some municipalities and school boards have begun implementing Safe Routes to School (SRTS) programs (Dumbaugh and Frank, 2007). Goals of SRTS programs include: the planning of safer walking routes for children to use to and from school and to promote active transportation as a way to incorporate physical activity into children's lives. For safety to be a meaningful part of SRTS programs, SRTS must provide a measurable reduction in the real risk of injury to children on their journeys to school that helps to offset the perceived and real barriers to increased active travel.

The general theme of this dissertation is understanding and enabling safe walking routes to school for children. We restrict our focus to safety issues related to the motorized-transportation environment, thereby defining safety as a function of factors that determine whether or not a child will be struck by a motor-vehicle on their journey to or from school. Our primary contribution is the development of a statistical model that determines the local features of the road environment that influence the probability of a child pedestrian injury, and use the results of this model to understand and plan safer walking routes to school for children. We use Hamilton, Ontario, Canada as our study area. Our analysis is unique because it is at a small geographical scale but is representative of an entire urban environment. The scale of analysis is important; working at a small geographic scale allows us to evaluate the variability in safe routes for children within our study area and apply our findings to develop a decision support tool that could be used to plan individualized routes for children in other similar urban environments.

Each of the chapters in this dissertation contributes to general knowledge about planning safer routes to school for children. We finish this introduction with a brief description of the subsequent chapters. In chapter two we develop a statistical model that predicts the frequency of motor-vehicle collisions involving child pedestrians walking to and from school at a small geographic scale. This small scale analysis allows us to contrast the factors that influence collision risk at midblock and intersection locations. Our objective in this chapter is to enhance general understanding of how small scale features of the road environment differentially influence risk of collisions at intersection and mid-block locations. In this chapter we also assess the effect of using child pedestrian activity level information in small scale analyses of pedestrian safety. Chapter two is the foundation for all subsequent chapters in this thesis. Chapters three through five use the models created in chapter two to address specific questions related to the safety of children's routes to school.

In chapter three we evaluate the agreement between perceived and model-estimated safety of intersections in Hamilton, Ontario. The model-estimated assessment of safety is obtained using the model from chapter two where we estimate the probability of a child-pedestrian injury at intersections in the study area. We assess perceived safety based on a survey of parent's attitudes about the safety of nearby intersections. We compare these assessments and qualitatively assess intersections where there is disagreement. This analysis highlights the differences between parental and expert concerns about the factors that influence the safety of the transportation environment.

In chapter four we describe and apply a method for empirically assessing the safety of children's walking routes to school and use this information to compare the likely impact of SRTS programs on different school catchment areas in the study region. This method uses a journey based approach – where the cumulative probability of a child pedestrian injury for the entire route to school is used to measure the safety of a route. The probabilities are estimated using the models presented in chapter two. We use this method to evaluate the safety of routes to school for different school catchment areas in Hamilton, Ontario.

Chapter five introduces a decision support tool, called the *route to school decision tool* (RSDT), which can help parents to plan an individual route to school for their child. The RSDT incorporates both the safety related to features of the road environment and total length of the route to plan a route to school. The safety of the route is estimated using the models presented in chapter two. An important feature of this tool is that it allows parents and children to determine the trade-off between safety and distance travelled according to their personal risk assessment perspectives and priorities. We do this by allowing the individual using the tool to weigh the importance of safety compared to journey length when generating the route. Using the RSDT we generate routes for multiple locations in Hamilton, Ontario using different preference values for the safety and length of the routes and then compare the variability in both the length and safety of the routes generated.

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Chapter 2: Motor-vehicle collisions involving child pedestrians at intersection and mid-block locations

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Bennet, S.A., & Yiannakoulias, N., (2015). Motor-vehicle collisions involving child pedestrians at intersection and mid-block locations. *Accident Analysis & Prevention*. 78, 94-103.

Abstract:

We study motor-vehicle collisions involving child pedestrians walking to school in Hamilton, Ontario, Canada to understand and contrast collision risks at mid-block and intersection locations. We use a matched case control study design and apply it to intersection and mid-block locations instead of people. Cases are intersections/mid-blocks where collisions occurred and controls are locations where collisions did not occur. We match cases to controls on geography, socio-economic status and year. We use conditional logistic regression to predict the log-odds of collision risk at intersections and mid-blocks as a function of various environmental measures while controlling for volume of child pedestrian activity. Our results suggest that child pedestrian injuries at intersections are associated with intersection control type, traffic volume, and land use characteristics. In contrast, mid-block child pedestrian collisions are not associated with small scale environmental features. The results of this study suggest that some factors associated with the risk of collision differ across location types. These findings may be useful in the planning of safer walking journeys to school.

Keywords:

Child pedestrians; Collisions; Motor Vehicles; Built Environment; School; Case control study

2.1 Introduction

Child pedestrian injuries—resulting from collisions between child-pedestrians and motor-vehicles—are a leading cause of injury related deaths for Canadian children aged 14 years and under (Safe Kids Canada, 2009). Preventing child pedestrian injuries is challenging, but both educating children on road safety and modifications to the environment seem to reduce risk of injury and mortality (Desapriya *et al.*, 2011; Carver *et al.*, 2008; Donroe *et al.*, 2008). While changes in the urban environment can be more costly to implement compared to safety education programs, they may also be more effective in minimizing injuries to child pedestrians (Dimaggio and Li, 2012). As such, there remains interest in understanding how modification of the built environment can reduce child pedestrian injury (Mecredy *et al.*, 2011).

Considerable research has linked aspects of roadway infrastructure and other aspects of the built environment to the risk of collision between child pedestrians and motor-vehicles over the last 25 years. Stevenson *et al*. (1993) found that arterial roads were associated with more severe injuries to child pedestrians than smaller local roads. Children were found to be at greater risk of injury on roadways with more than two lanes of traffic compared to roadways with fewer lanes (Dougherty *et al*., 1990). The speed of traffic is also an important influence on a child's risk of injury (Donroe *et al.*, 2008; Roberts *et al.*, 1995), with a greater effect on risk than number of vehicle lanes and other attributes of the road environment (Mueller *et al.*, 1990). Several studies have found a positive association between motor-vehicle traffic volume and risk of child pedestrian injury (Yiannakoulias and Scott, 2013; Morency *et al*., 2012; Donroe *et al.*, 2008; Lascala *et al.*, 2004; Stevenson *et al.*, 1996; Stevenson, 1997; Roberts *et al.*, 1995; Stevenson *et al.*, 1995; Mueller *et al.*, 1990). Curb side parking has been found to increase a child's risk of injury as parked cars are thought to obstruct the visibility of both drivers and children (Roberts *et al.*, 1995;

Stevenson *et al.* 1996; Stevenson, 1997). Land-use was also found important for understanding child pedestrian injuries, where children living in multi-family dwellings, (such as apartment buildings) are at a greater risk of collision than children living in single family dwellings (Agran *et al.*, 1996).

Collisions between pedestrians and motor-vehicles occur at both intersection and mid-block locations, and understanding environmental risks in both these settings is critical for devising informed injury prevention strategies (Lightstone *et al.* 2001). Previous research shows that the majority of child pedestrian injuries occur at mid-block locations; for example, Oxley *et al*. (2012) and Lightstone *et al.* (2001) found that 59.4% and 62.3% of collisions between child pedestrians and motor-vehicles occurred mid-block, respectively. Using data from police reports, Brustman (1999) found that collisions between motor-vehicles and pedestrians where the pedestrian is at fault occur more frequently at mid-block locations, while collisions between motor-vehicles and pedestrians where the driver is at fault occur more frequently at intersections. The shortest path for a pedestrian to reach a destination—such as entrances to school yards—often involves crossing roads at mid-block locations (Sandt and Zegeer, 2006), and could partly explain why the proportion of child pedestrian injuries that occur at mid-block locations increases with closer proximity to a school (Walsh *et al.*, 2009). Similarly, the concentration of paths to school very likely increases as a child gets closer to their school destination. However the differences between intersection and mid-block collision risk is also due to differences in these environments. The majority of mid-block collisions occur at locations with no signals or crosswalk present; in contrast, most intersection collisions occur at intersections with signals or stop signs present (Ha and Thrill, 2011; Sandt and Zegeer, 2006). Mid-block injuries frequently occur on roads with lower traffic volume, two lanes of traffic or less and with a posted speed limit of 25 miles per hour or less (Agran *et al.*, 1994; Sandt and Zegeer, 2006). In contrast, child pedestrian injuries occurring at intersections tend to happen on roads with moderate to heavy traffic volume, more than two lanes of traffic and with a posted speed limit of greater than 25 miles per hour (Agran *et al.*, 1994).

The objective of this study is to identify and differentiate small scale features of the transportation environment that are associated with motor-vehicle collisions involving child pedestrians at mid-block and intersection locations. Our analysis is unique since it is at a small geographical scale but is representative of an entire urban environment. We also attempt to account for different levels of child pedestrian activity at different locations in the transportation system. Our hope is to enhance general understanding of how small scale features of the transportation environment differentially influence risk of collisions at intersection and mid-block locations, and secondarily, assess the effect of using child pedestrian activity information on small scale analyses of pedestrian safety generally.

2.2 Material and Methods

Our study area is Hamilton, Ontario, Canada, and is located midway between Toronto, Ontario, Canada and Buffalo, New York, USA on the western end of Lake Ontario.

2.2.1 Data

2.2.1.1 Collision data

We use a pedestrian-motor-vehicle collision database maintained by the City of Hamilton to obtain information on pedestrian collisions involving motor vehicles. Minor collisions that did not involve police or other emergency services are not included in the database. The database includes collisions that occurred from 2002 to 2011 inclusively. We restrict our study to collisions involving children aged 5-14 that occurred on weekdays, during the months from September to June and occurred between 7:00 am to 5:00 pm. These time and date restrictions are used to restrict our analysis to injuries that are likely to occur when school aged children commute to or from school. All the collision locations are geo-coded to a location on a road network. The location represents approximately where the collisions occurred and can be located at mid-blocks or at intersections. If the collision occurred 10 meters or less from an intersection then it was classified as an intersection collision, otherwise, the collision was classified as a mid-block collision.

2.2.1.2 Road and intersection data

We created a detailed pedestrian road database based on a road database provided by the City of Hamilton (2010). Off-road pedestrian infrastructure, including trails and pathways, were manually added to the database using a map produced by the City of Hamilton (2005). Short-cuts (including walking across green spaces and schoolyards) and unmarked pedestrian infrastructure were verified using Google Earth imagery (Google Inc., 2015). Roads classified as "expressways" and "major highways" are excluded from the pedestrian road database because walking is prohibited on these roadways. The pedestrian road database is comprised of interconnected sets of segments each with a unique identifier. A segment refers to an individual line digitized within the pedestrian road database; all road and off-road infrastructure in the database is made up of multiple segments. For segments along roadways (primarily sidewalks), the database contains information on road attributes such as road classification, speed limit, and if it is a one-way road. Other sources of digital data made available by The City of Hamilton were linked to the pedestrian road database, including: transportation signs (speed limit signs, chevron warning signs and general information signs), bus stops, fire hydrants, bike lanes, and sidewalks. The length of each segment in meters was calculated using a geographic information system.

We also created a database containing information on each individual intersection in the study area. The resulting intersection database contains location information on crossing guards, signalized intersection controls, and yield or stop sign intersection controls. We also calculated mean speed limit, defined as the mean of the speed limit of the segments travelling through the intersection and one-way, a dummy variable indicating if any of the segments connected to the intersection are a one-way road, for each intersection in the database.

Land use information was added to both the pedestrian road and intersection databases using parcel land information (Teranet Inc, 2010). The land use data are classified into five discrete categories: residential, commercial, industrial, institutional and vacant or open space. Estimated traffic volume is also added to the road and intersection databases. For the intersection database, the mean traffic volume for each intersection was calculated using the traffic flow estimates for all segments travelling through the intersection. We used the methods outlined by Morency *et al*. (2012) to estimate traffic volume for the study area. Using Journey to Work data from Statistics Canada (2008 (a)) we generated an origin-destination table to represent trips taken by drivers living within the study area. We then used a trip allocation model that incorporates road capacities to estimate the traffic volume on the roads in the original road database that included major highways and expressways. The estimated volumes for road segments were compared to traffic counts from 62 locations in the City of Hamilton, and correlated modestly (R=0.56). This value is similar to the correlation result presented in Morency *et al.* (2012).

2.2.2 Child pedestrian injury clustering distance

We used a spatial scan clustering detection method to determine the critical distance at which child pedestrian injuries cluster around primary public school locations. This method provides a value indicating the distance from schools at which the largest magnitude of clustering occurs (Yiannakoulias and Bland, 2012). The result from the focused spatial scan clustering detection method is a distance value of 150 meters Euclidean distance away from schools.

Case and control locations are classified as within or not within this critical distance, and this indicator is used as a variable in our analysis to control for the effect of school-related traffic volume that may not be accounted for in the motor-vehicle traffic volume estimation above.

2.2.3 Estimating pedestrian activity

The concept of 'exposure to risk' is central to understanding the epidemiology of child-pedestrian injuries (Roberts *et al.*, 1994). Children who walk to school are exposed to the risk of injuries and death on that particular journey while children who are driven to school are not. Estimating the probability of a child-pedestrian injury occurring at a particular geographical location requires data on the use of that location by child-pedestrians. Unfortunately, there is little routine collection of comprehensive child pedestrian activity data so pedestrian activity of geographic locations is usually estimated (Miranda-Moreno *et al*., 2011).

We estimate the child-pedestrian activity of road segments and intersections using a journey-based model of child pedestrians; we refer to this method as child activity using shortest distance (CASD). The CASD method estimates child pedestrian activity on roads and intersections in the study area by assuming that children walk the shortest route between their home and school. Using a journey allocation model we estimate the shortest routes to school using segment lengths from the pedestrian road database. The allocation model results in a list of segments and intersections likely used by children on their route to school. We sum up the total number of children that travel on each individual segment and intersection to come up with an estimate of the volume of children that use that location on their walk to and from school. This is done for all intersections and mid-block locations in the study area. Primary schools are the destination locations of journeys, where each school is assigned to the nearest intersection. Statistics from the Hamilton Wentworth District School Board

(2011) indicate that more than 80% of children live within the catchment area of the primary school they attend. The school catchment area boundaries distinguish between areas of the boundary where children are bussed to school and those children who are within walking distance of the school. Using a parcel land database (City of Hamilton, 2010), individual house locations are designated as origin locations, where each house location is assigned to the nearest intersection. Metrolinx (2011), the transportation authority for the Greater Toronto Area, found that 33% of children in Hamilton walk to and/or from school. Using Dissemination Area populations we select a number of house locations within walking distance to a primary school which corresponds to 33% of the child population. Each house location is then assigned a school location destination using the school catchment area boundaries.

There is some evidence that children take the shortest walking distance to school (Cooper *et al.* 2010; Hill, 1984), however recent research suggests otherwise (Buliung *et al.*, 2013). To account for uncertainties in route choice, we considered two additional methods of estimating child pedestrian activity levels: one based on a preferred route choice, and one based on child population. The child activity using preferred route (CAPR) method determines a child's walking route to school based on parental safety preference literature (Nevelsteen *et al.* 2012; Rivara *et al.* 1989). This results in a hierarchy (from most preferable to least preferable) as follows for road types: trail/pathways > minor road > major road. The intersection hierarchy (from most preferable to least preferable) is as follows: crossing guard > traffic lights > stop or yield sign > no intersection control. These rankings are used to find alternative routes to the shortest path that reflect greater emphasis on perceived safety. We then use a journey allocation model weighted by these preferences, and as above, sum up these journey counts to estimate child pedestrian activity on all intersection and mid-block locations.

The final method for accounting for child pedestrian activity levels is to use the density of child population in the area. The child pedestrian activity based on child population (CACP) method uses child population aged 5 to 14 at the dissemination area scale from the 2006 Census (Statistics Canada, 2008 (b)). Each intersection and mid-block road segment is assigned the child population of the dissemination area it resides in.

To test the effect of different route choice decisions on the regression model results, we perform a sensitivity analysis on the intersection and mid-block models. This was conducted as follows. First, each road length was given a new value comprised of the true road length plus the product of this value and a random number (selected form a uniform distribution) between -0.5 and 0.5. Then we used the CASD method described above to determine the activity of child pedestrians walking to school, but with these updated road lengths. Then these data were modelled using this new child activity data. This process was repeated 1000 times, and provides a sense of how much the coefficients in the regression models change when the route choices are perturbed with the vagaries of child route choice decisions. Stable coefficients would suggest that individual-level variations have little effect on the model, variable coefficients would suggest that individual-level variations greatly affect our results.

2.2.4 Analysis

We use a matched case-control study design to evaluate the association between attributes of the transportation environment and the risk of child pedestrian injuries. Typically case-control studies compare exposure in persons with an outcome of interest (cases) and a suitable control group of persons without the outcome of interest (Porta, 2008). We use the case-control study design and apply it to intersection and mid-block locations instead of people. 'Cases' are mid-block or intersection locations where children aged 5-14 were involved in a collision with a motor-vehicle (subject to the selection criteria above, i.e. occurred on a weekday, during the months of September to June and occurred between the hours of 7:00 am and 5:00 pm). Matched control locations are selected and matched on the year the collision occurred, the geographic area of the city the collision occurred in, and the socio-economic status of the dissemination area the case is located in. The measure of socio-economic status is a combination of data at the dissemination area scale from the 2006 census and includes: median income, proportion of renters, rate of unemployment, and proportion of population that has recently immigrated to Canada (Statistics Canada, 2008 (b)). Four matched control locations are randomly selected, with replacement, for each case location because it would be difficult to find additional control locations that meet the matching criteria and any greater number of controls per case has little effect on power (Gail *et al*., 1976). The crossing guard locations have changed for the years of collision data so the presence of a crossing guard for each of the case and control locations selected is based on the year the collision occurred. On street parking data are not available for the entire pedestrian road database but is thought to be an important component of the transport environment. On-street parking is manually added using Google Earth imagery (Google Inc., 2015) for each of the segments selected for the case control study. The land use variables are combined into two variables due to a lack of data representing multi-family use: “residential land use only” where only residential land use is found surrounding the segment or intersection, and “mixed residential or non-residential land use” where a combination of residential with non-residential land use is found or no residential land use is found surrounding the segment or intersection.

We use conditional logistic regression to model the risk of child pedestrian injuries as a function of specific attributes of the transportation environment. Conditional logistic regression applies the matching used in selecting the controls during the analysis to avoid bias in the estimated logistic regression coefficients (Breslow and Day, 1980; Schleeselman, 1982). The matching criteria used to select the controls are used to stratify the data. Mid-block collisions and intersection collisions are studied using separate models and results are compared qualitatively. Our analysis was performed using SAS® software, version 9.2 for windows (SAS Institute Inc. 2008).

2.3 Results

After applying our case selection criteria, there were 107 mid-block child pedestrian collisions (53.8%) and 92 intersection child pedestrian collisions (46.2%). The locations of collisions and schools are displayed on Figure 1. Table 1 provides summary information on the dichotomous independent variables used in the mid-block and intersection models below. While many measures show statistically significant associations with collisions, several measures are homogenous features of the transportation landscape in Hamilton. For example, the majority of the intersections do not have a crossing guard present; so while the attribute has a statistically significant association with the odds of collision at an intersection, it is important to note that it applies to a small proportion of intersections in the data set, and the city generally. Most crude odds ratios are significant at the 0.05 level for both mid-block and intersection locations. Table 2 provides descriptive statistics of the continuous variables representing features of the mid-block and intersection case and control locations. Traffic volume predicts higher risk of collisions for the intersection and mid-block models.

The results for the intersection and mid-block models are presented in Tables 3 and 4. CASD is associated with an increased risk of collision at intersections. Compared to the reference category (intersections with traffic signals) intersections with yield/stop sign controls and no intersection controls correspond to a lower risk of motor-vehicle collision involving a child pedestrian. Traffic volume and location in a mixed or non-residential land use area is also associated with increased risks of collision at intersections. While average traffic speed predicts greater crude odds of collision at intersections, the effect is not statistically significant once included in a model with the other environmental factors. Only CASD and road segment length are statistically significant in the mid-block model, both predicting higher risk of collision involving child pedestrians.

We ran the same models as above with the two alternative measures of child pedestrian activity (CAPR and CACP). A qualitative comparison of the odds ratios derived from the intersection and mid-block models using all three measures of pedestrian activity is presented in Tables 5 and 6. In all three of the intersection models, the presence of signs, types of intersection control, traffic flow and land use variables are all statistically significant, and of similar magnitudes. For the mid-block models, road length is the only measure that is statistically significant across all models. CACP is not statistically significant for either the mid-block or intersection models, whereas the other two measures (CASD and CAPR) are of similar magnitude and are statistically significant at the 0.05 level.

In regression models residual confounding occurs when a factor that confounds relationships between other study independent variables and the dependent variable is missing in a model or is measured inaccurately. Residual confounding can result in biased estimates of independent variables of particular interest. CASD is included in our analysis to control for the confounding effect of child pedestrian activity on other determinants of risk, but imprecision in this metric could be leaving some confounding uncontrolled for, and in turn, could affect the interpretation of environment variables included in our models. To judge the magnitude of this effect we performed a sensitivity analysis for the intersection and mid-block models, but show here only the figure for the mid-block model since the pattern is similar for the mid-block and intersection analysis (Figure 2). There were no changes in sign, and the variability of coefficients estimated in the sensitivity analysis was small. The largest variability was in the CASD coefficient, but even in this case, the variation was in a small band around the model estimate.

2.4 Discussion

Understanding risks of collision while controlling for child pedestrian activity levels is essential for making informed decisions about the safety of transportation environments. To date, most of the research comparing midblock and intersection safety is descriptive, and does not control for geographic differences in pedestrian activity levels. Different levels of pedestrian activity can confound descriptive assessments of risk; for example, a highly used intersection may be comparatively safe but still have a higher frequency of collisions than an infrequently used unsafe intersection. A great challenge to this kind of analysis has been the absence of good information on pedestrian activity at such small scales, particularly for a city as a whole. To date, most studies estimate the risk of a child pedestrian injury at a location using the population of the study area to measure pedestrian activity levels, however it is unclear if such an approach appropriately accounts for differences in pedestrian activity levels, particularly at small scales. In this study we addressed this challenge by estimating child pedestrian activity and including it into models predicting mid-block and intersection collision risk. The results of our analysis offer several general ideas about how features of these environments may and may not influence risk of collisions. It also offers methodological insight for future research on pedestrian safety at small geographic scales.

2.4.1 Mid-block and intersection environments

Mid-block and intersection environments fundamentally differ—both in the features present, but also in how children use the space. For the former, children are expected to remain on sidewalks and off the road (Abdel Aty et al., 2007), and for the latter, children are expected to navigate the road environment safely, following street signals and street crossing protocols so as not to cross paths with moving vehicles. It is unclear from our analysis if the greater frequency of mid-block collisions is due to children walking on roads instead of sidewalks, but evidence strongly suggests that children prefer sidewalks when they are available (Boarnet et al., 2005). As such mid-blocks collisions may be more likely to be explained by unsafe child behaviour (such as dart out road crossings) than intersections. Traffic volume is a positive and statistically significant predictor for collisions at intersections, which is consistent with existing literature (Yiannakoulias and Scott, 2013; Morency *et al*., 2012; Donroe *et al.*, 2008; Lascala *et al.*, 2004; Stevenson *et al.*, 1996; Stevenson, 1997; Roberts *et al.*, 1995; Stevenson *et al.*, 1995; Mueller *et al.*, 1990), however, it is not predictive of collisions at mid-block locations. One explanation for this difference is that children come into more direct and frequent contact with motor vehicles at intersection than mid-block locations; intersections are shared spaces in which rules of driver and pedestrian behaviour play a key role in separating pedestrians from motor-vehicles. High traffic volume intersections require more complex negotiating of space, and may be a less forgiving environment for pedestrians who err in judgement. Away from intersections children and motor-vehicles are more clearly separated, and are not as typically required to negotiate shared space. In fact, low traffic volume may attract certain higher risk behaviour mid-block—such as j-walking—which could offset the otherwise expected relationship between volume and collision risk.

Land use is common to both intersection and mid-block models and is a statistically significant predictor in the intersection but not the mid-block analysis. The general finding—that mixed land use increases collision risk—is also consistent with previous research (Clifton and Kreamer-Fults 2007; Cho *et al.*, 2009), though we note that unlike previous work, our study attempts to control for both traffic and pedestrian activity. We speculate that the effect may be partly explained by the behaviours of drivers and pedestrians in more complex urban environments. Mixed land use areas can include shopping centers, other commercial businesses, and residential areas, resulting in more complex interactions between pedestrians and motor vehicles. In mixed and non-residential areas, drivers and pedestrians may be more focused on destinations and more distracted by other features of the immediate environment. More generally, this result suggests that driver and/or pedestrian choices are highly contextual; for example, drivers may take extra precautions in residential areas because they see it as a shared transportation space, particularly for children. This may be particularly true in a driver's home residential environment (Yiannakoulias and Scott 2013). The effect may also be related to differences in hazard perception between residential and non-residential areas, particularly if these environments offer different expectations of pedestrian activity levels (Borowsky *et al*., 2012).

In addition to traffic volume, intersection control features were also statistically significant terms in the intersection model. Earlier research using a similar study design has suggested that crosswalks and traffic signal intersections are associated with an increased risk of collisions involving pedestrians, with signalled intersections responsible for a higher increase in risk compared to uncontrolled intersections (Moudon *et al*., 2008). Our results are consistent with this latter observation, but with the added benefit of having controlled for the volume of child pedestrian and motor-vehicle traffic activity. Nevertheless, the finding seems counter intuitive, and appears to recommend that intersections with no traffic controls or signs should be preferred over intersections with street light controls. Our observations here could be a result of some residual confounding in our model—from either imprecisely measured risk factors (such as traffic volume) or unknown missing contributors to risk. Intersection traffic controls are more likely to be present on roads with more traffic, suggesting some positive correlation with traffic volume. If traffic volume is imprecisely measured (even without bias) at these intersections, then the estimated traffic control coefficient could be biased. The direction of the bias (amplification or attenuation) is unclear, but the effect is not likely to be very large since the magnitude of the coefficient is large.

Another explanation for this finding is that all else being equal, intersections with traffic lights are in fact more dangerous than intersections without these controls. Intersection traffic control devices are usually located where traffic volume is highest, but the intersection control variable in our model may reflect a variety of unmeasured dangers that persist at intersections even after controlling for traffic volume. For example, intersection control devices may influence behaviours of drivers and pedestrians differently than behaviours at intersections controlled by only yield or stop signs, or without any controls at all. This has been a suggested explanation for the higher risks in mid-street crosswalks, for example; mid-block crossing signs may impart some sense of security that actually could make crossings less safe when compared to locations without formalized crossings (Leder *et al.*, 2006). While counter-intuitive, our finding does not recommend that these intersection traffic controls should be removed; indeed, they probably do reduce absolute risk of collisions at intersections where they are currently located. However, our finding suggests that it could be important to consider these behavioural factors when assessing or comparing safe intersections for the purpose of route planning, particularly for children.

Other than child pedestrian activity the only feature that is a statistically significant predictor in the mid-block model is road length. Longer roads could be associated with increased collision risk because the longer the road, the more frequent the potential contact between a motor-vehicle and a child pedestrian. Longer roads may also be associated with faster motor-vehicle speeds, which presents a greater risk of severe injury, and a perceptual challenge for children, who have difficulty judging motor vehicle speeds (Connelly *et al.*, 1998). In addition, longer roads may also encourage more mid-block crossing, since it would often be much easier to cross at mid-block rather than walk to the closest intersection.

The absence of other statistically significant environmental features implies that mid-block collisions are either the result of environmental features not included in our models or that small scale environments simply do not explain geographic variation in collision risk at mid-block locations. This latter interpretation is consistent with research that suggests behavioural or development factors account for a large proportion of injuries to children (Ha and Thrill, 2011; Macpherson *et al*., 1998; Ampofo-Boateng and Thompson, 1991). On the other hand, our findings also indicate that a number of features of the small scale environment are important for pedestrians at intersections. Independent of their contributions to understanding factors that influence child pedestrian safety, this apparent difference may be useful for planning more individualized routes to school. For a child inclined to make dangerous mid-block crossings when short-cut opportunities are available, a shorter route with more intersections may be safer than a longer route with fewer intersections. On the other hand, children who are less inclined to make mid-block crossings may be more suited to taking longer routes with fewer intersections and/or safer road infrastructure. Planning student specific routes to school may not yet be practical, but our results suggest there may be some benefit in further exploration of how safe route planning is sensitive to the contexts of child personality, age and gender.

2.4.2 Child pedestrian activity

An important feature of this study is that we attempt to control for the confounding of child pedestrian activity levels by estimating road and intersection pedestrian journeys, and summarizing these journeys into measurements of activity at intersection and mid-block locations. The measure of child pedestrian activity was based on assumptions about child behaviour that are difficult to evaluate empirically in this application or generally. To address this uncertainty, we compared several methods of estimating child pedestrian activity to observe the potential differences between different measures of activity on our results. Of these three methods, CACP is the easiest to implement since it merely involves assigning area child population counts to roads and intersections, while the other two methods require calculating journeys for child pedestrians. It is very likely that the journeys estimated by the CASD and CAPR methods are a poor approximation of the journeys that any individual child takes, and the use of population makes no assessment of journeys whatsoever. However, the chief role of these variables in this analysis was to control for activity levels in the estimation of risk factors related to the environment—such as traffic volume and speed—since there can be little doubt that risk of a collision at a particular location must be at least partly related to the activity of pedestrians at that location.

Surprisingly, our results suggest that the three methods of estimating child activity levels have very similar effects on the models. With respect to magnitude and statistical significance, no variable in the models changes substantially whichever method is used to control for activity levels. Our expectation was that the journey-based approaches (CASD and CAPR) would differ from the child population counts (CACP) since the latter provides no information at small geographic scales, and takes no account of the route options available for children. However, our results suggest that using child population to control for differences in activity may be sufficient in similar applications, and that future research need not endure the burden of controlling for differences in child pedestrian activities by estimating the journeys that child pedestrians take to school. This observation is supported by our sensitivity analysis; adding considerable randomness to route choice decisions did affect estimates of child activity, but had little effect on the other model parameters. Assuming that estimations of child activity levels are imprecise but unbiased, the models appear robust.

In spite of this observation, estimating the child pedestrian activity at intersection and mid-block locations using journey based approaches may have other uses. CASD and CAPR are statistically significant terms in our models, and therefore, are important for estimating the absolute risk of collisions at mid-block and intersection locations. Estimating these probabilities can be the basis for estimating collision risk at locations that can then be used directly in route planning activities. For example, the model predicted probabilities can be minimized across a set of prospective journeys to find the journey with the total lowest risk of collision. CASD and CAPR were highly significant terms in all our models, and could contribute to more accurate prediction of collision risk at both mid-block and intersection locations, and in turn, along prospective journeys to school. However, further work must first be done to determine how well these approaches estimate the activity levels at intersections and mid-block locations generally.

2.5 Limitations

There are several noteworthy limitations to this study. First, we do not know the actual routes that children take on their journey to school. In our main analysis we estimate these routes based on the shortest path, and these data are used to control for pedestrian activity in our models. Buliung *et al*. (2013) found that the shortest walking route may be a poor approximation of walking routes actually taken by children. This would introduce error into (and very likely attenuation of) our estimate of the effect of child pedestrian activity levels in our analysis, and residual confounding in other model variables. We compared several different methods of adjusting our model for child pedestrian activity levels, and in no cases were there noteworthy changes in our model results. In addition, we performed a sensitivity analysis by adding random error to the child pedestrian activity data, and then re-running our models. These results suggest that random error in estimating route is insufficient to dramatically change the coefficients of other terms in the model. However, it possible that our sensitivity analyses did not fully account for residual confounding; non-random error could introduce bias, or our sensitivity analysis could have underestimated the magnitude of error in the estimate of child pedestrian activity level. In either case this could affect other model terms, either attenuating or amplifying other effects in our model. This would have the greatest impact on model coefficients of small magnitude.

A second limitation is that we have no precise way of identifying which collisions actually involved children walking to or from school, and instead estimate it by restricting the collisions involving school-aged children injured during school operating times. This could mean that some collisions were incorrectly classified as happening on journeys to school and that some journey to school collisions may not have been included. In either case, it is unlikely that this misclassification would have a large effect on our results since the attributes of the environment that make walking to school safe and unsafe likely do not change drastically in the times immediately before and after school.

A third limitation is that our analysis combines data collected over 10 years (2002 to 2011), and as a result, our model may be insensitive to time varying effects. Changes in the environment in some locations may have a significant effect on the risk of collision, and such changes are not directly measured by our models. Given the small number of collisions per year, a longitudinal analysis was not feasible, and year specific information was not available. For this reason, we would caution against applying any of our specific results to understanding risks of collision in our study area without first validating the presence / absence of these features in the environment. A further complication is the possibility that a collision at a location may precipitate environmental interventions at that location (such as lowering speed limits or adding traffic controls) particularly when a child is severely injured or dies. If this were the norm, this could result in downward bias in model terms, where a high risk attribute (e.g., high traffic volume) has been changed in the real world due to an intervention, but is treated as constant in our data. Our matching of cases and controls on year and geography may go part way to mitigating this problem; large scale safety countermeasures should have similar effects on risks at case and control locations, and are therefore at least partly controlled for by the year-matched selection of controls.

A fourth limitation is our choice to model mid-block and intersection collisions separately. This means that comparisons between models are qualitative, rather than through explicit statistical tests (using interaction terms, for example). Our analysis implicitly assumes that collisions at mid-block and intersection locations are independent of each other, which may not always be the case—for example, traffic controls at an intersection may affect risk on the street segments nearby. This may make mid-block and intersection results difficult to interpret independent of one another. This separate model approach was necessary, since there are features of the transportation environment found at mid-block locations that are not found at intersection locations and vice versa. Handling the missing variables within a single model, along with the large number of interaction terms would have made for a cumbersome model. Furthermore, the differences between the model results were large enough that this methodological shortcoming is unlikely to greatly affect our conclusions.

A fifth limitation is that the precise location of collisions could not be determined. We classified collisions as mid-block and intersection based on locations reported in the data provided by the City of Hamilton, but these lacked precision sufficient to determine where precisely on a midblock a collision occurred. It is for this reason that mid-block environment variables are characterized as present or absent for the road segment as a whole, rather than near the location of collision. This is likely to attenuate any relationship between the environment variables and risk of collision; specifically, the mid-block model coefficients are probably biased to the null. This may partly explain why none of these environmental measures did not seem to predict increased risk of collision. It is worth noting, however, that this only applies to point measures (signs, bus stop and fire hydrant) for which there is mixed evidence of an association with risk in other research.

A sixth limitation is that we did not include parent's assessment and acceptance of risk for their children walking to and from school in our models. The acceptance of risk includes if a parent feels their child needs adult accompaniment on their walk to and from school. The reason for a parent feeling their child needs to be accompanied could be due to environmental features on a child's route to school or their child's personality, age and gender. Regardless of the reason, adult accompaniment have been found to reduce the risk of a child pedestrian injury (Morrongiello, 2005; Roberts, 1995) and also influence child pedestrian behaviour (Barton and Schwebel, 2007); therefore, if a child was supervised or not could either attenuate or amplify the effects of local environmental features on the risk of a child pedestrian injury. Unfortunately the collision database did not have any information on if the child was accompanied by an adult at the time of the child pedestrian injury.

A final noteworthy limitation is the presence of spatial dependence between the locations of child pedestrian injuries. We include geography and socio-economic status as matching criteria for the selection of control locations, which results in our controls being selected from the same geographical area and dissemination area's with similar socio-economic status as the corresponding case. The matching criteria addresses the spatial dependence between controls locations and their corresponding case locations, but there is the possibility of spatial dependence between the case locations which is not addressed. This could result in biased estimation of the coefficients and underestimation of the uncertainty surrounding them, leading to narrower confidence levels (Schabenberge and Gotway, 2005).

2.6 Conclusion

Our objective was to identify small scale traffic and roadway features that are associated with child pedestrian injuries at mid-block and intersection locations using an observational case-control study design. Our results imply that environment has a greater influence on the risk of collision at intersections than at mid-block locations, which may recommend more individualized route planning. Children who are more likely to j-walk or dart out at mid-blocks may be safer taking walking routes that are as short as possible, even if they cross more controlled intersections on the journey. On the other hand, children who are less likely to dart out at mid-blocks may be best served taking journeys that minimize their contact with intersections. These journeys may be slightly longer in many cases, but will avoid the primary danger that these particular children face--namely, risk of collision at an intersection. Such individualized planning needs careful consideration prior to implementation, and may never be possible in practice. However our results are a reminder of the importance of understanding the interaction between environment and behaviour in research on traffic safety, and offers some caution to the notion of a universal 'safe route' to school. Whether or not a particular route to school is safe will very likely be dependent both on the environment and the child's behaviour in that environment.

Acknowledgement

The research was supported financially by a grant from the Social Sciences and Humanities Research Council of Canada (410-2008-0789). The authors would also like to thank the anonymous reviewers for their helpful and insightful comments.

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Figure 1. Study area with locations of collisions and schools

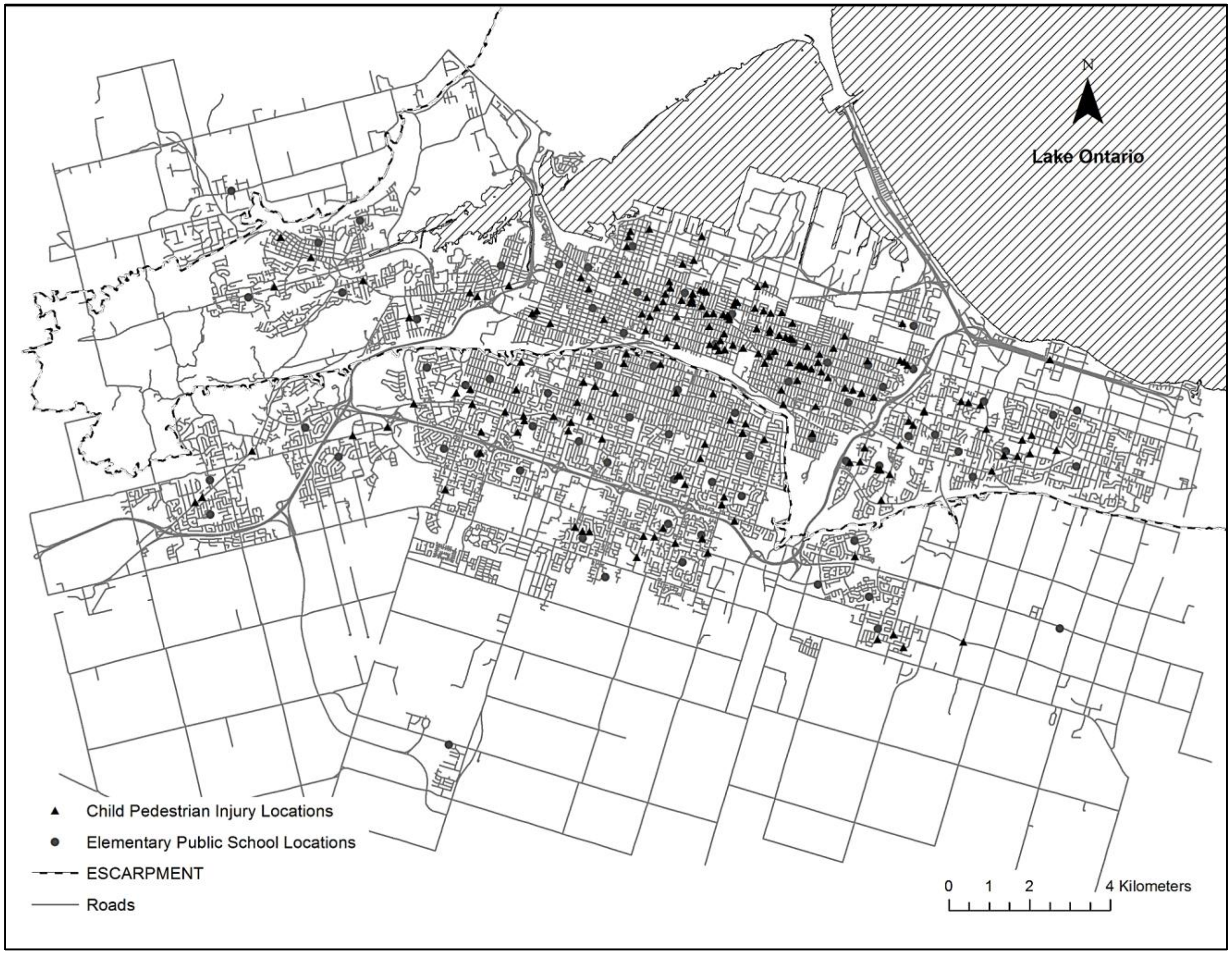


Table 1. Dichotomous independent variables used in the intersection and mid-block models including crude odds ratios estimating the risk of a collision occurring at a location where a feature is present

Location	Feature	Feature present		Feature absent		Crude Odds Ratio
		Case	Control	Case	Control	
Intersection	Yield or stop sign intersection control	49	300	43	68	0.26+
	Traffic signal intersection control	43	43	49	325	6.63+
	No intersection control	3	35	89	333	0.32
	Mixed or non residential land use	86	273	6	95	4.99+
	Average speed > 50 km/h	57	137	35	231	2.75+
	Crossing guard	15	17	77	351	4.02+
	One way on one or more entry streets	18	66	74	302	1.11
	Within 150 meters of school	9	23	83	345	1.63
Mid-block	Bike lane	4	6	103	422	2.73
	Bus stop	30	18	77	410	8.87+
	On street parking	62	328	45	100	0.42+
	Street sign	71	123	36	305	4.89+
	Mixed or non residential land use	95	318	12	110	2.74+
	Speed > 50 km/h	32	65	75	363	2.38+
	Fire hydrant	63	89	44	339	5.45+
	Sidewalk	105	397	2	31	4.10
	One-way	8	54	99	374	0.56+
	Within 150 meters of school	22	41	85	387	2.44+

+ Significant at 0.05 level

Table 2. Descriptive statistics of the continuous independent variables for the intersection models

Variable	Intersection model			Mid-block model		
	Mean	Standard Deviation	Crude odds ratio	Mean	Standard Deviation	Crude odds ratio
Child activity using shortest distance	16.48	26.93	1.01+	12.13	32.18	1.01+
Child activity using preferred route	19.71	36.07	1.01+	8.23	23.51	1.01+
Child activity using population	66.54	40.93	1.00	76.29	61.57	1.00
Average traffic flow (# of motor-vehicles)	1058.52	650.65	2.45+	844.79	749.46	1.40+
Road length (meters)	N/A	N/A	N/A	47.51	54.56	5.23+
+ Significant at 0.05 level						

Table 3. Conditional logistic regression results for the intersection model

Parameter	Estimate	Standard Error	Odds Ratio (95% CI)
Child pedestrian activity (CASD method)	0.0174^{+}	0.0071	1.02 (1.00-1.03)
Yield or stop sign*	-1.7702^{+}	0.4094	0.17 (0.08-0.38)
No intersection control*	-2.6098^{+}	0.7360	0.07 (0.02-0.31)
Crossing guard	0.7637	0.5208	2.15 (0.77-5.96)
Average traffic flow (per 1000 motor-vehicles)	1.7886^{+}	0.4207	5.98 (2.62-13.64)
Average speed > 50 km/h**	-0.1561	0.4496	0.86 (0.35-2.07)
Mixed or non residential land use***	1.4448^{+}	0.5229	4.24 (1.52-11.82)
One way	-0.2819	0.6326	0.75 (0.22-2.61)
Within 150 meters of school	-0.4376	0.6040	0.65 (0.20-2.11)

* Reference: Intersections with traffic controls
** Reference: Average speed ≤ 50 km/h
*** Reference: Residential only land use
$^{+}$ Significant at 0.05 level

Table 4. Conditional logistic regression results for the mid-block model

Parameter	Estimate	Standard Error	Odds Ratio (95% CI)
Child pedestrian activity (CASD method)	0.0078^{++}	0.0038	1.01 (1.00-1.02)
Speed > 50 km/h*	0.6639	0.5352	1.94 (0.68-5.55)
Average traffic flow (per 1000 motor-vehicles)	0.4222	0.2693	1.53 (0.90-2.59)
One way road	-0.7144	0.6258	0.490 (0.14-1.67)
Fire hydrant	0.3687	0.3997	1.45 (0.66-3.17)
Bike lane	2.3651	1.4857	10.65 (0.58-195.77)
Bus stop	0.7436	0.4686	2.10 (0.84-5.27)
Sidewalk	2.3014	1.2045	9.99 (0.94-105.87)
Sign present	0.6387	0.3476	1.89 (0.96-3.74)
On street parking	-0.6152	0.3859	0.54 (0.25-1.15)
Mixed or non residential land use**	-0.0227	0.4253	0.98 (0.43-2.25)
Road length (per 100 meters)	1.4013^{++}	0.3595	4.06 (2.01-8.21)
Within 150 meters of school	0.6198	0.4629	1.86 (0.75-4.61)

* Reference: Speed ≤ 50 km/h
** Reference: Residential only land use
$^{+}$ Significant at 0.05
$^{++}$ Significant at 0.01

Table 5. Odds ratios (and 95% confidence intervals) values for the intersection logistic regression models using the different methods for estimating the child-pedestrian activity of intersection locations

Parameter	Child pedestrian activity using shortest distance (CASD)	Child population (CACP)	Child pedestrian activity using preferred route (CAPR)
Child pedestrian activity	1.02 (1.00-1.03) ++	0.68 (0.07-6.84)	1.01 (1.00-1.02) +
Yield or stop sign*	0.17 (0.08-0.38) +	0.16 (0.07-0.36) +	0.17 (0.08-0.38) +
No intersection control*	0.07 (0.02-0.31) +	0.08 (0.02-0.32) +	0.08 (0.02-0.36) +
Crossing guard	2.15 (0.77-5.96)	2.38 (0.86-6.55)	2.39 (0.84-6.78)
Average traffic flow (per 1000 motor vehicles)	5.98 (2.62-13.64) +	6.21 (2.73-14.12) +	6.50 (2.82-14.98) +
Average speed > 50 km/h**	0.86 (0.35-2.07)	0.77 (0.33-1.83)	0.88 (0.36-2.11)
Mixed residential /non residential land use***	4.24 (1.52-11.82) +	4.37 (1.56-12.26) +	4.69 (1.65-13.33) +
One way	0.75 (0.22-2.61)	0.579 (0.17-1.97)	0.55 (0.16-1.92)
Within 150 meters of school	0.65 (0.20-2.11)	0.96 (0.30-3.10)	0.58 (0.17-2.01)

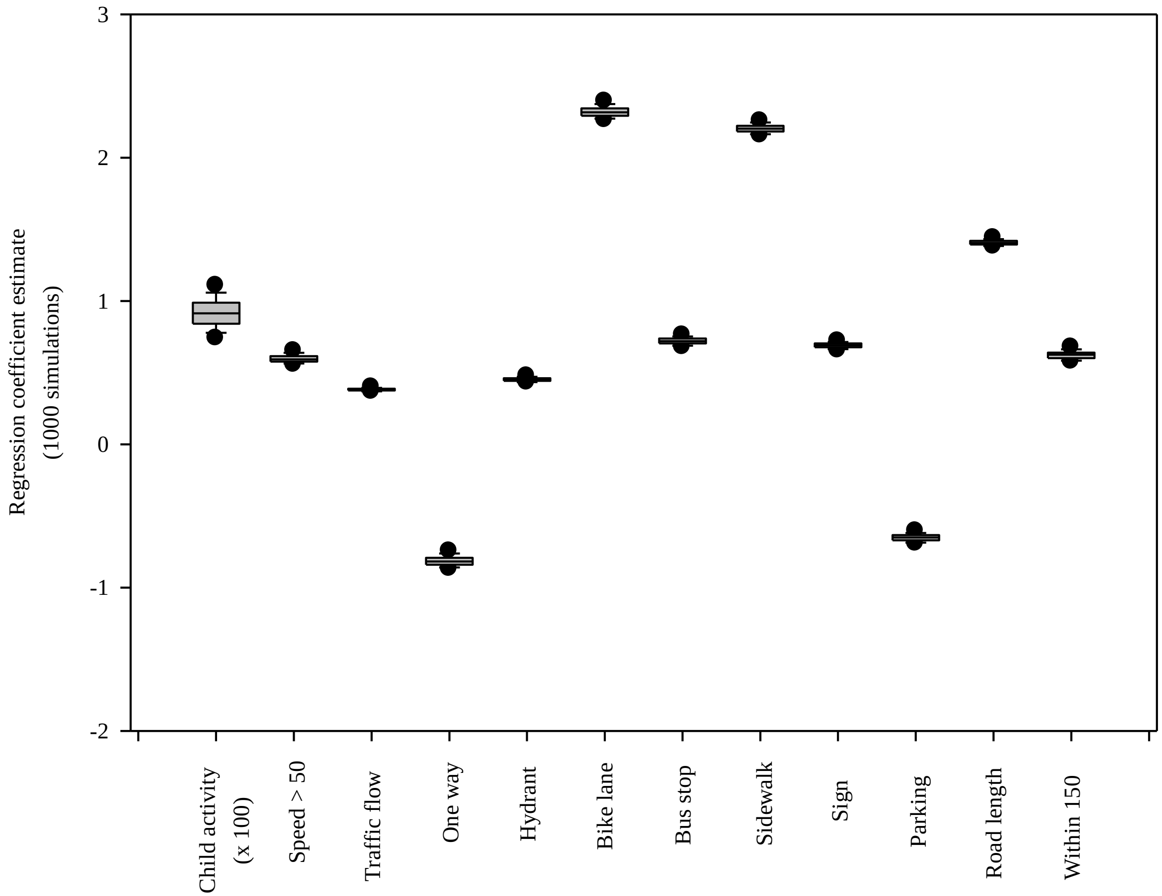
* Reference: intersections with traffic controls
** Reference: Average speed 50 km/h or less
*** Reference: Residential only land use
\+ Significant at 0.05
\++ Significant at 0.01

Table 6. Odds ratios (and 95% confidence intervals) for the mid-block logistic regression models using the different methods for estimating the child-pedestrian activity of mid-block locations

Parameter	Child pedestrian activity using shortest distance (CASD)	Child population (CACP)	Child pedestrian activity using preferred route (CAPR)
Child pedestrian activity	1.01 (1.00-1.02) ++	1.04 (0.35-3.08)	1.01 (1.00-1.03)+
Speed > 50 km/h*	1.94 (0.68-5.55)	1.92 (0.68-5.44)	2.02 (0.71-5.77)
Average traffic flow (per 1000 motor-vehicles)	1.53 (0.90-2.59)	1.552 (0.93-2.60)	1.51 (0.90-2.52)
One way road	0.490 (0.14-1.67)	0.435 (0.13-1.47)	0.50 (0.15-1.65)
Fire hydrant	1.45 (0.66-3.17)	1.418 (0.65-3.08)	1.42 (0.65-3.11)
Bike lane	10.65 (0.58-195.77)	10.451 (0.57-190.94)	10.39 (0.62-173.68)
Bus stop	2.10 (0.84-5.27)	2.136 (0.85-5.34)	2.37 (0.94-5.97)
Sidewalk	9.99 (0.94-105.87)	10.453 (1.00-109.68)	9.44 (0.95-94.16)
Sign present	1.89 (0.96-3.74)	1.92 (0.97-3.89)	1.70 (0.85-3.39)
On street parking	0.54 (0.25-1.15)	0.60 (0.29-1.26)	0.61 (0.29-1.31)
Mixed residential or non residential land use**	0.98 (0.42-2.25)	1.04 (0.45-2.40)	1.06 (0.46-2.44)
Road length (per 100 meters)	4.06 (2.01-8.21)++	3.82 (1.91-7.65) ++	3.63 (1.80-7.30) ++
Within 150 meters of school	1.86 (0.75-4.61)	2.38 (1.00-5.67)	2.35 (0.98-5.61)

* Reference: 50 km/h or slower
** Reference: Residential only land use
\+ Significant at 0.05
++ Significant at 0.01

Figure 2. Box plot of results from sensitivity analysis for mid-block model



Chapter 3: Evaluating the agreement between perceived and empirical safety of intersections for child-pedestrians.

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Abstract:

In this study we evaluate the agreement between perceived and empirical safety of intersections in Hamilton, Ontario. The empirical assessment is done using a model that estimates the probability of a child-pedestrian injury at an intersection. We assess perceived safety based on a survey of parents' attitudes about the safety of nearby intersections. We find there is some agreement – about what intersections are unsafe – between the parental survey and the empirical assessment. There are also intersections in disagreement which we qualitatively assess by observing the physical environment at those locations. Parents' most common environmental concern is high traffic volume, resulting in busy intersections and their most common behavioural concern is that drivers speed through intersections. We found that many of the features of the road environment parents suggest make an intersection less safe are included in the model. Concerns related to driver behaviour were not included in the model but we suggest that many of the behaviour concerns can be addressed with changes to the road environment. These findings may be useful in improving the safety of intersections for child-pedestrians.

Keywords:

Child pedestrians; Intersections; Parents Perception; Modelled Probability; Collisions; Motor Vehicles

3.1 Introduction

Using active transportation modalities — such as walking — for travel to and from school offers children an opportunity to increase their physical activity (Mitra *et al.* 2010; Tudor-Locke *et al.*, 2001) as school travel constitutes approximately 26 percent of all trips made by children (McMillan, 2005). Childhood activity is important for reducing the risk of child obesity and other health problems (Mitchell *et al.*, 2013; Tudor-Locke *et al.*, 2001; Sleap and Warburton, 1993), yet the number of children walking or cycling to school has declined considerably since the 1960s (Macdonald 2011). Reasons for a reduction in the number of children walking or cycling to school include: the perceived safety of the route to school by parents and children, as well as children's lack of motivation (McMillan, 2005; Zhu *et al.*, 2008; Carver *et al.*, 2008; Kerr *et al.*, 2006; Schlossberg *et al.*, 2006).

When children lack the motivation to use active transportation, parents are more inclined to drive them, thereby reducing the number of children who walk to school (McMillan, 2005). Part of the motivation to walk may be influenced by perceptions of safety. Most research suggests that a child's perception of safety is primarily concerned with fear of strangers and road safety (Carver *et al.*, 2008; Timperio *et al.*, 2004; Valentine and McKendrick, 1997). Child perceptions of road safety are largely influenced by obvious visual signs of motor-vehicle activity – such as the volume of traffic, and parked cars on their local road (Mullan, 2003). While a child's perceptions have some influence on their decision to use active transportation to and from school, a parent's authority and perception of safety is much more influential on modal choice (van Loon and Frank, 2011; Carver *et al.*, 2008; Davison *et al.*, 2008; Kerr *et al.*, 2006; Timperio *et al.*, 2006; McMillan, 2005, Sallis *et al.*, 1997).

Compared to children, parents are more concerned about the safety of the route to school (Carver *et al.*, 2008) and many parents feel that children are less safe walking to school compared to when their generation walked to school (Skenazy, 2009; Malone, 2007). When parents have few concerns about the safety of their child's route to school or their child's desire to walk to school, children are five times more likely to walk to school compared to when parents have many concerns (Kerr *et al.*, 2006). Similar to children, most parental concerns about child safety on walks to school can be divided into two categories; (1) fear of their child being injured due to features of the physical environment – such as the volume of traffic – and characteristics of the roads and intersections their children walk along (Ridgewell *et al.*, 2009; Ahlport *et al.*, 2008; Kerr *et al.*, 2006; Gielen *et al.*, 2004) and (2) the fear of their child being abducted or injured due to interaction with strangers or bullies (Larsen *et al.*, 2012; Davison *et al.*, 2008; Ridgewell *et al.*, 2009; Ahlport *et al.*, 2008; Kerr *et al.*, 2006; Gielen *et al.*, 2004). Risk analysis literature might suggest that a parent's evaluation of the safety of an event or activity – such as allowing their child to walk to school – is composed of an emotional and cognitive assessment of risks, with the emotional assessment often having the strongest influence on an individual's decision (Slovic *et al.*, 2005; Loewenstein *et al.*, 2001). For example, if an individual's feelings toward an activity are subjectively favourable, independent of the probability of harm, then the individual tends to judge the probability as low (Finucane *et al.*, 2000; Slovic and Peters, 2006; Slovic *et al.* 2004). Furthermore, the feelings an individual has towards an activity are highly contextual, influenced by their emotional state at the moment decision making, and can be strongly influenced by past experiences that may have little to do with the activity they are evaluating (Loewenstein *et al.* 2001; Slovic 1993).

While it is unsurprising that individual experiences and fears often result in the misjudgement of risks (particularly as probabilities) (Slovic 1987), they also frequently differ from the evaluations of experts (Loewenstein *et al.* 2001).

The conflict between expert and non-expert opinion can present a challenge to ambitious policy ideas – such as a recent program promoting more walking to school. Therefore, the best approach might be one that involves acknowledging and understanding public risk perceptions while remaining informed by empirical risk assessments (Loewenstein *et al.* 2001).

In this study we evaluate the agreement between parents' perception of safety and a statistical model predicting safety at intersections. The statistical model estimates the probability of a child-pedestrian injury, where a child-pedestrian injury is an injury to a child-pedestrian resulting from a collision with a motor-vehicle at an intersection. Parents' perceptions of safety are based on a survey of attitudes about the safety of nearby intersections. We compare these assessments, and qualitatively assess intersections where there is disagreement. Our hope is to understand the contributions of parental concerns and experts analysis based on empirical assessments for improving the safety of intersections for child-pedestrians.

3.2 Methods

This study involves a comparison of risk based on two sources of estimation: a parental survey and the results of a statistical model of collision probability based on historical data on child pedestrian injuries.

3.2.1 Parental perceptions of risk

The City of Hamilton administered a survey in 2010 to 2011, as part of a project called *Stepping It Up*, which aimed at helping parents and elementary school students choose active and environmentally-friendly modes of school transportation (Green Communities Canada, 2010). The survey was sent home to families at 10 different schools (5 in low socio-economic (SES) neighbourhoods and 5 in high SES neighbourhoods). Parents were asked to complete the survey (for their eldest child only) and return it to the school their child attends. The average response rate for the survey was forty-seven percent. The survey asks parents questions regarding the mode of transport to school, the length of time the trip takes and the parents' opinion on their child using active modes of transportation to get to school. One of the questions on the survey asks parents to list three intersections of greatest concern on their child's walk to and from school and explain why they think the intersection is unsafe. The parents' responses are tabulated into a database, resulting in a list of intersections that parents feel are unsafe for children to use when walking to school. We categorize the parent survey responses into physical environment concerns and behaviour concerns.

3.2.2 Modelled estimated risk

We assign every intersection in Hamilton's transportation network a probability of a child-pedestrian injury occurring during a single trip through that intersection while walking to or from school. This probability is based on a matched case-control study where collisions at intersections involving child-pedestrians between 2002 and 2011 are treated as 'cases' and intersections where collisions did not occur as 'controls'. These probabilities are used as an 'expert' benchmark for comparing expert and parental assessments of safety at intersections. The analysis to derive these probabilities is described in Chapter 2, but in short, combines data on historical collision events and features of the physical environment into a model informed by the child pedestrian injury literature.

3.2.3 Assessing agreement between survey and model results

The *Stepping It Up* survey asked parents about unsafe intersections on a child's walk to or from school and all of the intersections parents mentioned were located within a 1600 meter radius of the primary schools that participated in the survey. As a result, we only compare agreement between the survey and model results for intersections that are within 1600 meters of schools. We compile a list of intersections, suggested by parents as unsafe, and sum up the number of times the locations were suggested by parents as unsafe for children to use on their walk to and from school. We geo-code the intersections using a Geographic Information System (GIS). These geo-coded intersections are matched up with intersections on a digital road network.

Table 1 shows the two-by-two table used for calculating the agreement between the survey responses and the modelled probability values of the safety of intersections. The survey responses are set up as a binary response, where if the intersection was mentioned in the survey as an unsafe location it is given a value of 1, and if it was not mentioned, it is give a value of 0. The model probability values are dichotomized for comparison with the survey data. We dichotomize the model probabilities using four methods: (1) the upper five percent of observations, where intersections with probabilities in the upper five percent of the distribution are considered locations of greater risk to children walking to school; (2) the upper ten percent of observations, where intersections with probabilities in the upper ten percent of the distribution are considered locations of greater risk to children walking to school; (3) upper quartile, where intersections with probabilities in the upper twenty-five percent of the distribution are considered locations of greater risk to children walking to school; (4) standard deviation, where intersections with probability values that are greater than one positive standard deviation of the distribution are considered locations of greater risk to children walking to school.

The intersections in agreement between the model and parent survey are those that fit in the cell labelled “A” in table 1. The areas of disagreement are also of interest and are those intersections that fit in the cell labelled “B” in table 1. There are a large number of intersections not mentioned by parents in the survey and thereby considered safer by default. This perception results in a large number of the intersections fitting into cell “C” or “D” in table 1, depending on how the model probabilities are classified. We are less interested in cells "C" and "D" because we are assessing the agreement between intersections that are considered unsafe using our modelled probabilities and those intersections parents feel are unsafe; these intersections are represented in cells "A" and "B" in table 1.

We calculate the Kappa Statistic to evaluate the magnitude of agreement between the parental survey results and the model probabilities. The Kappa Statistic is a measure of the difference between how much agreement is actually present compared to how much agreement would be expected to be present by chance alone (Viera and Garrett, 2005). The Kappa Statistic is standardized to lie on a -1 to 1 scale, where 1 is perfect agreement, 0 is agreement that would be expected by chance alone and -1 is when agreement occurs less often than predicted by chance alone (Viera and Garrett, 2005). The Kappa Statistic is influenced by the distribution of the data into concordant and discordant pairs in the two by two tables, so we calculate the maximum attainable Kappa Statistic value, the prevalence index and biased index to help interpret the Kappa Statistic (Sim and Wright, 2005). The maximum attainable Kappa Statistic is calculated by adjusting the distribution of cell values in the two by two tables to achieve the greatest possible agreement (Sim and Wright, 2005). The prevalence index looks at the variation in distribution between cells where parental survey results and the model probabilities are in agreement (cells "A" and "D"), where a set of data with a large prevalence index value results in a reduction of the Kappa value (Sim and Wright, 2005). The prevalence index is the absolute value of the difference between cells "A" and "D" divided by the total number of observations. The bias index looks at the variation in distribution between cells where parental survey results and the model probabilities are not in agreement (cells "B" and "C"), where a large bias results in a higher kappa value (Sim and Wright, 2005). The bias index is the absolute value of the difference between cells "B" and "C" divided by the total number of observations.

3.2.4 Qualitative comparison of intersections not in agreement

We observe some of the intersections not in agreement. We follow guidelines for observational research outlined by Hay (2010): choice of locations, recording data, and analysis of data. First, we narrow down the list of intersections to observe. We observe intersections that parents suggest are unsafe more than once in the survey; this results in twenty-one intersections to observe. The time of day we observe the intersections is less important for this study compared to other observation studies because we are only interested in observing the physical features of the intersections. We conduct our observations on weekday mornings after children have already arrived at school.

The objective of observing the intersections is to provide further details regarding the physical features of the intersection. At each intersection we record observations about the intersections and the surrounding road features and landuse types. We take pictures of the intersection from all directions of travel. After observing an intersection we review our notes and pictures of the intersection and reflect on our observation of the intersection. We document any further thoughts or observations that come to mind. Our observations are tabulated into a database along with the parental survey results. The observations in combination with the comments from parents – collected in the survey – are examined to understand the differences between the model and parents' assessments of risk.

3.3 Results

Survey respondents reported 222 unsafe intersections. There are a total of 5062 intersections within 1600 meters of the schools surveyed. We find there is some agreement between the survey and the dichotomized model probabilities. The two-by-two tables showing the agreement are found in table 2. The greatest agreement (105 intersections) is when the upper quartile is used to classify the model data. The smallest agreement (49 intersections) is when the upper 5% of the model data is classified as high probability locations.

Table 3 shows the Kappa Statistic results between the model and parental survey. When calculating the Kappa Statistic for each two-by-two table, we find that cell "A" has a strongest influence on the Kappa Statistic calculation because this is where we see the greatest difference between the observed and expected values. The resulting Kappa statistic for all four classifications is above zero, indicating that there is some agreement between the model and parental survey. We find there is a large difference in the distribution of values of agreement between cells "A" and "D" in the two by two tables in table 2. This results in large prevalence index values and suggests that the large difference in the distribution of values between cells "A" and "D" could be causing a reduction of the Kappa Statistic. We find that there is a difference in the distribution of values of not in agreement between cells "B" and "C" in the two by two tables in table 2. The bias index values are small for all four classifications and suggests that the differences in the distribution of the values not in agreement has less of an effect on the resulting Kappa Statistic. Therefore the differences in the distribution of the values not in agreement are less likely to be inflating the Kappa Statistic values.

While we find that there is some agreement between the parental survey and the model, there are still intersections that parents consider unsafe but the model considers safe (cell "B" in the two-by-two tables). The number of intersections in disagreement ranges from 117 intersections when the upper quartile is used to classify the model data, to 173 intersections when the upper 5% of the model data is classified as high probability locations. We observe twenty-one of the locations in disagreement to understand why there is disagreement between the model and the survey responses. Table 4 is a summary of the parents' survey responses of the intersections we observed about why the intersections are unsafe for child-pedestrians. The most common environmental concern is that there is high traffic volume, resulting in busy intersections. Another common concern is the perceived need for a crossing guard at the intersection to assist children in crossing the road. Other parent concerns of the environment include a lack of stop signs or signal lights for all directions of traffic at the intersection. The most common behavioural concern is that drivers speed on the roads that cross through the intersection. Other common behaviour concerns are that drivers turn without looking for children crossing the road at the intersection and that drivers do not obey stop or yield signs and traffic lights – e.g. do not stop at stop signs and run red lights. Table 5 is a summary of our observations of the twenty-one intersections in disagreement. The most common observation is that one or more of the roads crossing the intersection are a collector or major roadway. These roadways are designed to accommodate greater volumes of traffic than minor roadways and could result in busier intersections. Many of the intersections observed are an all-way stop or have traffic lights to control traffic. We observe that a few intersections only have a stop sign or traffic signal controlling traffic travelling on one of the roads entering the intersection. Some entrances to a school or to a playground were also found to be at some of the intersections observed. These intersections could see an increase in motor-vehicle and child pedestrian volume because of their close proximity to schools and playgrounds. The complete responses from parents and notes from our observation of the intersections can be found in Appendix A.

While all intersections are important for understanding the reasons for the disagreement between the parent survey and the model, we find there are some features common to many of the locations we observed. Many of the intersections are located close to schools with only stop signs used to control traffic. We include photographs of five of the intersections observed that are estimated to have a high volume of child-pedestrians and that encompass many of the concerns parents have regarding the built environment or driver behaviour. A detailed explanation of the method we used to estimate child pedestrian volume can be found in Chapter 2. We use the remainder of the results section to describe these locations and the features that are present. A summary of our observations and the reasons that parents believe the intersections are unsafe for these five intersections are shown in table 6. Pictures of these intersections are found in figures 1 through 5.

The location shown in figure 1 is a t-intersection with a stop sign for only one direction of traffic; the minor roadway that is adjacent to the through road. Looking at figure 1, to the left of the intersection is a major arterial roadway and the road that travels straight through the intersection is one of the main access roads to the neighbourhood and the school across the street (to the right of the playground shown in the picture). There is no crosswalk for crossing the road that travels straight through the intersection and there is a playground directly across the street, with a sidewalk leading to the playground from the intersection. The sidewalk leading from the intersection to the playground and the placement of the playground itself could encourage children to cross the street at this intersection because it is the most direct access to the playground. Parents mention that this is an unsafe place to cross the street because of the high volume of traffic that passes through the intersection, and that cars do not look for children when turning right from the through road to the adjacent road.

Figure 2 shows a t-intersection with stop signs for all directions of travel. This intersection would be busy during morning drop-off and afternoon pick-up from school as there are two schools in close proximity to the intersection. There is a curve in the road which could make it difficult to see children crossing when there are cars parked along the side of the road (parking is allowed on both sides of the roadways entering the intersection). Parents mention that there are cars stopping illegally along the roads adjacent to the intersection resulting in parents and children having to maneuver around cars to cross the street.

The location shown in figure 3 is a t-intersection with a stop sign for only one direction of traffic, the minor roadway that is adjacent to the through road; this intersection is similar to what we see in figure 1 except that the intersection in figure 3 is directly connected to a school. Not all directions of travel have a stop sign and there is not a marked location for children to cross the street. There is not a crosswalk at the intersection itself or anywhere else along that roadway for children to use to cross the road that runs straight through the intersection and along the front of the school. This could result in children either jaywalking mid-block or crossing at the intersection without the aid of a stop sign to stop traffic. Parents mention that this intersection and the roadways connected to it are very congested with cars and school buses during morning drop-off and afternoon pick-up from school.

Figure 4 shows a t-intersection with a stop sign for only one direction of traffic; the minor roadway that is adjacent to the through road, similar to what we see in figures 1 and 3. This intersection also has the school parking lot entrance located at the intersection, which adds additional traffic from a fourth direction during school hours. The parking lot entrance is at the same intersection where children are crossing the street after being dropped off by their parents. There is no sidewalk on the road that is controlled by the stop sign and the sidewalk on the through road is only on the side of the road nearest the school. There is a marked crosswalk both crossing the through road and crossing the road with the stop sign, but no sidewalk connecting to these crosswalks. These crosswalks are most likely busy during school drop-off and pick-up, as vehicles park on both sides of the street and would be improved by having complete sidewalks on both sides of the crosswalks. Parents mention that vehicles park on the corners of the intersection and on both sides of the street during school drop-off and pick-up, making one lane for both cars to drive along and children to walk along, as there are no sidewalks.

The location shown in figure 5 is a t-intersection with stop signs for all directions of travel. The through road is a main access road to the neighbourhood with a bus stop on both sides of the intersection. On the opposite side of the intersection from the road adjacent to the through road is a playground. The road adjacent to the through road does not have any sidewalks, so children most likely walk on the road. There are designated crosswalks for children to cross the street at the intersection but there are mail boxes and power boxes, in conjunction with bus stops, where the mail boxes, power boxes and stopped busses could block the view of drivers approaching the intersection and of children when crossing the road. Parents mention that vehicles pass stopped busses and that the intersection is busy during the morning and evening commute.

3.4 Discussion

We find there is some agreement between the parental survey and the expert analysis that is better than what would be expected by chance alone. The model provides an empirical measure of the risk of a child pedestrian injury at a given location, based on features of the road environmental at the intersections; whereas, the concerns of parents includes their intuitions and observations about driver behaviour and the road environment. The concerns of parents are influenced by personal experiences, media coverage, and their general anxieties of life (Slovic, 1987) and we have a limited understanding of the background behind a parent's suggestion of why a location is unsafe. It has been suggested that emotional assessment of risk could result in misjudgement of risk (Skenazy, 2009; Malone, 2007; Loewenstein *et al.* 2001, Slovic 1987) and that empirical evaluations might be a better solution for assessing what intersections are the least safe. We find there is agreement between what intersections the expert analysis and parents' survey responses suggest as unsafe and that the expert analysis and parents' survey responses provide different information about why the intersections are and are not unsafe; the inclusion of both components of risk analysis results in a richer understanding of the risks associated with the intersections.

While we find there is agreement between the parental survey and the model, there are some intersections that are not in agreement. The responses from parents of twenty-one intersections that were not in agreement suggest that there are other factors not included in the model which could affect the perceived risk of a child pedestrian injury. Parent responses are divided into concerns regarding the physical environment and behaviour concerns, the latter of which is not included in the model. Driver behaviour – including driving too fast, parking illegally near schools, and turning without yielding or watching for children crossing the street – is an important component of why parents feel an intersection is unsafe for most of the intersections we observe. Our findings are consistent with other studies where parents suggest that erratic driving behaviour makes intersections dangerous for child pedestrians (Anderson *et al.*, 2003; Bradshaw, 2001). Ways to improve driving behaviour include educating drivers on road safety (Carver *et al.* 2008; Abdel-Aty *et al.* 2007) and modifying the road environment (Ewing and Dumbaugh, 2009; Boarnet *et al.*, 2005). Modifications to the road environment that result in drivers and child-pedestrians being more aware of each other, and in improved pedestrian visibility – such as the installation of pedestrian activated crossing lights – are found to improve the safety of intersections for child pedestrians (Ewing and Dumbaugh, 2009; Boarnet *et al.*, 2005)

Our observation of intersections not in agreement provides additional knowledge on how parents' concerns regarding driver behaviour translate to road environment features of the intersections that could increase the risk of a child pedestrian injury. A common concern from parents regarding driver behaviour is that drivers are driving too fast. We observe that many of the intersections, where parents identify this issue have stop signs for only one direction of traffic entering the intersection. Intersections with stop signs in all directions of travel could reduce the risk of child pedestrian injuries when compared to intersections with stop signs for three or less directions of travel because all cars, regardless of their direction of travel, are required to stop at the intersection (Retting *et al.*, 2003). Intersections with stop signs in all directions of travel also reduce the severity of child pedestrian injuries because they result in motor vehicles travelling at slower speeds (Zeedyk *et al.*, 2002).

Parents were also concerned with cars parking on both sides of the road in combination with incomplete sidewalks, resulting in drivers and child-pedestrians sharing a single lane on the road. Complete sidewalks can reduce the risk of child pedestrian injuries in residential areas because they reduce the number of children who walk in the street (Boarnet *et al.*, 2005; Knoblauch *et al.*, 1987); at most of the intersections we observed, the sidewalks were not complete as there were not sidewalks on all sides of the roadways leading to the intersections, nor at the intersections themselves. While complete sidewalks do not address the parking issue, they do reduce the need for children to walk on the road.

One feature of the physical environment that we observed and was not mentioned by parents as a concern is the location of bus stops at intersections. In our observation of some of the intersections, we noticed that some bus stop locations were placed at locations that could block the view of both drivers and pedestrians. The location of bus stops at intersections has been found to have an effect on the risk of child pedestrian injuries, where relocating bus stops from the side of the road entering the intersection to the side of the road exiting the intersection increases the visibility of child pedestrians because it decreases the number of children who cross the intersection in front of a stopped bus (Retting *et al.*, 2003; Berger, 1975).

Many of the features of the road environment that concern parents are included in our model, but after completing our observation of intersections not in agreement, and reviewing the parents' road environment concerns of those same intersections there are some road environment variables that could be modified to better inform the model. Several studies have found a positive association between motor-vehicle traffic volume and risk of child pedestrian injury (Yiannakoulias and Scott, 2013; Morency *et al.*, 2012; Donroe *et al.*, 2008; Lascala *et al.*, 2004; Stevenson *et al.*, 1996; Stevenson, 1997; Roberts *et al.*, 1995; Stevenson *et al.*, 1995; Mueller *et al.*, 1990). Parents mention in their survey responses that traffic, due to the pick-up and drop-off of children makes an intersection less safe. Traffic flow during pick-up and drop-off times is localized near school locations. Traffic flow is included in the models but is estimated using data reflecting travel to work; this is thought to represent the overall traffic flow pattern but may not accurately reflect the traffic flow seen at intersections in close proximity to schools during pick-up and drop-off periods. In our observation of the intersections, we note that high traffic volume could potentially increase the risk of child pedestrian injuries at some of the intersections observed because increased traffic volumes would reduce the number of opportunities children would have to cross against the flow of traffic safely, especially at intersections without stop signs in all directions of travel.

The survey responses from parents include concerns about features of the road environment and driver behaviour concerns, but many of the driver behaviour concerns can be addressed with changes to the road environment. Our findings are consistent with previous literature, where if safety is to be meaningfully addressed then we need to understand how the road environment features at intersections influence the risk of a child pedestrian injury, as well as influence driver and child pedestrian behaviours, because they also influence the risk of child pedestrian injuries (Ewing and Dumbaugh, 2009). Thus, the safety of child pedestrians at intersections appears to be best enhanced by strategies that: (a) educate children and drivers on road etiquette and safety, and (b) result in road infrastructure that encourages appropriate interaction between child pedestrians and motor-vehicles (Dumbaugh and Frank, 2007) and addresses problematic driver and pedestrian behaviour.

3.5 Limitations

There are several noteworthy limitations to this study. First, the model probability values are measured on a continuous scale. Therefore, the model probability values are dichotomized for comparison with the survey data. The agreement between the parent survey and the model probabilities is affected by how the modelled probabilities are partitioned. We dichotomize the modelled probability values four different ways and evaluate the agreement between the parent survey and the model probabilities. The number of intersections in agreement between the parental survey and the model probabilities does vary depending on how the model probabilities values are dichotomized, but the Kappa Statistic shows there is some agreement for all four of the classifications that is greater than the expected agreement by chance alone.

A second limitation is the spatial distribution of the intersections used to assess the agreement between the parent survey and the model. The agreement calculations were limited to the intersections parents suggest as unsafe, which are all located within a 1600 meter radius of the ten different schools surveyed. This results in the agreement calculations being calculated using a small subsample of intersections from limited geographical areas to assess the agreement between the model and the parent survey. Surveying a greater number of schools would improve the spatial distribution of the intersections and account for spatial variability within the study area.

A final noteworthy limitation is that the parent survey only asked parents to comment on intersections that are unsafe; we know from Chapter 2 that child-pedestrian injuries frequently occur at mid block locations, and that child-pedestrians injuries occurring at mid block are influenced by different features of the environment than child-pedestrian injuries occurring at intersections. An additional survey question asking parents about unsafe mid-block locations would have allowed us to assess the agreement between the parent survey and mid block modelled probabilities. This limits the relevance of this paper to child pedestrian injuries that occur at intersections.

3.6 Conclusion

In this study we evaluate the agreement between perceived and empirical safety of intersections. The empirical assessment is done using a model that estimates the probability of a child-pedestrian injury, where a child pedestrian injury is an injury to a child pedestrian resulting from a collision with a motor-vehicle at an intersection. We assess perceived safety based on a survey of parents' attitudes about the safety of nearby intersections. We find there is some agreement – about what intersections are unsafe – between the parental survey and the empirical assessment that is better than what would be expected by chance alone.

There are also intersections in disagreement, where parents feel the intersection is unsafe but the model estimates the probability of a child pedestrian injury to be a lower probability. We observe twenty-one of the intersections in disagreement and look at the responses by parents to try to understand why there is a discrepancy between the model and the parents' responses. We categorized the parents' responses into concerns regarding the road environment and behaviour concerns and found that many of the features of the road environment parents suggest make an intersection less safe are included in the model. Concerns related to driver behaviour were not included in the model but we suggest that many of the behaviour concerns can be addressed with changes to the road environment. The findings in this study are consistent with previous literature, where if safety is to be meaningfully addressed then we need to understand how the road environment features at intersections influence the risk of a child pedestrian injury, as well as influence driver and child pedestrian behaviours, which can also increase the risk of child pedestrian injuries (Ewing and Dumbaugh, 2009).

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Table 1. Two-by-two table of the parent survey and probability model

		Model Results	
		Higher Probability	Lower Probability**
Parent Survey	Unsafe	A	B
	Safer*	C	D

*These intersections are considered safer because they were not mentioned by parents in the survey.

**There is still a chance of a child pedestrian occurring at these locations but the probability is below the probability value used to distinguish between intersections with higher probability and intersections with lower probabilities.

Table 2. Two-by-two tables of the agreement between the model and the parental survey for intersections of higher risk for child pedestrian injuries (Agreement is shown in cell A in the two by two tables)

Upper 5% of observations

		Model Results	
		Higher Probability	Lower Probability**
Parent Survey	Unsafe	49	173
	Safer*	207	4633

Upper 10% of observations

		Model Results	
		Higher Probability	Lower Probability**
Parent Survey	Unsafe	69	153
	Safer*	441	4399

Upper Quartile

		Model Results	
		Higher Probability	Lower Probability**
Parent Survey	Unsafe	105	117
	Safer*	1165	3675

Standard Deviation (+1 std away)

		Model Results	
		Higher Probability	Lower Probability**
Parent Survey	Unsafe	83	139
	Safer*	635	4205

*These intersections are considered safer because they were not mentioned by parents in the survey.
**There is still a chance of a child pedestrian occurring at these locations but the probability is below the probability value used to distinguish between intersections with higher probability and intersections with lower probabilities.

Table 3. Kappa Statistic results between the model and parental survey

	Kappa Value (95 % CI)	Maximum Possible Kappa Value	Ratio of Observed Kappa to Maximum Kappa	Prevalence Index	Biased Index
Upper 5% of observations	0.1658 (0.1159 - 0.2157)	0.9254	0.1792	0.9056	0.0067
Upper 10% of observations	0.1357 (0.0969 - 0.1745)	0.5809	0.2336	0.8554	0.0569
Upper Quartile (75)	0.0714 (0.0495 - 0.0933)	0.2409	0.2964	0.7053	0.2070
Standard Deviation (+1 std away)	0.1175 (0.0848 - 0.1502)	0.4345	0.2704	0.8143	0.0980

Table 4. Themes from parent survey responses about why intersections are unsafe

Themes from parent survey responses about why intersections are unsafe	Number of times it was mentioned in the survey
Road Environment Concerns	
Busy intersection / too much traffic	14
Crossing guard needed	9
Traffic light needed	3
All way stop or stop sign needed	1
Parked cars / school buses are a problem	2
Need longer crossing light / more time to cross the road	1
Shape of street creates a blind spot for drivers	1
Need a school zone sign	1
No sidewalks	1
Behaviour Concerns	
Drivers Speed	10
Drivers turn without looking	6
Drivers not obeying stop/ yield signs and traffic lights	6
Drivers parked illegally	3
Drivers not paying attention	2
Drivers not obeying the crossing guard	2
Drivers use it as a short-cut	1
No safe area for children to cross the road	5

Table 5. Common themes from the observation of intersections

Road environment themes from the observation of intersections	Number of times it was observed
One or more of the roads crossing the intersection is a collector or major roadway	12
All way stop or traffic lights at intersection	10
A stop sign or traffic signal for only one road entering the intersection	6
Entrance to Playground / School at the intersection	8
Parked cars on roadway just before intersection	6
Parking lot entrance at intersection	3
Incomplete sidewalks	4
Bus stop at intersection	4
Driveways at intersections	2
Off angle road entrance into intersection	4
Large intersection	3
Commercial landuse at intersection	3
Pedestrian crossing warning signs before intersection (not crosswalk lights)	2
Street furniture present (e.g. news paper box, bus stop bench, electrical box)	2
Curve in road at intersection	1
Multiple schools at intersection	1

Table 6. Notes from observations and comments from parents in the survey of the intersections in the photographs

ID	Location in Study Area	Observations	Parent comments	
			Road Environment Concerns	Behaviour Concerns
1	Upper Mountain	A stop sign for only one direction of traffic (Not slowing down traffic on the collector roadway). T intersection (3 directions of travel). Access to major arterial after the intersection. Entrance to play ground at the intersection on side of intersection with no roadway (opposite the stop sign) .	There should be a stop sign for all roads. There are cars parked on the curb and it is difficult to see the other side when crossing the road. Very busy road with no crossing guard.	Cars turn right without looking for children. No safe area to cross.
4	Upper Mountain	Curve in road making it a blind intersection when travelling from one direction. Two schools close by making it a busy intersection during morning drop off and afternoon pick up.		Cars stopping illegally, kids/parents dodging between cars across the street. Cars fail to stop at stop signs.
9	Upper Mountain	T intersection right next to school. A stop sign for only one direction of traffic and is not slowing down traffic on the busier roadway that goes straight through the intersection and past the front of the school.	Because of cars parked on 1 side of the street and school buses, this corner is very congested.	Mismatched car speeds. Cars turning and parking to drop off kids.

ID	Location in Study Area	Observations	Parent comments	
			Road Environment Concerns	Behaviour Concerns
18	Stoney Creek	T intersection in front of a school. A stop sign for only one direction of traffic and is not slowing down traffic on the busier roadway that goes straight through the intersection and past the front of the school. The roadway that goes straight through the T is a busy collector road as it is the entrance to the residential area and access to the school off the major arterial. No side walk on the road opposite the school. Side walk only along one side of the roadway that goes straight through the T intersection (on same side as the school). The entrance to the school parking lot is at the intersection (crosses the through roadway of the T), opposite the road with the stop sign. Cars parked along both roadways (on the straight through roadway, cars are only allowed to park opposite the school where there is no sidewalk).	Very busy area as parents park to pick up children from school. After dismissal, lots of traffic and there are no sidewalks. No crossing guards /light (yield or stop).	Cars parking on corners and pulling out/ parking on both sides of the street creating one lane for cars and children walking. Busses and cars speed.
21	Ancaster	All-way stop (T intersection). A playground on one side of the intersection (on the side of the intersection with no roadway). No side walk on the road opposite the playground. One block off a major arterial. The roadway that goes straight through the T is a busy collector road as it is the entrance to the residential area off the major arterial. Neighbourhood group mailbox at intersection beside crosswalk to playground. Bus stop at intersection.	Busy intersection	Cars travel too fast and rarely making complete stops at stop signs.

Figure 1. Picture of intersection with ID 1

Figure 2. Picture of intersection with ID 4

Figure 3. Picture of intersection with ID 9

Figure 4. Picture of intersection with ID 18

Figure 5. Picture of intersection with ID 21

Appendix A. Notes from observations of intersections and comments from parents collected in the survey

ID	Location in Study Area	Count*	Observations	Parent comments: Road Environment Concerns	Parent comments: Behaviour Concerns
1	Upper Mountain	9	A stop sign for only one direction of traffic (Not slowing down traffic on the collector roadway). T intersection (3 directions of travel). Access to major arterial after the intersection. Entrance to play ground at the intersection on side of intersection with no roadway (opposite the stop sign) .	There should be a stop sign for all roads. There are cars parked on the curb and it is difficult to see the other side when crossing the road. Very busy road with no crossing guard.	Cars turn right without looking for children. No safe area to cross.
2	Upper Mountain	10	Three way crossing, all-way stop. Both roadways are used as shortcuts to get out of the residential area. Both roadways could be considered small collector roadways.	No crossing guard. Traffic can be dangerous.	Cars go through stop sign without stopping.
3	Upper Mountain	4	Multiple drive ways, close together (row house / town house). Side walk only on one side of one street. T intersection. Pathway entrance on the side of T with no roadway	Very busy in the morning making it difficult to cross the street. No crossing guard	Cars speed through stop signs. Cars driving too fast.
4	Upper Mountain	4	Curve in road making it a blind intersection when travelling from one direction. Two schools close by making it a busy intersection during morning drop off and afternoon pick up.		Cars stopping illegally, kids/parents dodging between cars across the street. Cars fail to stop at stop signs.

*Number of times the intersection was reported in the survey by parents

ID	Location in Study Area	Count*	Observations	Parent comments	
				Road Environment Concerns	Behaviour Concerns
5	Upper Mountain	5	One roadway is a collector road with bike lanes and turning lanes for both directions. Stop sign only for the minor road way crossing the collector road. Neon yellow crossing signs before intersection (5 meters) warning drivers along major collector. Bus stop on corner of intersection along collector road.	Need a traffic light with a crossing guard.	
6	Upper Mountain	5	Busy collector roads with a turning lane for one direction of traffic. One of the roads is the entrance to the residential area off the major arterial.	Busy intersection. No crossing guard.	Very busy highways, not comfortable with my children crossing. Cars turn right and left without looking.
7	Upper Mountain	8	Lots of cars, Both collector roadways that meet at the intersection. Commercial land use on 3 corners of the intersection. Traffic lights for all directions of travel, turning advance lights for two directions of travel.	Busy intersection.	Drivers not paying attention.
8	Upper Mountain	4	All-way stop. 4 directions of travel. Parked cars on both roadways. One roadway is a collector road for a major arterial.	No crossing guard.	Drivers don't stop or pay attention.
9	Upper Mountain	3	T intersection right next to school. A stop sign for only one direction of traffic and is not slowing down traffic on the busier roadway that goes straight through the intersection and past the front of the school.	Because of cars parked on 1 side of the street and school buses, this corner is very congested.	Mismatched car speeds. Cars turning and parking to drop off kids.

*Number of times the intersection was reported in the survey by parents

ID	Location in Study Area	Count*	Observations	Parent comments	
				Road Environment Concerns	Behaviour Concerns
10	Upper Mountain	7	Signalized intersection to stop traffic on collector road, minor residential road (crossing the collector) has a stop sign. Sidewalk on all sides of the intersection, parked cars along the minor residential road.	Very busy intersection. No traffic light.	The crossing guard thinks he is the traffic cop. Drivers ignore the crossing guards.
11	Upper Mountain	8	Two busy collector roadways, signalized intersection, with dedicated turning lanes and turning advances. Sidewalk on all sides of the intersection. Large intersection to cross. Commercial land use on all sides of the intersection. Parking lot entrances close to all four sides of the intersection.	No cross guard.	Busy intersection, cars driving too fast. Speeding vehicles.
12	Upper Mountain	6	All-way stop, with one direction of travel into a cul-de-sac (dead end). Parked cars on all sides of the street. Sidewalks on all sides of the roadways.	Very busy during "drop off" and "pick up". The shape of the street creates a blind spot for cars travelling east. Is a city bus route. School and city buses have a hard time making the turn and often travel over sidewalks	Cars speed.
13	Lower Mountain	5	Five streets connect at the intersection, with one of the roadways being a major arterial. Signalized intersection. Bus stop right at intersection. Lots of street furniture (bus stop bench, electrical box, news paper box		Cars use it as a through-way. Cars speed.

*Number of times the intersection was reported in the survey by parents

ID	Location in Study Area	Count*	Observations	Parent comments	
				Road Environment Concerns	Behaviour Concerns
14	Lower Mountain	5	T intersection, with the stop sign for only one direction of traffic and is not slowing down traffic on the busier roadway that goes straight through the intersection. One block off major arterial. Drive way entrances for single family houses right at intersection (one in the intersection opposite the roadway with the stop sign). Sidewalk and parked cars on all sides of the roadways.	Heavy traffic in morning. Need cross walk sign. No crossing guard.	Speeding cars.
15	Lower Mountain	5	School on corner of intersection. A school yard entrance at the intersection. All-way stop. Sidewalk on all roadways. Parked cars on all roadways.	Need a 40km school zone sign.	Cars begin to turn, even though children still crossing intersection. Cars run stop sign. Cars blocking cross walks, illegally parked.
16	Lower Mountain	4	Downtown intersection, one of the roadways is a major arterial (4 lanes, one way traffic). Not a signalized crossing. Stop sign on the roadway opposite the major arterial. School is located just passed the intersection along the minor roadway. Crossing guard present during morning drop off and afternoon pick up. Parking on one side of major arterial and on both sides of the minor roadway. Neon yellow crossing signs before intersection (5 meters) warning drivers along major arterial.		Drivers don't obey the crossing guard.
17	Stoney Creek	5	Intersection is off 90 degree angle. One of the roadways is a major arterial. Signalized intersection, with turning advance for the major arterial. Commercial landuse on all four corners of the intersection. Parking lot entrances for the businesses close to the intersection.	Busy intersection.	Cars going way too fast, hard to cross street!

*Number of times the intersection was reported in the survey by parents

ID	Location in Study Area	Count*	Observations	Parent comments	
				Road Environment Concerns	Behaviour Concerns
18	Stoney Creek	6	T intersection in front of a school. A stop sign for only one direction of traffic and is not slowing down traffic on the busier roadway that goes straight through the intersection and past the front of the school. The roadway that goes straight through the T is a busy collector road as it is the entrance to the residential area and access to the school off the major arterial. No sidewalk on the road opposite the school. Side walk only along one side of the roadway that goes straight through the T intersection (on same side as the school). The entrance to the school parking lot is at the intersection (crosses the through roadway of the T), opposite the road with the stop sign. Cars parked along both roadways (on the straight through roadway, cars are only allowed to park opposite the school where there is no sidewalk).	Very busy area as parents park to pick up children from school. After dismissal, lots of traffic and there are no sidewalks. No crossing guards /light (yield or stop).	Cars parking on corners and pulling out/ parking on both sides of the street creating one lane for cars and children walking. Busses and cars speed.
19	Stoney Creek	8	Intersection is off 90 degree angle. Large intersection because of additional dedicated turning lanes. One roadway is a major arterial. School one block away from this intersection on the minor roadway. Sidewalk only on one side of the street after intersection towards the school. Sidewalk on both sides of the street in all other directions.	There is not adequate time given to cross the road before the stoplights change. High traffic.	Cars look to the left for oncoming traffic, but do NOT watch for pedestrians.
20	Stoney Creek	7	Large intersection, with a major arterial and major collector crossing. Dedicated turning lanes on 3 of the four sides of the intersection. Signalized intersection with turning advances. Park / green space entrance on two sides of the intersection. Sidewalks on all sides of the street, no parked cars along any of the roadways.	Busy intersection.	Cars pull out of driveway without looking.

*Number of times the intersection was reported in the survey by parents

ID	Location in Study Area	Count*	Observations	Parent comments	
				Road Environment Concerns	Behaviour Concerns
21	Ancaster	3	All-way stop (T intersection). A playground on one side of the intersection (on the side of the intersection with no roadway). No side walk on the road opposite the playground. One block off a major arterial. The roadway that goes straight through the T is a busy collector road as it is the entrance to the residential area off the major arterial. Neighbourhood group mailbox at intersection beside crosswalk to playground. Bus stop at intersection.	Busy intersection	Cars travel too fast and rarely making complete stops at stop signs.

*Number of times the intersection was reported in the survey by parents

Chapter 4: Empirical assessment of the safety of children's walking routes to school

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Abstract:

In this study we describe and apply a method for empirically assessing the safety of children's walking routes to school. We consider walking route safety a function of the probability of a child pedestrian injury involving a collision with a motor-vehicle on a child's walking journey to or from school. This method uses a journey-based approach — where the cumulative probability of a child pedestrian injury for the entire route to school is used to measure the safety of a route. The probabilities are calculated using a model that estimates the probability of a child pedestrian injury based on recent child pedestrian injury data. We use this method to evaluate the safety of routes to school for different school catchment areas in Hamilton, Ontario. We find that there is variability in the risk of child pedestrian injury across school catchment areas, but that the risks change depending on what type of routes are taken to school – specifically, whether or not they emphasize safety or length of route. We estimate that over one hundred child pedestrian injuries could be prevented over ten years in Hamilton, Ontario if children used safer routes instead of shorter routes to school. This equates to the prevention of one child pedestrian fatality over ten years.

Keywords:

Child pedestrians; Safe Route to School; Collisions; Motor Vehicles;

4.1 Introduction

Over the past decade, programs aimed to promote active transportation to school are gaining popularity as a way to incorporate physical activity into children's lives, and reduce traffic congestion in school zones by reducing the number of children who are driven to school. These programs, referred to as Safe Routes to School (SRTS), are commendable for their comprehensive approach to increasing the number of children who walk to school and for planning safe walking routes for children by integrating strategies culled from the "three E's" of traffic safety: engineering, enforcement, and education (Weignham 2008; Dumbaugh and Frank, 2007). While one of the mandates of the SRTS programs is to plan safe routes for children to use on their walk to and from school, there is limited evidence about the effectiveness of SRTS programs (Dumbaugh and Frank, 2007). For safety to be a meaningful part of SRTS programs, the strategies believed to enhance safety should result in a reduction in the risk of injury to child pedestrians while walking to or from school. The objective of this paper is to present a method for empirically assessing the safety of children's walking routes to school. We consider walking route safety a function of the probability of a child pedestrian injury involving a collision with a motor-vehicle on a child's walking journey to or from school. The method we present evaluates the safety of walking routes to school across school catchment areas in Hamilton, Ontario, while excluding other safety factors such as stranger danger and bullying. We begin with a review of the history of SRTS.

4.1.1 Safe Routes to School

The city of Odense, Denmark, is credited with launching the SRTS movement in the 1970's as a response to high rates of child pedestrian injuries (Hubsmith 2006). The goal of the city of Odense's program was to reduce the rate of child pedestrian injuries by identifying and addressing road dangers through modifications of the built environment – such as constructing new pedestrian pathways, adding traffic islands and narrowing roads (Appleyard, 2003). The program in Odense resulted in the creation of a national SRTS program in Denmark followed by the development of similar programs in other countries, including the United Kingdom, Australia, New Zealand, Canada and the United States (Boarnet *et al.*, 2005 (a)).

The SRTS programs began to appear in the United Kingdom in the 1980's with the goal of creating safer routes to school for children through new facilities and design such as raised intersections and bike lanes (Appleyard, 2003, Weigand, 2008). Today the SRTS program in United Kingdom is one of the most successful and well funded national programs, with financial support coming from all levels of government (Green Communities Canada, 2010).

In the 1990's, SRTS programs began to appear in Australia, New Zealand and Canada. All three programs addressed the physical dangers of walking and cycling, and also incorporated education and enforcement components to increase the number of children who walked to school (Hubsmith, 2006). In Canada SRTS began with the "Way to Go" program in British Columbia and "Go for Green" program in Toronto, Ontario (Appleyard, 2003). The "Way to Go" program introduced the idea of bringing together community stakeholders to create a team that devises a location-specific program that integrates the "5 E's" for safe routes to school – evaluation, engineering, education, encouragement and enforcement (Hubsmith, 2006). In Toronto, the "Go for Green" program began as a program offering safer and healthier travel for students to and from school (Green Communities Canada, 2010). The "Go for Green" program eventually became known as the Active Safe Routes to School (ASRTS) program, which offered an opportunity for communities in southern Ontario to create networks that would make active student travel safe, healthy and fun (Tools of Change, 2012). The ASRTS program developed a curriculum for individual schools in the Toronto area that included ideas such as the walking school bus, international walk to school day and neighbourhood walkabouts (Halton District School Board, 2011; Tools of Change, 2012). In 2002 the ASRTS program became a part of Green Communities Canada — a national association of community organizations that help people go green — and began to take on a national focus (Green Communities Canada, 2010). The program continued to gain momentum, where in 2010 the ASRTS program was provided funding from the Federal Government to support the introduction of school travel planning to 120 schools in Canada (Green Communities Canada, 2010).

In the United States, crossing guards and safety patrols were popular beginning in the 1960's and 1970's but SRTS programs did not begin until 1997 when the first grass roots SRTS was started in New York City (Hubsmith 2006). In 2000 the National Highway Traffic Safety Administration (NHTSA) funded two pilot projects in Marin County, California and Arlington, Massachusetts (Weigand, 2008; Green Communities Canada, 2010). Both pilot projects were built on the "5 E's" originally developed by the "Way to Go" program in Canada, and today the "5 E's" have become the standard for SRTS programs in the United States (Hubsmith 2006). The Marin County program saw an increase in rates of walking within the first year it was introduced and led to the establishment of a national SRTS model program and toolkit (Weigand, 2008; Appleyard, 2003). Federal legislation was passed by US Congress in 2005 that established a National Safe Routes to School program to improve the safety of walking routes to school and to encourage children and families to travel between home and school using active modes of travel (Hubsmith, 2006; Green Communities Canada, 2010). The legislation allocated guaranteed long-term funding of $612 million (USD) through 2009 that allowed individual states the freedom to use their funds to customize their SRTS programs for their unique needs (Buckley *et al*., 2013; Green Communities Canada, 2010; Hubsmith, 2006). The program was continued until 2012 with federal dollars being allocated to individual states based on student enrollment with no state receiving less than $1 million (USD) (Buckley *et al*., 2013).

The funding structure for the SRTS program in the United States has changed, beginning in 2012 with the passing of a transportation bill: Moving Ahead for Progress in the 21st Century (MAP-21). MAP-21 consolidated the available funds for SRTS into a competitive process with other programs related to recreation trails, environment mitigation and other pedestrian and bicycling needs and minor road projects (Buckley *et al*., 2013). Individual states can now choose to opt-out and transfer up to 50% of the funds that use to be designated for SRTS to other uses such as bridge rehabilitation; if there is a state emergency then 100% of the funds can be used for rebuilding damaged highways (Buckley *et al*., 2013). SRTS programs must now compete for funding and have to develop programs without a guaranteed source of funding. This dramatic competition-focused change in funding for SRTS programs intensifies the need to evaluate SRTS programs and determine what programs are the most effective for reducing child pedestrian injuries and promoting active transportation (Buckley *et al*. 2013).

4.1.2 SRTS Evaluation

SRTS programs have been embraced by schools, communities and governments world-wide but there is limited literature on assessing the success of the programs. A successful SRTS is a program that has increased the safety and/or number of children walking to school resulting in corollary benefits such as improved health, reduced congestion, and better air quality (Stewart *et al.*, 2012). To date, most evaluations of SRTS programs have focused largely on whether the program is effective at increasing rates of walking, without considering their effects on child pedestrian safety (Dumbaugh and Frank, 2007**;** Boarnet *et al*., 2005 (b); Appleyard, 2003).

Parents' concerns about the safety of the road environment may explain the relatively low rate of children who currently walk to school (Larson *et al.*, 2013; Makarewicz *et al.*, 2013). The implementation of SRTS programs is a means of addressing these concerns, but many safety benefits associated with SRTS are assumed and unsupported by evidence (McArthur *et al.*, 2014; Dumbaugh and Frank, 2007). Studies looking at the improved safety of SRTS programs usually consider an increase in the number of children walking to school as a successful program because an increase in the number of children walking is thought to indicate that parents perceive that their child's walk to school is now safer than before (Boarnet *et al.*, 2005 (a); Staunton, *et al.*, 2003; Boarnet *et al*., 2005 (b)). Parents' perception of risk is usually based on a subjective assessment of their child's route to and from school (Dumbaugh and Frank, 2007) but may not be a good indicator of the actual or relative risk of a child being hit by a car while walking that route. There is limited literature looking specifically at planning SRTS programs by estimating the risk of a collision for walking routes. McArthur *et al.* (2014) suggests comparing the expected number of collisions between child pedestrians and motor vehicles with the actual number of collisions for a given school catchment area. Other studies have looked at improving the safety at a specific intersection on a route to school. Using input from parents to determine dangerous locations, Yee *et al.* (2007) assessed and recommended modifications to the locations to make them safer for child pedestrians. Most of the current methods of assessing safe routes to school are either unable to assess the safety of individual trips to school, or they merely assess the safety of particular locations along a trip instead of the entire trip. We build on the current literature and present a method for measuring how safe a route to school is based on the entire trip, where the safety of a route is estimated using a statistical model. The statistical model estimates the probability of a child pedestrian injury based on recent child pedestrian injury data. We use this method to compare the safety of routes to school for different school catchment areas in Hamilton, Ontario, Canada. We demonstrate how the method presented can be applied to determine what school catchment areas would benefit the most from the implementation of a SRTS program and as a way to promote the importance of safe routes for child pedestrians for reducing the risk of child pedestrian injuries.

4.2 Methods

The study area is Hamilton, Ontario, which is located midway between Toronto, Ontario, Canada and Buffalo, New York, USA on the western end of Lake Ontario. We create a pedestrian transportation network, for Hamilton, Ontario, that contains roads, trails, pathways and shortcuts — such as walking across green spaces and schoolyards — that could be used by children on their walk to school. Roadways that prohibit pedestrians were removed from the pedestrian transportation network. The pedestrian transportation network is an interconnected set of lines, each with a unique identifier. A segment refers to an individual line within the road network and starts or ends when another line crosses it; each road or off-road infrastructure in the network is made up of multiple segments. Each segment in the pedestrian road network is assigned a length in meters and is calculated in a geographic information system.

Every segment and intersection in the pedestrian road network is assigned a probability of a child-pedestrian injury occurring during a single trip through that intersection or along that segment while walking to or from school. Intersection and segment probabilities are determined separately as different features of the built environment have been found to contribute to child pedestrian injuries occurring at intersection versus non-intersection locations (Sand and Zeeger, 2006). The probabilities for the intersection and non-intersection model are combined together; if a segment ends at an intersection then the estimated probability of that intersection is added to the estimated probability of the segment. This probability is based on a matched case-control study where collisions at intersection or non-intersection locations involving child pedestrians between 2002 and 2011 are treated as ‘cases’, and intersection or non-intersection locations where collisions did not occur, as ‘controls’. The precise details in selection of cases and controls and the analysis to derive these probabilities is described in Chapter 2, but in short, combines data on historical collision events and features of the physical environment into a model informed by the child pedestrian injury literature.

We estimate the safest and shortest routes to school for individual house locations that are within walking distance (1.6 kilometres) of an elementary school, where the safest route is a route that minimizes the probability of a child pedestrian injury along the route and the shortest route is a route that minimizes the total length of the route. We compare the safest route with the shortest route because there is some evidence that children take the shortest route to school (Cooper *et al.*, 2010; Hill, 1984). Using Dissemination Area populations — of children aged 5 to 14 — we randomly select house locations, within walking distance to a primary school, which corresponds to 33% of the child population (Statistics Canada, 2008). It has been found that 33% of children walk to and/or from school in Hamilton (Metrolinx, 2011). Each house location is assigned a school location using the school catchment area boundaries as it has been found that greater than 80% of children live within the catchment area of the primary school they attend (Hamilton Wentworth District School Board, 2012 ; Hamilton Wentworth District School Board, 2011).

We aggregate the cumulative probability of a child pedestrian injury up to the school catchment area, for both the safest and shortest routes, by calculating the mean collision risk value, weighted by the number of routes per school catchment area, for both the safest and shortest routes; we call these the local collision risk values and calculate one for each catchment area. The mean probability of a child pedestrian injury for the entire study area is calculated for both the safest and shortest routes using all the estimated routes; this is referred to as the global risk value. We calculate the relative risk (RR) for each catchment area by dividing the local collision risk value by the global collision risk value. This is done for both the safest and shortest routes and shows what catchment areas have a relatively higher or lower collision risk value compared to the entire study area.

We calculate the attributable risk for each catchment area by subtracting the mean safest local collision risk value from the mean shortest local collision risk value. This attributable risk value represents the number of additional child pedestrian injuries attributable to children walking, assuming they use the shortest route instead of the safest route. The number of additional collisions per day is a very small number, so we estimate the number of additional collisions per year.

We estimate the number of additional child pedestrian injuries and deaths due to a collision with a motor-vehicle for the entire study area over a 10 year period, assuming children used the shortest routes instead of the safest routes to walk to school. Our analysis is performed using SAS® software, version 9.2 for windows (SAS Institute Inc. 2008).

4.3 Results

Figure 1 shows the number of additional child pedestrian injuries per year for school catchment areas, assuming children use the shortest route instead of the safest route. Every catchment area sees an increase in the number of child pedestrian injuries if we assume all children in each catchment area use the shortest route instead of the safest route. There is variability in the number of additional child pedestrian injuries between the catchment areas with Rosedale having the largest increase in child pedestrian injures at 0.50 per year. The other catchment areas above 0.4 additional child pedestrian injuries per year are: Gordon Price and Mount Albion. Rounded to the nearest integer, we estimate there to be 72 child pedestrian injuries over 10 years if all children take the safest routes to school. When children take the shortest routes to school we estimate there to be 173 child pedestrian injuries over 10 years. Therefore, assuming children use the safest routes to school instead of the shortest routes to school we estimate that over one hundred additional child pedestrian injuries and one child pedestrian fatality could be prevented based on the study by Safe Kids Canada (2009), where they find that one percent of child pedestrian injuries end up in a fatality.

Figure 2 shows the spatial variability in the number of additional child pedestrian injuries between the school catchment areas. The data was classified using Jenks Natural Breaks because three distinct groups of school catchment areas were present: catchment areas with 0.25 or less additional child pedestrian injuries per year; catchment areas with more than 0.25 and less than 0.4 additional child pedestrian injuries per year; and catchment areas with 0.4 or greater additional child pedestrian injuries per year. The school catchment areas with the largest increase in child pedestrian injuries are clustered mostly in two groups, (1) located at the north end of the study area, and (2) in the centre of the study area near the escarpment.

We calculate the relative risk (RR) of a child pedestrian injury for each catchment area assuming children take the shortest route and the safest route. Catchment areas with a relative risk greater than one indicate that the mean probability of a child pedestrian injury for that catchment area is greater than the mean probability for the entire study area. Figure 3 shows the spatial variability of the relative risk of a child pedestrian injury for school catchment areas assuming children use the shortest route to school. Most of the catchment areas of greater risk (RR greater than one), assuming children use the shortest route, are located north of the escarpment. There are two catchment areas with a RR greater than two, suggesting that the mean probability of a child pedestrian injury for these catchment areas is greater than twice the mean probability for the entire study area, when we assume that all children take the shortest routes to school. Figure 4 shows the spatial variability of relative risk of a child pedestrian injury for school catchment areas assuming, children use the safest route to school. The catchment areas of greater risk (RR greater than one), assuming children are taking the safest routes, are located south, north –west, and north-east of the escarpment. There is one catchment area with a RR greater than two, suggesting that the mean probability of a child pedestrian injury for this catchment area is greater than twice the mean probability for the entire study area when we assume children use the safest routes to school. The catchment areas northeast of the escarpment are areas of greater risk for both the safest and shortest routes to school. This could be because there are limited route options, thus both the shortest route and the safest route use similar infrastructure.

4.4 Discussion

In this paper we present and apply a method for empirically assessing the safety of children's walking routes to school. This method uses a journey-based approach – where the cumulative risk of a child pedestrian injury for the entire route to school is used to estimate the safety of a route. The journey-based approach is an improvement over other methods for empirically measuring the safety of a route to school because it incorporates the entire route to school instead of assessing individual locations along a route to school.

Part of the mandate of SRTS programs is to plan safe routes to school, but there is limited evidence about the effectiveness of the safety improvements developed as a part of the SRTS programs (Dumbaugh and Frank, 2007). With changes to the funding structure for SRTS programs in the United States, funds that were previously available for SRTS projects are now being consolidated with other funds and SRTS programs must now compete for funding against other programs related to recreation trails, environment mitigation, other pedestrian and bicycling needs, and minor road projects (Buckley *et al*., 2013). Most evaluations of SRTS programs have focused largely on whether the program is effective at increasing rates of walking, without considering what their effects on child pedestrian safety might be (Dumbaugh and Frank, 2007**;** Boarnet *et al*., 2005 (b); Appleyard, 2003). Thus the need to be able to evaluate the potential of SRTS programs for improved safety is becoming a necessity to secure and maintain funding.

We calculate the relative risk of a child pedestrian injury for school catchment areas for both the shortest and the safest routes to school. This provides a way to assess what schools are of greater risk depending on the type of route children use to walk to school, and where the implementation of an SRTS program would be most effective in reducing the risk of child pedestrian injuries. We find that there is variability in what school catchment areas are at greater risk of a child pedestrian injury and that the schools of greatest risk change if we assume children use the safest routes compared to the shortest routes. In our study area, if we assume children use the shortest routes to school, then many of the school catchment areas north of the escarpment area are at higher relative risk for child pedestrian injuries. In contrast, if children use the safest routes to school then many of the school catchment areas north of the escarpment are at lower relative risk for child pedestrian injuries. Therefore, catchment areas with the greatest reduction in risk of a child pedestrian injury are located north of the escarpment, assuming children use the safest routes instead of the shortest routes to school. Accordingly, if the Hamilton municipality was looking to implement SRTS programs, the school catchment areas north of the escarpment would potentially see the greatest benefit from the implementation of planned safe routes to school for child pedestrians.

We calculate the risk attributable to taking the shortest routes to school instead of the safest routes to school for each school catchment area. We found that over one hundred child pedestrian injuries and one child pedestrian fatality could be prevented in Hamilton, Ontario if children used the safest routes instead of the shortest routes to school. While shortest routes would account for an increase in injuries for all schools when compared to the safest routes, there is considerable variability between catchment areas. The variability suggests that some catchment areas have a larger difference between the safest routes and shortest routes, resulting in a greater number of child pedestrian injuries that could be prevented. A larger difference between the safest and shortest routes could be due to a greater range in estimated probabilities of a child pedestrian injury for roadways within the catchment area, where the shorter routes include road segments that have less favourable road environments for child pedestrians and therefore have an increased probability of a child pedestrian injury, while the safer routes avoid those unsafe road segments. Catchment areas estimated to see less of a reduction in the number of child pedestrian injuries could be due to the fact that the safest and shortest routes in catchment areas have similar cumulative risk estimates. While this is useful for estimating the reduction in the number of child pedestrian injuries, given the current estimates of the number of children who walk to school and assuming that all children who walk use the safest routes rather than the shortest routes to school, the attributable risk calculated in this paper does not give us an indication of the how safe the routes to school are for a given catchment area compared to other catchment areas.

In this paper, we use the safest and shortest routes as a comparison to demonstrate the method and its relevance for supporting the development and funding of SRTS programs. We do not know the actual routes that children take on their journey to school. We compare the shortest routes and the safest routes to school. Buliung *et al*. (2013) found that the shortest walking routes may not reflect the actual walking routes used by children. Children may use routes that are a combination of both safety and route length. We would most likely see a reduction in the estimated number of child pedestrian injuries prevented by children using safer routes to school if we compared the safer routes to routes that are neither the safest nor the shortest, but a combination of the two. Further analysis could be done where we assign a weighting to vary the importance of safety or length of a route in the route generating algorithm, or by comparing children's actual routes to school with the safest routes estimated using the probability model.

We have shown how the method presented in this paper is valuable because it provides a way to empirically assess the safety of children's walking routes to school, but it could also help to increase the number of children who walk to school. A common reason for parents not allowing children walk or bike to school is their fear of their child being injured due to features of the physical environment (Ridgewell *et al.*, 2009; Ahlport *et al.*, 2008; Kerr *et al.*, 2006; Gielen *et al.*, 2004). Kerr *et al.*, (2006) found that children are five times more likely to walk to school when parents have few concerns about the safety of their child's route to school. This method could be used to provide parents with walking routes that minimize the probability of a child pedestrian injury and more parents may be willing to allow their children to walk to and from school.

4.5 Limitations

There are several noteworthy limitations to this study. First, we do not include socio-economic status (SES) variables in the probability model we used to estimate the risk of a child pedestrian injury; instead, we match our control locations with our case locations using SES. It is already well established in the literature that children living in areas of low socio-economic status have the least safe routes to school (Pabayo et al., 2011; van Loon and Frank, 2011). We account for the effects of SES in our selection of controls so that we do not need to incorporate SES variables in the probability model. The probability model estimates the risk of a child pedestrian injury on a child's route to school due to features of the built environment. The benefit of not having SES variables in the regression model is that the resulting probability of a child pedestrian injury is easier to interpret and use to empirically assess the safety of routes to school because the logistic regression model only includes variables related to features of the built environment. Accounting for the effects of SES in our selection of controls improves the ability of the model to predict what catchment areas would benefit the most from the development of an SRTS program. As an example, some of the catchment areas north of the escarpment in Hamilton are areas of lower SES. In this paper we find that catchment areas north of the escarpment in Hamilton would potentially see the greatest benefit from the implementation of planned safe routes to school, including some of the catchment areas of low SES. This further emphasizes the potential benefit of planning safe routes for school catchment areas north of the escarpment because, regardless of SES, we estimate that the catchment areas north of the escarpment would see a reduction in the number of child pedestrian injuries if children walked to school using safer routes.

Second, we do not know how many children actually walk to school for each catchment area, or from what geographic areas within the 1.6 kilometre boundary of a school catchment area. The number of children and the spatial distribution of the children who walk to school could have an effect on the estimated number of child pedestrian injuries for a school catchment area for both the safest and shortest routes. Using a random number generator we select house locations within the school catchment areas that correspond to 33% of the child population because it has been found that 33% of children walk to and/or from school in Hamilton (Metrolinx, 2011). Many of the school catchment areas cover a small area and are separated by major roadways. Therefore, many routes to school will be on similar types of infrastructure and use the same routes as each other resulting in similar estimates for the number of child pedestrian injuries. There are some school catchment areas located around the boundary of our study area that cover larger areas. These larger catchment areas have the potential for more route choice and variability but they also tend to have fewer houses within the 1.6 kilometre distance of the school because many of the houses are located in rural areas.

Lastly, we assume that the safest routes are actually practical routes to use. The safest routes are often longer and could be considered too impractically circuitous for any child to use as a route to school. If the length of the routes does not matter, which is rarely the case, then all else being equal, the safest route would most likely be the preferred option. But we know the length of the route does matter, thus we included the length of the road segment as a variable in the probability model to help constrain safer routes to a reasonable length.

4.6 Conclusion

In this study we present a method for empirically assessing the safety of children's walking routes to school. This method uses a journey-based approach, where the cumulative risk of a child pedestrian injury for the entire route to school is used to estimate the safety of a route. The journey-based approach is an improvement over other methods for empirically measuring the safety of a route to school because it incorporates the entire route to school instead of assessing individual locations along a route to school. We use this method to evaluate the safety of routes to school for different school catchment areas in Hamilton, Ontario. We find that there is variability in the risk of a child pedestrian injury across school catchment areas in Hamilton, but that the risks change depending on which type of routes are taken to school – specifically, whether or not they emphasize safety or length of route. We demonstrate how the method presented can be applied to determine what school catchment areas would benefit the most from the implementation of a SRTS program and determine that if the Hamilton municipality was looking to implement SRTS programs, the school catchment areas north of the escarpment would potentially see the greatest benefit from the implementation of planned safe routes to school for child pedestrians. We apply the method to estimate the total number of child pedestrian injuries that could be prevented if all child pedestrians in Hamilton used safer routes to school. We estimate that over one hundred child pedestrian injuries could be prevented over ten years in Hamilton, Ontario if children used safer routes instead of shorter routes to school. This equates to the prevention of one child pedestrian fatality over ten years.

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Figure 1. The estimated number of additional child pedestrian injuries if all children walk the shortest routes to school instead of the safest routes to school by school catchment area.

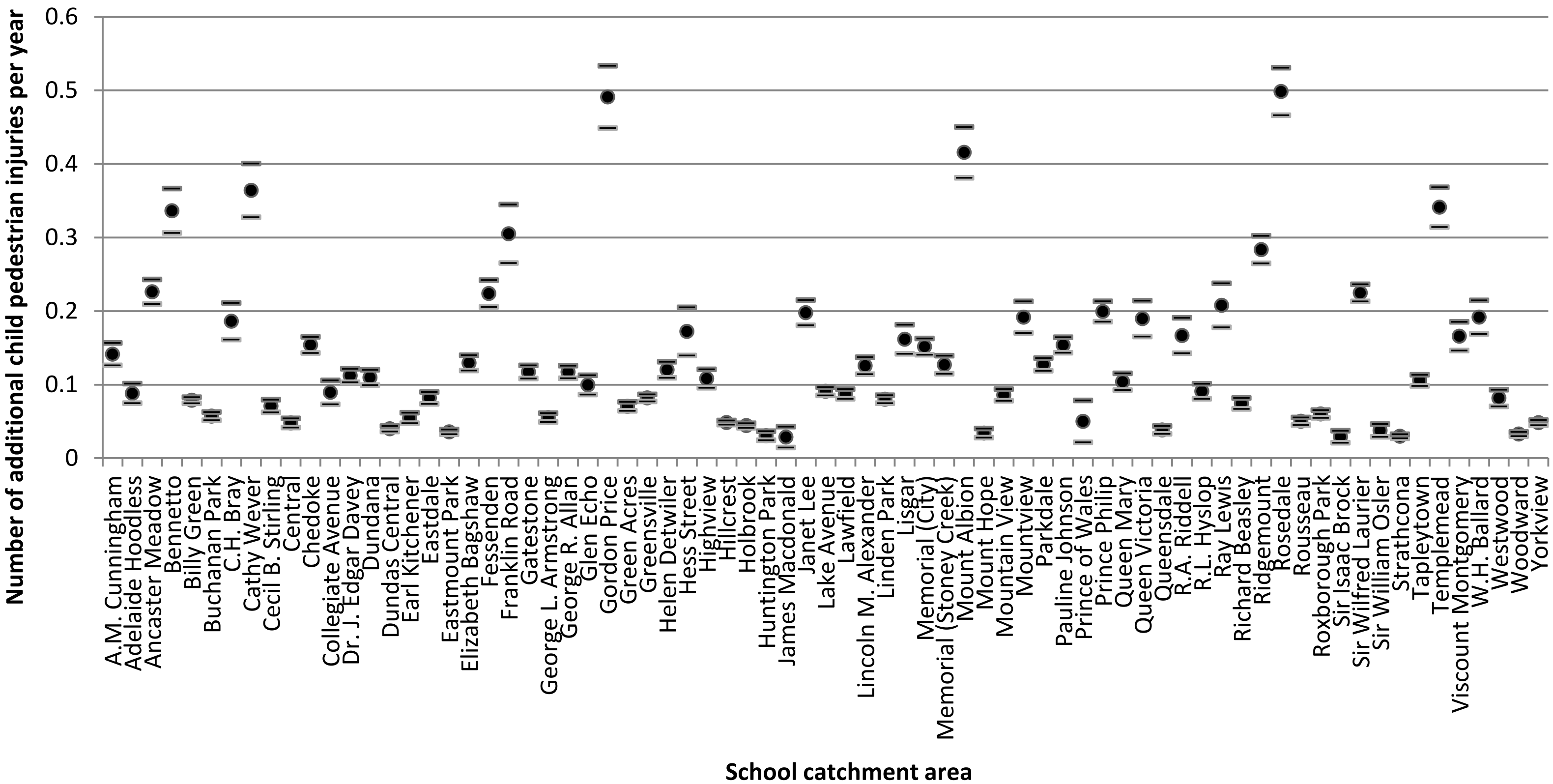

Figure 2. The number of additional child pedestrian injuries per year, by school catchment area, if all children walk the shortest routes to school instead of the safest routes to school. Classified using Jenks Natural Breaks.

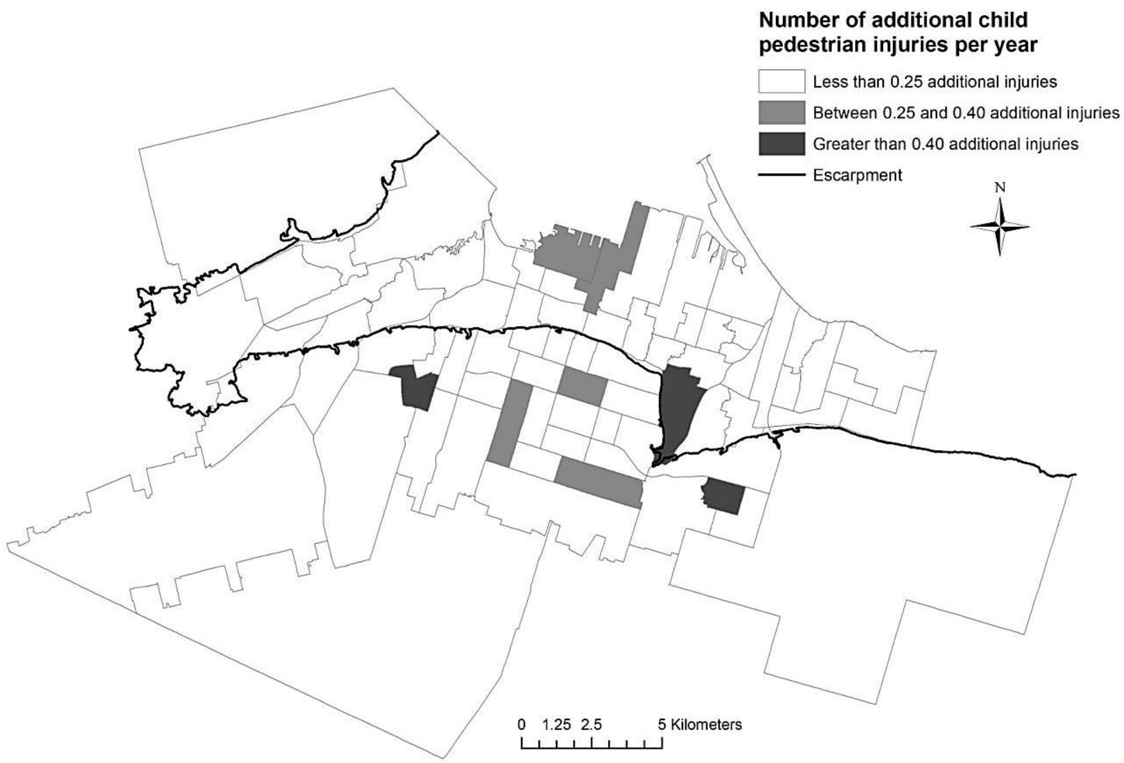

Figure 3. The relative risk (RR) of a child pedestrian injury (due to a collision with a motor-vehicle) while walking to or from school if all children use the shortest route.

Figure 4. The relative risk (RR) of a child pedestrian injury (due to a collision with a motor-vehicle) while walking to or from school if all children use the safest route.

Chapter 5: A decision support tool that incorporates safety and route length, to plan individualized routes for children walking to school

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Abstract:

This paper introduces a decision support tool, called the *route to school decision tool* (RSDT), which allows a parent to plan an individual route to school for their child. The RSDT incorporates both the safety related to features of the built environment, and total length of the route, to plan a route to school. The individual using the tool decides the importance of safety compared to length when generating the route. Using the RSDT we generate routes for multiple locations in Hamilton, Ontario, Canada using different preference values for the safety and length of the routes. In our analysis of comparing the routes generated using the RSDT we find that the safety and length of routes varies, both within and between school catchment areas.

Keywords:

Child; Decision Support Tool; Active Transportation; Safe; Built Environment; School

5.1 Introduction

Inactivity in children and youth is associated with child obesity and other health problems (Mitchell *et al.*, 2013; Tudor-Locke *et al.*, 2001; Guillaume *et al.*, 1997; Katzmarzyk *et al*., 1999; Suter and Hawes, 1993). Studies show that lifelong patterns of physical activity are established during childhood, and children who are regularly driven to and from school are less likely to appreciate the benefits of being physically active into adulthood (Tudor-Locke *et al*., 2001; Sleap and Warburton, 1993). Declining rates of physical activity among children highlights the need for children to have more opportunities to be physically active (Davison and Lawson, 2006). Using active transportation modalities — such as walking — for travel to and from school offers children an opportunity to increase their physical activity (Mitra *et al.* 2010; Tudor-Locke *et al.*, 2001) as school travel constitutes approximately 26 percent of all trips made by children (McMillan, 2005). This being said, the number of children who actively travel to school has declined considerably since the 1960's (Macdonald, 2011). Reasons for a reduction in the number of children walking or cycling to school include: the perceived safety of the route to school by parents and children, and the distance to school (McMillan, 2005; Zhu *et al.*, 2008; Carver *et al.*, 2008; Kerr *et al.*, 2006; Schlossberg *et al.*, 2006).

Children's perceptions of road safety are mostly concerned with fear of strangers and traffic (Carver *et al.*, 2008; Timperio *et al.*, 2004; Valentine and McKendrick, 1997). While a child's perceptions of the safety of their route to school has some influence on their decision to walk or bike to and from school, a parent's authority and perception of safety is much more influential on modal choice (van Loon and Frank, 2011; Carver *et al.*, 2008; Davison *et al.*, 2008; Kerr *et al.*, 2006; Timperio *et al.*, 2006; Davison and Lawson, 2006; McMillan, 2005; Sallis *et al.*, 1997). When parents have few concerns about their child's safety on the walk to school, or their desire to walk to school, children are five times more likely to walk to school compared to when parents have many concerns (Kerr *et al.*, 2006). Most parental concerns can be divided into two categories; (1) fear of their child being injured due to features of the built environment, such as traffic volume, and road characteristics (Ridgewell *et al.*, 2009; Ahlport *et al.*, 2008; Kerr *et al.*, 2006; Gielen *et al.*, 2004), and (2) fear of their child being abducted or injured due to interaction with strangers and bullies (Larsen *et al.*, 2012; Davison *et al.*, 2008). In this paper we introduce the *route to school decision tool* (RSDT), which allows a parent to plan an individual route to school for their child suited to the parents concerns about their child being injured from a collision with a motor-vehicle. The RSDT incorporates both the safety related to features of the built environment and total length of the route to plan a route to school. We measure the safety of the route as the probability of a child pedestrian injury, where a child pedestrian injury is a collision between a child pedestrian and motor-vehicle. The individual using the RSDT tool decides the importance of safety compared to length when generating the route.

Features of the built environment commonly associated with an increase in the risk of a child pedestrian injury includes: higher traffic volumes, faster speed limits, incomplete sidewalks, and roads with two lanes of traffic or greater (Yiannakoulias and Scott, 2013; Morency *et al*., 2012; Donroe *et al.*, 2008; Lascala *et al.*, 2004; Stevenson, 1997; Stevenson *et al.*, 1996; Roberts *et al.*, 1995; Stevenson *et al.*, 1995; Dougherty *et al*., 1990; Mueller *et al.*, 1990). Research on the risk of child pedestrian injuries due to features of the built environment has highlighted the modification of road/neighbourhood environments as a way to improve the safety of the traffic environment for pedestrians (Carver *et al.* 2008). Modifying the physical environment is a good solution for reducing the risk of child pedestrian injuries involving motor-vehicles but does not address the need to reduce the overall risk for a child's entire trip to school. As a decision support tool, the RSDT estimates a route to school that has the lowest risk of a child pedestrian injury, using the priorities a parent specifies for the safety and length of the route.

Distance to school may be an important influence on children's active travel choices. Some research finds that children commonly prefer shorter and more direct walking routes to school (Cooper *et al.* 2010; Hill, 1984) and that the farther a child lives from school, the less likely they will use active transport (Mitra *et al.* 2010; McMillan, 2007; Timperio *et al.*, 2006). Children are three times more likely to walk to school instead of being driven to school if they live within 1.6 kilometers of their school (McMillian, 2007). While distance is important in mode and route choice, the route also needs to be considered safe for child pedestrians (Panter *et al.*, 2010). Research shows that parents are willing to let their children walk greater distances to school provided they travel in a group, and the road and sidewalk infrastructure is safe (Schlossberg *et al.*, 2006).

The RSDT is a decision support tool designed to help parents plan the route their child uses to walk to and from school. McMillan (2005) finds that the rates of children walking to school are decreasing regardless of how close they live to school and suggests that other factors influence the decision about the mode of travel used for traveling to school. These factors may include a lack of planned safe routes for children to use when walking to school. The RSDT is useful for encouraging more parents to allow their children to walk to school because it allows a parent to plan an individualized route to school for their child that incorporates both safety and distance. An important feature of this tool is that it allows parents and children to determine the trade-off between safety and distance travelled, according to their personal risk assessment perspectives and priorities.

5.2 Methods

5.2.1 Data

We apply the RSDT tool using Hamilton, Ontario as our study area. Hamilton is located midway between Toronto, Ontario, Canada and Buffalo, New York, USA on the western end of Lake Ontario. The RSDT tool uses a pedestrian transportation network to plan a child's route to school. We create a pedestrian transportation network, for Hamilton, Ontario, that contains roads, trails, pathways and shortcuts — such as walking across green spaces and schoolyards — that could be used by children on their walk to school. Roadways that prohibit pedestrians were removed from the pedestrian transportation network. The pedestrian transportation network is an interconnected set of lines, each with a unique identifier. A segment refers to an individual line within the road network and starts or ends when another line crosses it; each road or off-road pathway in the network is made up of multiple segments. Each segment in the pedestrian transportation network is assigned a length in meters and is calculated in a geographic information system.

Every segment and intersection in the pedestrian road network is assigned a probability of a child pedestrian injury occurring during a single trip through that intersection or along that segment while walking to or from school. Intersection and segment probabilities were determined separately as different features of the built environment have been found to contribute to child pedestrian injuries occurring at intersection versus non-intersection locations (Sand and Zeeger, 2006). The probabilities for the intersection and non-intersection model are combined together; if a segment ends at an intersection then the estimated probability of that intersection is added to the estimated probability of the segment. This probability is based on a matched case-control study with collisions at locations involving child-pedestrians between 2002 and 2011 treated as 'cases', and a random selection of locations where collisions did not occur, as 'controls'. The precise details in selection of cases and controls and the analysis used to derive these probabilities is detailed in Chapter 2, but in short, combines data on historical collision events and features of the physical environment into a model informed by the child pedestrian injury literature.

5.2.2 Architecture of the RSDT

A schematic of the RSDT is shown in figure 1. The first step in the RSDT is input from the user: their origin location (house location), their destination location (school location) and a value between zero and one hundred, representing their preference for the safety of the route compared to the length of the route. For example, if a user enters a value of 75 for safety then the route generated is weighted by a factor of 75 towards a safer route, while the length of the route is given a weighting of 25. The next step is standardizing the values of length and safety in the road network used to generate the route so that they can be combined; this is done by converting the values to a standard score. The standard score values are multiplied by their corresponding factors (i.e. in the case of the previous example the standardized safety score is multiplied by 75, while the length is multiplied by 25) and summed together, resulting in one value per segment. A route is generated that minimizes the summed standardized values of the segments used in the route. The coordinates of the route are saved as an xml file. The resulting xml file is displayed using Google Earth (Google Inc., 2015). The RSDT is created in the Python programming language.

5.2.3 Variability of routes

To examine the variability in the routes planned using the RSDT we use the tool to 'plan' routes to school from individual houses that are within walking distance (1.6 kilometers) of an elementary school. Roughly 33% of children walk to and/or from school in Hamilton (Metrolinx, 2011), so using Dissemination Area populations — of children aged 5 to 14 — we randomly select house locations within walking distance to a primary school, which corresponds to 33% of the child population (Statistics Canada, 2008). Each house location was assigned a school location destination using the school catchment area boundaries, as greater than 80% of children live within the catchment area of the primary school they attend (Hamilton Wentworth District School Board, 2012; Hamilton Wentworth District School Board, 2011). We run the RSDT for each of the house locations using four different preference value scenarios for the safety of the route and length of the route: (1) a preference value of 100 for the safety of the route and 0 for the length of the route, (2) a preference value of 75 for the safety of the route and 25 for the length of the route, (3) a preference value of 25 for the safety of the route and 75 for the length of the route, (4) a preference value of 0 for the safety of the route and 100 for the length of the route.

We calculate descriptive statistics of the total length of the routes generated for each of the four different preference value scenarios for safety and distance, weighted by the number of routes per school catchment area. We use these descriptive statistics to compare how varying the preference for safety and distance affects the average length of route. We also compare the length of the routes by subtracting the route with a greater distance over safety priority value from the route length with a greater safety over distance priority value for a given location. We subtract routes generated using preferences (4) from (1) and (3) from (2). To compare the variability in the length of the routes for different school catchment areas, using the preference values from scenario (2) and (3) for safety and distance, we map the difference in the length of the routes for each house location.

We compare the safety of the routes generated using the four different preference value scenarios for safety and distance. The safety value for each route is a value representing the probability of a collision between a child pedestrian and motor-vehicle for that trip. Using the mean safety value weighted by the number of routes per school catchment area, we calculate the relative risk by dividing the mean safety value of trips generated using one set of preference values by the mean safety value of trips generated using a different set of preference values. Our analysis is performed using SAS® software, version 9.2 for windows (SAS Institute Inc. 2008).

5.3 Results

Figure 2 and figure 3 show four outputs from the RSDT using different preference values for the safety of the route and length of the route for the same house location. The top image in figure 2 shows a route using a preference value of 100 for safety and 0 for the length of the route. The bottom image in figure 2 shows a route using a preference value of 0 for safety and 100 for the length of the route. The top image in figure 3 shows a route using a preference value of 75 for the safety of the route and 25 for the length of the route. The bottom image in figure 3 shows a route using a preference value of 25 for the safety of the route and 75 for the length of the route. The RSDT provides the user with a map suggesting the route that best meets their input criteria. The routes generated with an emphasis on safety follow a less direct path using mostly residential roadways. The safest route is also the longest route and suggests using minor road ways until the child reaches the main road the school is located on, where it then recommends crossing at the intersection and then walking within the school yard to the school entrance. In contrast, the shortest route recommends a route mostly on arterial roads and a short-cut through an alley. The route with a preference value of 75 for safety and 25 for route length is shorter than the safest route and a mix of local and arterial roads. The route with a preference value of 25 for safety and 75 for route length is the same route as the shortest route.

The descriptive statistics showing the variability in route lengths generated using four different preference values for the safety of the route and length of the route are shown in table 1. The mean and median length of the routes increases as the preference of safety over length becomes greater. We also see an increase in the standard deviation, suggesting a greater variability in the route lengths, as the preference of safety over length becomes greater. The differences between the routes are show in table 2, where we subtract one route length from a different route length. The greatest difference in length of the routes is between the routes with 100% priority for safety subtracted from the routes with 100% priority for distance. The safest and shortest routes have a large standard deviation, suggesting that there is a large amount of variability between the safest and shortest routes. There is a considerable difference and standard deviation in the route lengths between the safest route and the route with a 75 safety and 25 length preference values, suggesting that a preference of the safest route seems to result in much longer routes compared to routes with a high preference for safety, but also include the length of the route as a part of the preference in the route choice. The difference between the routes using the other preference values suggests that there are still differences between the routes, but the differences are smaller compared to the differences between the routes with greater safety and route length priorities.

We map the standard deviation of the difference between the length of the routes with a 75 safety and 25 length preference values and routes with a 25 safety and 75 length preference values for each of the school catchment areas; the result is shown in figure 4. We chose to compare the in-between priority values because both safety and distance have been suggested by parents as reasons for not allowing their children to walk to school. These route priorities take both safety and length of the route into consideration when planning the routes. The map shows that there is variability in the length of routes, both between school catchment areas and within school catchment areas. The variability both between school catchment areas and within school catchment areas shows the importance of planning individualized routes to school that incorporate localized features of the built environment.

The comparison of the relative risk of the routes using the four different preference scenarios is shown in table 3. The greatest difference in the probability of a child pedestrian injury is between the safest and shortest routes, where the risk of a child pedestrian injury is on average 2.5 times greater for the shortest routes compared to the safest routes. When comparing the routes with 100% priority for safety to other routes, the relative risk decreases as the other routes have an increased priority for safety. On average, the risk of a child pedestrian injury is 1.34 times greater for routes with a priority of 100% distance and no safety, compared to 75% safety and 25% distance. The lowest relative risk is between the routes with 25% safety and 75% distance, and 75% safety and 25% distance. The lower relative risk between routes that are not the safest or shortest but have some weighting for both distance and safety could be due to the fact that there are only small changes to the routes when both distance and safety are given some priority in the RSDT.

5.4 Discussion

This paper presents the RSDT, a decision support tool that allows parents to plan an individual route to school for their child by assigning preferences for the safety and the length of the route. The RSDT is one of the first decision support tools designed specifically to plan routes to school for children that incorporates both the safety and length of the route in the decision making process, both of which influence the modal and route choices of parents and children.

We vary the importance of safety and length to compare the variability in the routes generated using the RSDT. The comparison of the routes to school shows there is variability in the length of the routes generated by the RSDT with the greatest variability between the shortest and safest routes. We see less variability in length of the routes between the routes generated with a mix of safety and road length preference values — such as, the comparison between the routes generates with 75% safety and 25% distance, and the routes generated with 25% safety and 75% distance — suggesting that some children have limited route options for walking to school, i.e. three different route options: the shortest, the safest, and a route somewhere in-between.

The comparison of the safety of the routes to school, generated using different safety and route length values shows a similar pattern to the length of the routes. The greatest difference in safety of routes is between the safest and shortest routes. The routes with a higher priority of safety have lower overall average probability values, compared to routes with a higher priority for shorter route lengths. The relative risk value gets closer to 1 as the priority of safety and distance get closer to being equal. This suggests there is less variability, on average, between the routes that are a combination of safety and length. The difference between the average route distance and safety values for the entire study area is useful for understanding how varying the importance of safety and length has an effect on the generation of routes, but it is also important to look at the route variability within school catchment areas for each of the scenarios using different safety and route length preferences.

Our results show that there is variability in the length of routes within each scenario, with the safest route scenario showing the greatest variability. We calculate the difference in length between routes with 75% safety and 25% length preference values and routes with 25% safety and 75% length preference values for each of the school catchment areas, and mapped the standard deviation of the differences. If there is little variability between route lengths as the priority of safety and distance is changed, then we would see small standard deviations for all school catchment areas. Instead, we find that there is variability in the standard deviation between catchment areas. We infer that school catchment areas with a larger variability have some roads or intersections that are less safe for child pedestrians, resulting in an increased route length for a safer route compared to a shorter route in order to avoid the unsafe infrastructure. Not all routes within a catchment area may be affected by the less safe infrastructure; therefore, a large standard deviation could be the result of a small number of routes that vary considerably in route length, while the majority of the routes see small changes in route length. Either way, the variability in routes revealed using the RSDT suggests that there is variability in the safety of routes depending on where a house is located within a school catchment area. This calls for further research in studying the equity of individual children's routes to school. The RSDT is a valuable tool for school trip planning because it accounts for within catchment variability by planning a route that is individualized for a specified house and school location.

Perhaps unsurprisingly, our results show that as the priority of safety increases, so does the length of the route. The safest routes — a preference of 100% safety and 0% route length — have the longest average route length when compared to any of the other route preferences where the length of the route has a preference value greater than zero. This is because when estimating the safest route, the RSDT only uses the risk of a collision to plan the route and comes up with a route that has the lowest risk of a collision with less regard for the length of the route. However these routes can sometimes be impractically circuitous. Instead, previous literature (and common sense) suggests that both the safety and the length of the route most likely have an influence on the likelihood of a child using a given route to walk to school and so it is important for the user to be able to incorporate both when planning a route. The advantage of the RSDT, as a decision support tool, is that it gives parents and children the opportunity to explore the effects of safety and distance on routes to school. This exploration process not only empowers informed decision making, but gives parents and children an opportunity to discuss, and even deliberate, over concepts of risk and reward.

5.5 Limitations

A limitation of the RSDT is the lack of contextual knowledge for planning the routes. The RSDT generates an individualized route that incorporates the safety and length of the route, but does not include local information, such as the location of the school entrance, and local geological features – i.e. the escarpment in Hamilton, Ontario that separates upper and lower Hamilton. With the RSDT, parents and children have the responsibility of applying their contextual knowledge to interpret the route and then modify the route if required. The addition of local contextual knowledge to the RSDT would further improve the individuality of the routes generated but is very difficult to achieve. Instead, the RSDT could be improved by providing the user with more options to modify their route choice. One example is to add to the RSDT an option to modify routes so that crossing major roadways always occurs at signalized intersections.

Another limitation is that we do not determine what routes are considered safe and not safe using the calculated absolute risk of a collision between a child pedestrian and motor-vehicle. Instead we compare the risk of the routes relative to other routes. The RSDT does not suggest if a route has too high of a risk value for a child to use it to walk to or from school; this decision is still dependent on the parent assessing the suggested route generated by the RSDT. A way to assess the relative safety of a child's route would be to calculate the relative risk of the individual route by comparing the risk of the individual route to the study area or school catchment area average. The relative risk could be included as an output along with the XML file showing the suggested route.

Lastly, in the RSDT road segment length has an influence on both the safety variable and the distance variable. For the safety variable, road segment length is included as a variable in the model used to estimate the probability of a child pedestrian injury. We include length of the segment in the probability model because the longer the segment, the greater the potential contact between a motor-vehicle and a child pedestrian, which could increase the risk of a child pedestrian injury. A potential issue arises when a user of the RSDT specifies that both route length and safety matter. For example, if a user enters a value of 75% for safety then the route generated is weighted by a factor of 75% towards a safer route, while the length of the route is given a weighting of 25%. In this situation, road segment length has an influence on the route in both the safety variable and the distance variable but for different reasons. The distance variable uses the segment lengths to reduce the overall route length, regardless of how safe the route is. In the safety variable, segment length is incorporated with other variables representing features of the built environment and is contributing to planning a route that is safer for child pedestrians. While the segment length is incorporated in the safety or distance variable for different reasons, the effect is the same: a reduction in the overall route length. That being said, we find that segment lengths have a greater influence in the RSDT when the priority is for a shorter route rather than a safer route and is most likely because route length is the only component that makes up the distance variable, while route length is one of multiple variables included in the probability model used to calculate the safety variable. When safety is a priority, the route length tends to be longer because distance is not the only factor to consider when planning the safer route, but the segment length helps constrain safer routes to a more reasonable route length.

5.6 Conclusion

In this paper we introduce the *route to school decision tool* (RSDT), which allows a parent to plan an individualized route to school for their child. The RSDT is one of the first decision support tools designed specifically to plan routes to school for children that incorporates both the safety and length of the route in the decision making process; both of which are common reasons for parents not allowing their child to walk to or from school. Advantages of the RSDT are that it plans individualized routes to school for children and allows parents and children to determine the trade-off between safety and distance travelled according to their personal risk assessment perspectives and priorities. In our analysis of comparing routes generated using the RSDT in Hamilton, Ontario, we find that the safety and length of routes varies both within and between school catchment areas and calls for the need for further research studying the equity of individual children's routes to school.

5.7 References

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Figure 1. Schematic of the route to school planner tool

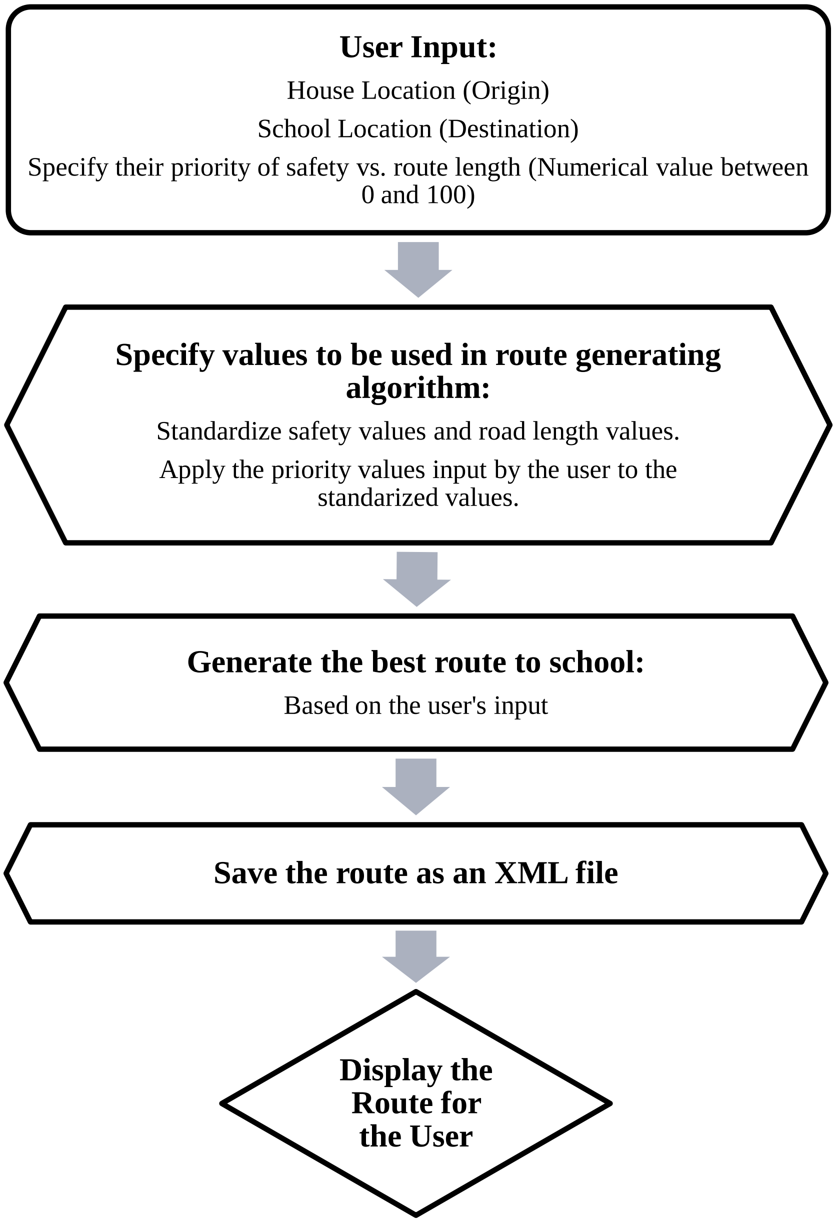

Figure 2. Example outputs of routes using different priority values. The route on the top is using a 100% priority for a safer route and 0% priority for the length of the route; the route on the bottom is using a 0% priority for a safer route and 100% priority for the length of the route (Google Inc., 2015)

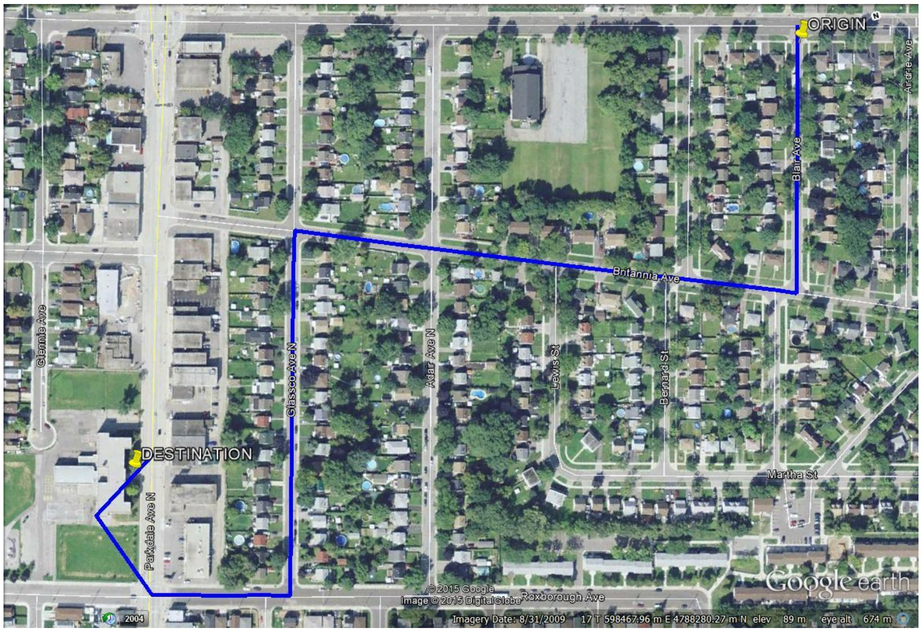

Figure 3. Example outputs of routes using different priority values. The top route is using a 75% priority for a safer route and 25% priority for the length of the route; the bottom route is using a 25% priority for a safer route and 75% priority for the length of the route, the route is the same as the 0% priority for safety and 100% priority for length of the route (Google Inc., 2015)

Table 1. Descriptive statistics, weighted by the number of routes per school location for the different route choice scenarios

Routes using a 25% priority for a safer route and 75% for route length		Routes using a 75% priority for a safer route and 25% for route length	
	(meters)		(meters)
Mean	855.94	Mean	928.54
Median	788.71	Median	844.95
Mode	220.63	Mode	220.63
Standard Deviation	476.46	Standard Deviation	537.97
Routes using a 0% priority for a safer route and 100% for route length		Routes using a 100% priority for a safer route and 0% for route length	
	(meters)		(meters)
Mean	770.08	Mean	1195.58
Median	720.07	Median	971.80
Mode	0.00	Mode	627.02
Standard Deviation	411.07	Standard Deviation	943.29

Table 2. Descriptive statistics, weighted by the number of routes per school location, showing the difference between route choice scenarios

Subtraction of the routes (route with 25% distance priority - route with 75% distance priority)		Subtraction of the routes (route with 0% distance priority - route with 100% distance priority)	
	(meters)		(meters)
Mean	72.60	Mean	423.84
Median	0.00	Median	200.73
Mode	0.00	Mode	0.00
Standard Deviation	173.60	Standard Deviation	699.44

Subtraction of the routes (route with 75% distance priority - route with 100% distance priority)		Subtraction of the routes (route with 0% distance priority - route with 25% distance priority)	
	(meters)		(meters)
Mean	84.20	Mean	267.04
Median	8.73	Median	0.00
Mode	0.00	Mode	0.00
Standard Deviation	141.29	Standard Deviation	679.07

Figure 4. A map showing the standard deviation of the difference between the routes (route length with 75% distance priority subtract the route length with 25% distance priority) for school catchment areas

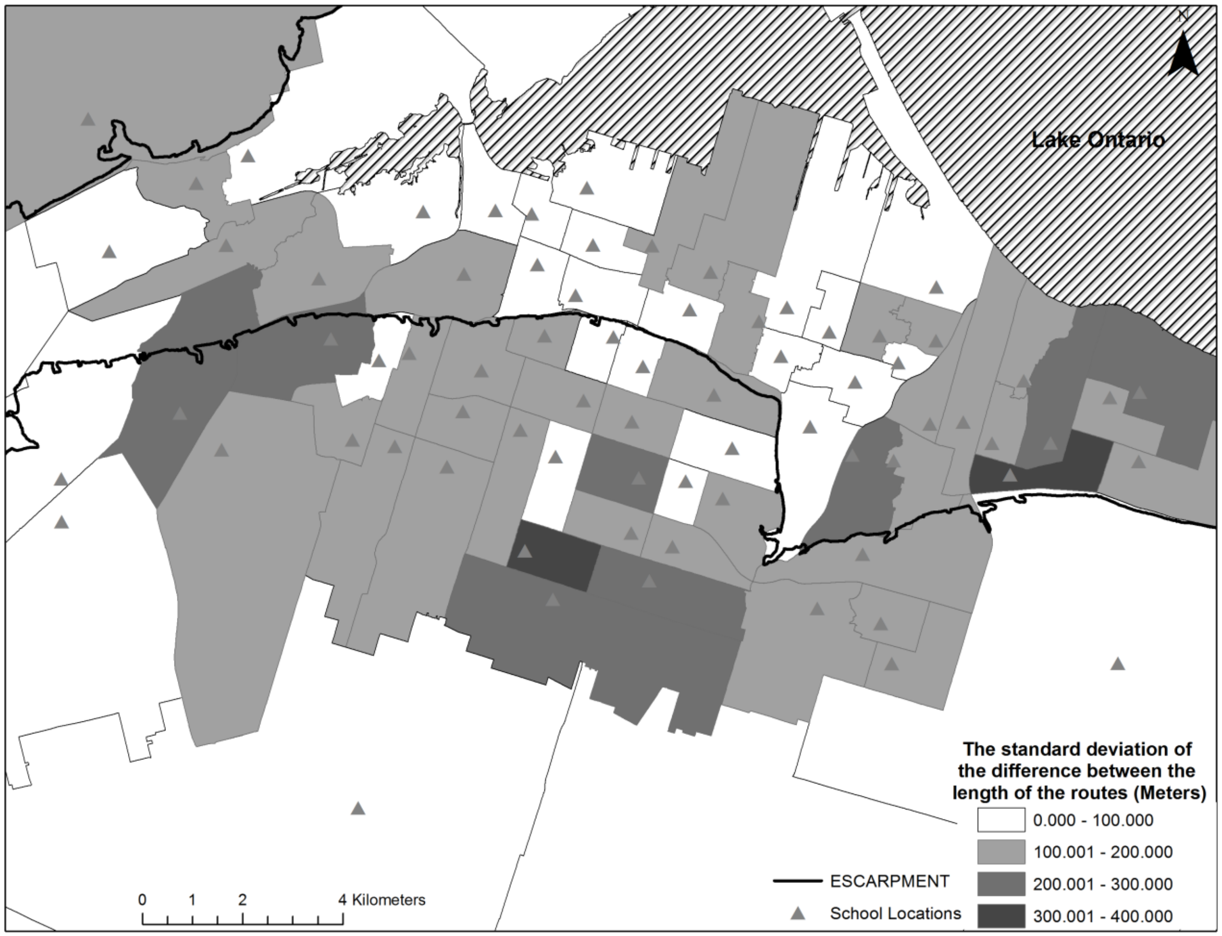

Table 3. Relative risk of a collision between a child pedestrian and motor-vehicle for the different route scenarios

	Relative Risk
0% Safety 100% Distance / 100% Safety 0% Distance	2.52
25% Safety 75% Distance / 100% Safety 0% Distance	2.13
75% Safety 25% Distance / 100% Safety 0% Distance	1.88
25% Safety 75% Distance / 75% Safety 25% Distance	1.13
0% Safety 100% Distance / 75% Safety 25% Distance	1.34

Chapter 6: Conclusion

The general theme of this dissertation is understanding and enabling safe walking routes to school for children. The foundation of this dissertation is chapter two, where our objective is to enhance general understanding of how small-scale features of the road environment differentially influence risk of collisions at intersection and mid-block locations. In this chapter we also assess the effect of using child pedestrian activity level information in small-scale analyses of pedestrian safety. We restrict our focus to safety issues related to the motorized-transportation environment, thereby defining safety as a function of factors that determine whether or not a child will be struck by a motor-vehicle on their journey to or from school.

Our results imply that the environment has a greater influence on the risk of child pedestrian injuries at intersections than at mid-block locations. We find that using child population to control for differences in walking activity levels may be sufficient in similar applications, and that future research need not endure the burden of controlling for differences in child pedestrian activities by estimating the journeys that child pedestrians take to school. That being said, the variables representing the estimated child pedestrian activity at intersection and mid-block locations are found to be highly significant in all our models, and are thought to contribute to more accurate prediction of collision risk at both mid-block and intersection locations. This could contribute to more accurate prediction of the probability of a child pedestrian injury at both mid-block and intersection locations, and in turn, along prospective journeys to school. Understanding risks of child pedestrian injuries while controlling for child pedestrian activity is essential for making informed decisions about the safety of children’s routes to school.

In chapter three we evaluate the agreement between perceived and model-estimated safety of intersections within our study area. We find there is some agreement between what intersections the expert analysis and parents’ survey responses suggest as unsafe but also that the expert analysis and parents' survey responses provide different information about why the intersections are unsafe. We observe some intersections in disagreement and use the survey responses from parents to understand why there is a discrepancy between parental and expert concerns for some intersections. We find that parents' concerns are a combination of the road environment and driver behaviour concerns, where many of the features of the road environment parents suggest make an intersection less safe are included in the model. Concerns related to driver behaviour were not included in the model but we suggest that many of the behaviour concerns can be addressed with changes to the road environment. Our results imply that if safety at intersections is to be meaningfully addressed then we need to understand how the road environment features at intersections influence the risk of a child pedestrian injury, as well as influence driver behaviours.

In chapter four we present a method for empirically assessing the safety of children's walking routes to school. Safe Routes to School (SRTS) programs are being embraced by schools, communities and governments world-wide but there is limited literature looking specifically at planning SRTS programs by estimating the risk of a collision for walking routes. The method we present uses a journey-based approach and is an improvement over other methods for empirically measuring the safety of a route to school because it incorporates the entire route to school instead of assessing individual locations along a route to school. With changes to the funding structure for SRTS programs in the United States, funds that were previously available for SRTS projects are now being consolidated with other funds and SRTS programs must now compete for funding against other programs. Thus, the ability to evaluate the potential of SRTS programs for improved safety is becoming a necessity to secure and maintain funding. We demonstrate how the method can be applied to promote the potential of SRTS programs for improved safety and to determine what school catchment areas would benefit the most from the implementation of a SRTS program. We determine that if the Hamilton municipality was looking to implement SRTS programs, the school catchment areas north of the escarpment would potentially see the greatest benefit from the implementation of planned safe routes to school for child pedestrians.

Working at a small geographic scale allows us to evaluate the variability in safe routes for children and apply our findings to develop a tool that could be used to plan individualized routes for children. We present a tool in chapter five, called the *route to school decision tool* (RSDT). The RSDT is one of the first decision support tools designed specifically to plan routes to school for children that incorporates both the safety and length of the route in the decision making process; both of which are common reasons for parents not allowing their child to walk to or from school. Advantages of the RSDT are that it can be used to plan individualized routes to school for children and it allows parents and children to determine the trade-off between safety and distance travelled according to their personal risk assessment perspectives and priorities.

Our analysis is unique because it is at a small geographical scale but is representative of an entire urban environment. We use Hamilton, Ontario as our study area. Using the results from a statistical model that determines what local features of the road environment influence the probability of a child pedestrian injury, we demonstrate the importance of planning safer routes to school. We estimate that over one hundred child pedestrian injuries could be prevented over ten years in Hamilton, Ontario if children used safer routes instead of shorter routes to school. This equates to the prevention of one child pedestrian fatality over ten years. This study not only demonstrates the potential reduction in the risk of child pedestrian injuries by planning safer routes to school, it also introduces methods that can be used to plan safer routes for children.

We use a journey-based approach where the cumulative probability of a child pedestrian injury for the entire route to school is used to measure the safety of a route. Furthermore, working at a smaller geographic scale allows us to evaluate variability between individual routes to school. Most of the current methods of assessing safe routes to school are either unable to assess the safety of individual trips to school or they merely assess the safety of particular locations along a trip instead of the entire trip. In our assessment of individual trips to school we find there is variability in the safety of routes to school between school catchment areas in Hamilton, and that the safety of the route changes depending on whether the importance is on safety or length of route. Additionally, using the RSDT we found that the safety of routes varies within school catchment areas, which suggests the need for further research studying the equity of individual children's routes to school.

This study provides valuable insight about the influence local features of the road environment have on the risk of a child pedestrian being injured by a collision with a motor-vehicle. We account for the effects of socio-economic status (SES) in our selection of controls so that we do not need to incorporate SES variables in the probability model. This also improves the generalizability of our findings because it allows us to assess the safety of routes to school based only on variables related to features of the road environment and, therefore, could be applied more generally to assess the safety of children's walking routes in other municipalities. The findings of this study also support the modification of the road environment to address local problems related to design of the road environment and driver behaviour that put children at a greater risk of being injured by a collision with a motor-vehicle. Furthermore, while we narrow our assessment in this study to children walking to school, the findings could be applied to children's walking routes more generally because children are likely at similar risk of injury when walking to other destinations. With the increasing popularity of SRTS programs comes a need for more customized routes to school.

The RSDT could be implemented by other municipalities to give parents and children the opportunity to explore the effect safety and distance has on their individual routes to school. Additionally, the RSDT could be used to plan routes to school for groups of children, such as walking school busses. If the methods presented in this study are implemented in municipalities similar to our study area, then they should achieve reductions in the risk of child pedestrian injuries. Our findings are most generalizable to municipalities with: a grid type street design and limited mid-block crosswalks, where the expectation is that pedestrians cross at intersections; smaller school catchment areas, designed to service neighbourhoods in close proximity to the school; a smaller central downtown core surrounded by older housing developments, with newer housing developments around the fringe of the municipality; single family homes being the dominate housing type. Our results may not be generalizable to municipalities that do not have similar characteristics to our study area because the effects of the road environment on child pedestrians could be different. Therefore, local road environment features found to be significant in the models used to estimate risk could vary due to the differences in characteristics between municipalities. This could be especially important for municipalities that incorporate mid-block crossings in their road environments, as the presence of mid-block crossings would most likely change the probabilities we estimate using our current models. It would be beneficial to compare our findings to findings from other municipalities to investigate geographic similarities or differences in what constitutes a safer route for child pedestrians.

The findings in this study contribute ideas about how features of the local road environment may and may not influence risk of collisions between child pedestrians and motor-vehicles. It also offers methodological insight for future research on pedestrian safety at small geographic scales. The scale of analysis is important; we demonstrate the importance of assessing the safety of routes to school for individual children as we find there is variability in the safety of routes to school with school catchment areas. However, our results are a reminder of the importance of understanding the interaction between environment and behaviour in research on traffic safety, and offers some caution to the notion of a universal 'safe route' to school. Whether or not a particular route to school is safe will very likely be dependent both on the environment and the child's behaviour in that environment.