

**The Effects of Land Use Patterns and Street Network Connectivity on the
frequency of Child Pedestrian-Vehicle Collisions:
An aggregate analysis in Portland, Oregon**

By

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TERMINAL PROJECT

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Abstract

The rise in childhood obesity rates have led to an increased focus on encouraging children to use active commuting, walking or bicycling, to increase physical activity levels. However, parents often cite traffic safety concerns for not allowing their child to walk to and from school. Unfortunately, risk of being struck by a vehicle is a prominent threat to child pedestrians. Pedestrian-vehicle collisions are the second leading cause of accidental death among children. Moreover, children represent a disproportionate number of pedestrian-vehicle collisions. Nationwide, children, ages 15 and younger, represented 25 percent of all pedestrian-vehicle collisions in 2009. Understanding the impacts of the built environment on child pedestrian-vehicle collisions can lead to policy aimed at reducing total number of child pedestrian-vehicle collisions as well as increasing active commuting among children.

Previous research shows the built environment influences both pedestrian activity and rate of pedestrian-vehicle collisions. However, little is understood of land use patterns and street network connectivity and their impacts on child pedestrian-vehicle collisions. This study seeks to understand how land use patterns and street network connectivity affect child pedestrian-vehicle collisions using an aggregate analysis at the census tract level. Results of the study provide recommendations for land use and transportation planning.

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I. Introduction

Rising rates of childhood obesity have focused on encouraging children to use non-motorized forms of transportation to increase physical activity levels (McDonald 2007). However, parents often cite safety as a factor for not allowing their child to walk to and from school (Schlossberg, Phillips et al. 2005; Schlossberg, Greene et al. 2006; Carver, Timperio et al. 2010). Unfortunately, risk of being struck by vehicle is a prominent threat to child pedestrians. Pedestrian-vehicle collisions is the second leading cause of accidental morbidity among children (McMillan 2005). Additionally, child pedestrians represent a disproportionate number of pedestrian injuries. In 2009 children, ages 15 and younger, represented 25 percent of all pedestrian-vehicle collisions (Administration 2010). These high rates of child pedestrian injuries remain while child pedestrian activity has decreased significantly. In 1969 50 percent of children walked or biked to school (Dellinger and Staunton 2002). In 2002 only 12 percent of children walked or biked to school (Dellinger and Staunton 2002). Planners, public health officials, and public policy professionals are faced with the challenge of increasing the rate of child active commuting while reducing the rate of child pedestrian vehicle collisions.

Research on walkability tells us access to public transit, increased street network connectivity, greater land use mix, and increased density promote walking as a form of transportation (Frank and Pivo 1994; Ewing, Handy et al. 2006; Gebel, Bauman et al. 2009). However, child pedestrians function at a different cognitive than adults (Vinje 1981; Dunbar, Hill et al. 2001; Barton and Morrongiello 2011; Wann, Poulter et al. 2011) and it is unknown how these measurements of the built environment effect the rate of child pedestrian-vehicle collisions.

Previous studies on child pedestrian vehicle collisions have focused on localized “hot-spots” or specific land uses such as recreational facilities and public schools. Few studies have looked at child pedestrian vehicle collisions at an aggregate level and even fewer have assessed measurements of walkability such as land use mix and street connectivity. This study considers factors from previous

research associated with child pedestrian vehicle collisions in addition to two measurements of walkability namely, land use mix and street network connectivity at an aggregate level.

The remaining paper presents a brief summary of the literature, discusses the methods, presents the results, and ends on a discussion of policy implications and future research.

II. Literature Review

Factors influencing child pedestrian vehicle collisions can be broken into five categories, cognitive and behavioral, demographic, socioeconomic, land use, and street design. Cognitive and behavioral factors make children more prone to pedestrian-vehicle accidents than adults (Miller, Austin et al. 2004; Barton and Schwebel 2007; Panter, Jones et al. 2008; Pediatrics 2009; Barton and Morrongiello 2011). Demographic, socioeconomic factors, land use, and street design play a compounding role influencing child pedestrian exposure to traffic and ability to provide safe behavioral cues for both child pedestrian and driver (Posner, Liao et al. 2002; LaScala, Gruenewald et al. 2004; Barton and Schwebel 2007; Barton and Morrongiello 2011). Since planners have more influence on the built environment than cognitive, demographics, or socioeconomic factors this literature review focuses on land use and the street design but briefly touches upon the former subjects. Table 1 displays personal attribute factors—demographics and socioeconomic—and built environment factors found in the literature to influence the rate of child pedestrian vehicle collisions.

Table 1: Influential Variables on the Rates of Child Pedestrian-Vehicle Collisions found in Literature

	Variables	Correlation	Author
Personal attributes	Demographics <i>Child density</i>	Positive	(LaScala, Gruenewald et al. 2004)
	Socio economic factors <i>Areas of fewer high income households</i>	Positive	(Cottrill and Thakuriah 2010)
	<i>Lower median income</i>	Positive	(Lascale, Gerber et al. 2000)
	<i>Higher percent of population non-white</i>	Positive	(Cottrill and Thakuriah 2010)
Built Environment	Land Use <i>Multifamily residential</i>	Positive	(Agran, Winn et al. 1996)
	<i>Recreational facilities</i>	Positive	(Clifton and Kremer-Fults 2007)
	<i>Middle schools</i>	Positive	(LaScala, Gruenewald et al. 2004)
	<i>Elementary schools</i>	Negative	(LaScala, Gruenewald et al. 2004)
	<i>High schools</i>	Negative	(LaScala, Gruenewald et al. 2004)
	Street Design <i>Higher Traffic Volume</i>	Positive	(Posner, Liao et al. 2002; Wann, Poulter et al. 2011)
	<i>Higher Operating Speeds</i>	Positive	(Wann, Poulter et al. 2011)
	<i>Arterial roadways</i>	Positive	(Wier, Weintraub et al. 2009)
	<i>Greater transit access</i>	Positive	(Clifton and Kremer-Fults 2007)
	<i>Street network connectivity</i>	Mixed	(Mecredy, Janssen et al. 2012)

Child Cognitive ability and Behavior

Child pedestrians are particularly vulnerable to vehicle collisions due to less developed cognitive abilities than adults and more often exhibit risky pedestrian behavior. Children lack the cognitive ability to judge the speed of oncoming traffic, report difficulty of spotting vehicles in their periphery vision, and display less capability than adults on using auditory senses to assess the ability to safely cross the street (Barton 2006; Barton and Schwebel 2007; Pediatrics 2009; Barton and Morrongiello 2011; Wann, Poulter et al. 2011). Moreover, children are more likely to choose more risky pedestrian routes and be distracted while crossing the street or playing on the sidewalk (Dunbar, Hill et al. 2001; Barton and Schwebel 2007).

Unsafe pedestrian behavior has been attributed to the main cause of child pedestrian vehicle collisions (Retting, Ferguson et al. 2003). A child darting, running into the road, is often cited as a precursor to a collision. Additionally, studies have found that improper crossing, walking in the road

way, and playing in the street are the highest precursors to pedestrian vehicle crashes (Zegeer, Stutts et al. 2004). One study found a majority, 53 percent, of children were struck crossing at mid-block (Agran, Winn et al. 1994).

Socio Economic Factors

Lower income communities trend higher incidents of pedestrian vehicle collisions (Rivara and Barber 1985; Barton and Schwebel 2007; Cottrill and Thakuria 2010). Cottrill and Thankuria (2010) found pedestrian vehicle collisions to be twice as likely to occur in low income areas. Additionally, they found pedestrians struck in lower income areas tend to be younger. The study showed twenty-eight percent of all pedestrians struck in low income areas were under the age of 16 compared to 10 percent in higher income areas (Cottrill and Thakuria 2010). In part, this phenomenon is explained by higher number of pedestrian trips in lower income areas, thereby increasing pedestrian exposure to traffic (Cottrill and Thakuria 2010). Still, it has been shown children from lower income families and minority-background tend to select more risky pedestrian routes (Barton and Schwebel 2007).

Built Environment Factors

Land Use

In general pedestrian vehicle collisions occur most often in areas of mixed use, where residential areas are adjacent to commercial (Miranda-Moreno, Morency et al. 2011). Miranda-Moreno (2011) controlled for pedestrian exposure and average daily vehicular traffic and found a marginal correlation between areas of high proportion of commercial land-use, transit access, schools, and the frequency pedestrian-vehicle collisions. However, the marginal increase suggests that the highest contributing factors are traffic volume. Their model showed that a 10 percent decrease in traffic would create a 11 percent decrease in pedestrian vehicle collision (Miranda-Moreno, Morency et al. 2011). Another study highlighted that neighborhood commercial and residential commercial land areas were correlated with higher incidents of pedestrian-vehicle collisions (Wier, Weintraub et al. 2009). Additionally, pedestrian-

vehicle collision research has shown big box retail and commercial strips are correlated with greater pedestrian vehicle collisions while pedestrian oriented retail are correlated negatively with the rate of pedestrian vehicle collisions (Dumbaugh and Li 2011).

Specific to child pedestrian vehicle collisions, few studies have looked at area-wide land uses. Agran, Winn et al. (1996) looked at residential types and found a correlation between child pedestrian vehicle collisions and multifamily residential (Agran, Winn et al. 1996). However, most studies are localized, typically focusing near the child's home or near schools. No studies have assessed the relationship between commercial uses and child pedestrian-vehicle collisions at an aggregate level.

Schools and Recreational Facilities

Active school commuting has been a major policy focus to increase physical activity among children (Miller, Austin et al. 2004; McMillan 2005; Schlossberg, Phillips et al. 2005; Clifton and Kreamer-Fults 2007; Sirard and Slater 2008; Hume, Timperio et al. 2009) this has prompted studies to look at the effect of schools on child pedestrian-vehicle collisions (LaScala, Gruenewald et al. 2004; Boarnet, Anderson et al. 2005; Clifton and Kreamer-Fults 2007). Child pedestrian injuries occurring during in-school months strongly correlate with middle schools but less so with elementary and high schools (LaScala, Gruenewald et al. 2004). LaScala, Gruenewald et al. (2004) suggests this is because middle schools attain more pedestrian trips without the accompaniment of an adult than elementary schools wherein most children are too young to walk to school alone. Moreover, high school students are more likely to drive, or get a ride. If high school students do walk or bike their cognitive abilities are more similar to an adult than a child (LaScala, Gruenewald et al. 2004).

Clifton and Kreamer-Fults (2007) Investigated attributes of school design in relation to child pedestrian-vehicle collisions. They found schools with recreational facilities have high rates and more severe pedestrian injuries. Additionally, they found schools with driveways or turnarounds to have fewer pedestrian injuries (Clifton and Kreamer-Fults 2007).

Other studies have focused on the effectiveness of the federal Safe Routes to School program in improving pedestrian safety. One study found a 20 percent decrease in year to year pedestrian injuries after the implementation of a Safe Routes to School program (Delaney, Newstead et al. 2004). Another study evaluated the California Safe Routes to School to assess if the engineering improvements increased walking. The study showed a significant increase in the number of children walking associated with the engineering improvements (Boarnet, Anderson et al. 2005).

Street Design

Traffic Volume and Speed

Generally where high pedestrian activity occurs adjacent to high traffic volumes pedestrians are struck the most often (Roberts, Norton et al. 1995; Macpherson 1998; Ewing, Schieber et al. 2003; Graham and Glaister 2003; Elvik 2009). This is a pertinent factor for children; Roberts (1995) found increased number of incidences occurred on high traffic streets. Another study looked at the rate of child pedestrian exposure to traffic and found a high correlation ($R^2=0.53$)(Macpherson 1998). The study evaluated the number of streets crossed and rate of child pedestrian vehicle collision. They found the more streets children had crossed the more likely the child would be struck by a vehicle. Finally, another study conducted an aggregate model on child pedestrian vehicle collisions and found a significant portion of the model is predicted by traffic volume (LaScala, Gruenewald et al. 2004).

While traffic volume predicts rates of pedestrian-vehicle collisions vehicle operating speeds predict severity of injury sustained (Roberts, Norton et al. 1995; Ewing and Dumbaugh 2009; Dumbaugh and Li 2011). A pedestrian struck at forty miles per hour has an 85 percent chance of being killed. The rate of fatality decreases exponentially as speed decreases. For instance when struck at thirty miles an hour a pedestrian has a 45 percent chance of being killed, and at 20 miles per hour or less a five percent chance (Zegeer, United States. Federal Highway Administration. Office of Safety et al. 2002; Ewing and Dumbaugh 2009).

High traffic speeds are particularly dangerous for child pedestrians. Children are shown to be less capable of detecting and avoiding looming objects at speeds greater than 20 miles per hour than adults (Wann, Poulter et al. 2011). This is a necessary ability in order to make safe crossing decisions particularly at unmarked crosswalks and where no crossing indicators exist.

Street type

A majority of pedestrians are struck at high traffic volume arterials (Agran, Winn et al. 1994; Roberts, Norton et al. 1995; Elvik 2009; Miranda-Moreno, Morency et al. 2011). For children, ages 15 and under, the street type they are struck depends on their age (Agran, Winn et al. 1994). The median age struck at intersections on arterial streets is 10, the median age struck at midblock on local streets is age 6, median age of those struck in parking lots is age 4, and median age struck in driveways is age 2 (Agran, Winn et al. 1994).

Transit Access

Several studies have also highlighted areas with a high number of transit stops have higher incidents of pedestrian vehicle collision (Wier, Weintraub et al. 2009; Cottrill and Thakuriah 2010; Miranda-Moreno, Morency et al. 2011). All studies that have found this correlation have suggested the higher incident rates are likely due to increased pedestrian activity. Wier (2011) found a correlation of pedestrian vehicle collision along arterial roadways without transit lines, suggesting that traffic volumes are more influential than transit access.

Network Connectivity

The influence of street network connectivity on pedestrian vehicle collisions is mixed. One study has shown the greater street connectivity improves the safety of child pedestrians (Mecredy, Janssen et al. 2012). Mecredy et al (2012) looked at youth street injuries both child pedestrians and cyclists. The increase safety in gridded streets is mainly attributed to increase safety in cyclist (Mecredy, Janssen et al. 2012). One possible reason is lower street connectivity funnels children to high traffic major arterials;

whereas a gridded street pattern disperses traffic and gives children more local street options (Mecredy, Janssen et al. 2012). Other studies have shown Lower Street connectivity is safer. In particular cul-de-sacs have been shown to be safer for children at play (Southworth and Ben-Joseph 2004). It is argued however, that children who grow up in a cul-de-sac forego the lessons in how to safely cross the street because they are not exposed to that task (Cozens and Hillier 2008).

Urban Form and Child Pedestrian Activity

Research on child pedestrian activity show the built environment has a profound effect on influencing pedestrian trips (Schlossberg, Greene et al. 2006; Panter, Jones et al. 2008; Panter, Jones et al. 2010; Loon and Frank 2011). Panter, Jones et al. (2008) conducted a systematic review of the literature on urban form and child pedestrian activity. Their analysis revealed children were more likely to walk where land use mix is greater—at least one commercial use and at least one recreation facility—and if lived in a high residential density neighborhood (Panter, Jones et al. 2008). Another study found children were more likely to walk school if the route entailed greater intersection density (Schlossberg, Greene et al. 2006).

Research question

The following sections presents the method used to answer the underlying question driving the study.

1. How do street design and land use patterns affect the frequency of child pedestrian vehicle collisions?

Specifically this study is interested in the effect of greater land use mixes on child pedestrian vehicle collisions and the effect of street network density on child pedestrian-vehicle collisions I ask:

- a. Does street network density affect the rate of child pedestrian-vehicle collisions?
- b. Does greater land use mix increase the rate of child pedestrian vehicle collisions?

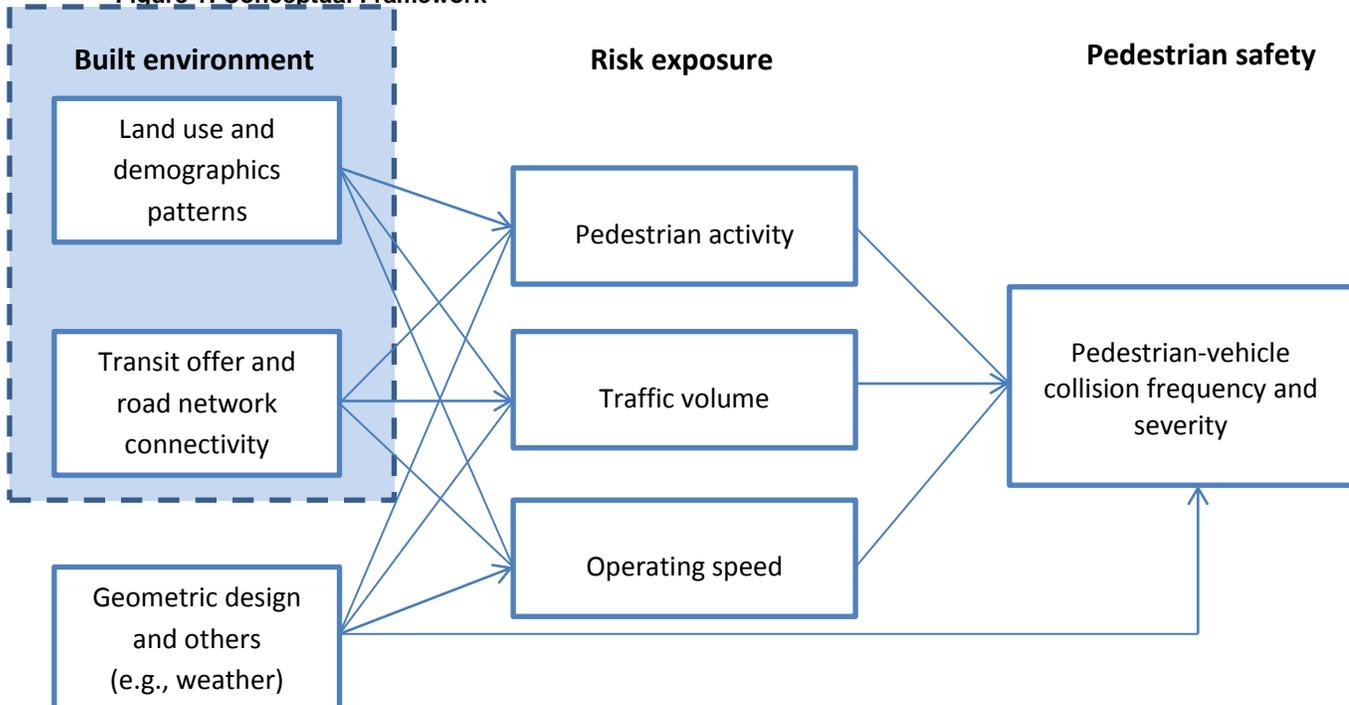
III. Methods

Conceptual Framework

Figure 1 displays a visual conceptual framework created by Miranda-Moreno, Morency et. Al. (2011). Previous research demonstrates the built environment has direct and indirect effects on the rate and severity of pedestrian-vehicle collisions. Land use, demographic patterns, transit access, road network connectivity, and geometric design of streets influence the amount of pedestrian activity, traffic volumes, and operating speeds (Ewing and Dumbaugh 2009; Dumbaugh and Li 2011; Miranda-Moreno, Morency et al. 2011). These factors in turn assess the rate and severity of pedestrian-vehicle collisions. Geometric design is the only variable that has a direct impact on the rate and severity of pedestrian vehicle collisions. This is because street design has the direct capability of limiting either pedestrian or vehicle access and influencing operating speeds (Ewing and Dumbaugh 2009; Miranda-Moreno, Morency et al. 2011).

This study focuses on land use and demographic patterns, and road network connectivity highlighted in the blue box of figure 1. It assumes that land use patterns, demographics, and road network connectivity affect child pedestrians different than adults therefore tests these attributes solely on child pedestrians.

Figure 1: Conceptual Framework



By: (Miranda-Moreno, Morency et al. 2011)

Research Design

The study is a two-step process. First, an aggregate analysis of child pedestrian-vehicle collisions at the census tract level is conducted. Variables, determined from previous research on child pedestrian-vehicle collisions and walkability, are used to create a multivariate linear regression model. Next, the model is applied to local “hot spots,” high incident areas of child pedestrian-vehicle collisions. A systematic area analysis was conducted at these hot spots using Geographic Information Systems and on-site investigation. The on-site investigation was used to determine the model fit at a smaller unit of analysis.

Study Area

This study focuses on Portland, OR, a city known for its pedestrian-friendly environment. It is ranked 12th most walkable city in the U.S. by walkscore.com. In addition the people of Portland Oregon

are known for their embrace of non-motorized transportation. Portland boasts the highest rate of persons commuting by bike to work, 5.44 percent, the highest in the nation (Bureau 2010).

Additionally, Portland's urban form is generally supportive of walking. One unique urban form quality of Portland is its short blocks, 250 sq. ft. by 250 sq. ft.. Shorter blocks typically translate to more intersections per sq. mi. a measurement that has been cited to encourage walking as a form of transportation (Berrigan, Pickle et al. 2010). Furthermore, Portland, Oregon has some of the most progressive policy on traffic calming in the U.S. (Ewing and Brown 2009).

Level of analysis occurs at the census tract level. This level of analysis was chosen because of its similar size to neighborhoods. In addition the level of analysis has been used prior in aggregate level analysis and proven effective (Wier, Weintraub et al. 2009). Aggregate analysis is more effective at the census tract level than block group and block level when the sample size is not robust, because it allows for greater aggregation and less study areas with zero data. Conducting an area level model can become increasingly unreliable where study boundaries contain zero data (Wier, Weintraub et al. 2009).

Additionally, American Community Survey is more accurate at the census tract level than the block group and block level (Wier, Weintraub et al. 2009).

Data Source

Pedestrian Vehicle Collisions

Pedestrian vehicle collisions were collected from the Oregon Department of Transportation (ODOT). Data received includes all collisions from 2000-2010. Only collisions involving child pedestrians 15 and younger were included in the study.

Pedestrian-vehicle collisions were compiled by ODOT from police reports. Collisions reported from 2007 to 2010 provided latitude and longitude data. Collisions reported from 2000 to 2006 did not have latitude and longitude data. Instead, pedestrian-vehicle collisions were marked by the street it occurred on, nearest intersection, direction from intersection and distance from intersection the

incident occurred. Using this data each collision occurring between 2000 and 2006 was manually mapped based on the measurements and intersections provided.

GIS Layers and Shapefiles

GIS layers and shapefiles were collected from the Regional Land Information Database (RLID) managed by the metropolitan planning organization (MPO) Metro. GIS layers and shapefiles used include street center lines, parcel data, schools, recreational facilities, and transit stops.

The census tract shapefile was sourced from the U.S. Census Bureau web site.

Demographic Data

Demographic data is from the 2010 decennial census and 2006-2010 American Community Survey. Population total, race, and ethnicity data came from the 2010 decennial census while percent of population at or below the poverty line, median income, percent unemployed, total vehicles available, and educational attainment came from the 2006-2010 American Community Survey. Demographic data is compiled at the census tract summary level.

Measures and Variables

Dependent Variable

The dependent variable is constructed by total collisions per total miles of roadway within each census tract. Roadways considered were those only accessible by both motorized vehicle and pedestrians—highways and freeways were not included. Weighting the collisions by miles of roadway helps to adjust for the varying sizes of census tracts. This dependent variable is used commonly in pedestrian- vehicle collision studies. In particular this dependent variable is the same used in LaScala, Greuenewald et al. (2004) who conducted an aggregate level study of child pedestrian vehicle collisions.

Children were defined as ages 15 and younger. This age group was chosen because it has been described as the most vulnerable group and legally dependent on foot travel for transportation (Roberts, Norton et al. 1995; McMillan 2005; Administration 2010)

Independent Variables

Table 2 displays all variables considered in the study and their unit of measurement. Variables are broken into four categories mirroring the literature, demographics, socioeconomic factors, land use and street design. Note control variables are marked with an asterisk.

Table 2: Independent Variables

Independent Variables	Measurement	Author
Demographics <i>*Percent of population 17 and younger density</i>	Total population 17 and younger per sq. mi.	LaScala, Greuenwald et. Al. (2004)
Socio Economic Factors <i>*Median income</i>	Median income	Cottrill (2010)
<i>*Percent of population at or below the poverty line</i>	Population at or below the poverty line by total population	Cottrill (2010)
<i>*Percent of population Asian</i>	Population Asian by total population	LaScala, Greuenwald et. Al. (2004)
<i>*Percent of population Black</i>	Population black by total population	LaScala, Greuenwald et. Al. (2004)
<i>*Percent of population Hispanic</i>	Population Hispanic by total population	Cottrill (2010)
<i>*Percent of population non white</i>	Population non-white by total population	Cottrill (2010)
<i>*Vehicles per capita</i>	Total number of vehicles available by total population	
<i>*Percent of population unemployed</i>	Total number of unemployed by total population sixteen and older	LaScala, Greuenwald et. Al. (2004)
<i>*Education attainment</i>	Total number of population 25 and older with a bachelors or higher by total population	LaScala, Greuenwald et. Al. (2004)
Built Environment <i>*Percent of land area dedicated to single family housing</i>	Total sq. ft. of single family residential by total land area	Agran (1996)

**Control variable*

Table 2 Continued: Independent Variables

Independent Variables	Measurement	Author
<i>Percent of land area dedicated to multifamily residential</i>	Total sq. ft. of multifamily residential by total land area	Agran (1996)
<i>Percent of land area dedicated to commercial use</i>	Total sq. ft. of commercial by total land area	Agran (1996)
<i>*Percent of land area dedicated to recreational facility</i>	Total sq. ft. of recreational facility by total land area	Clifton & Kreamer-Fults (2007)
<i>*Recreational facility density</i>	Total number of recreational facilities per sq. mi.	Clifton & Kreamer-Fults (2007)
<i>*School density</i>	Total number of schools per sq. mi.	Wier, Weintraub et. Al. (2009)
<i>*High school density</i>	Total number of high schools per sq. mi.	LaScala, Greuenwald et. Al. (2004)
<i>*Middle schools density</i>	Total number of middle schools per sq. mi.	LaScala, Greuenwald et. Al. (2004)
<i>*Elementary school density</i>	Total number of elementary schools per sq. mi.	LaScala, Greuenwald et. Al. (2004)
<i>Land use mix</i>	Dissimilarity index using four land uses single family residential, multifamily residential, commercial, and recreational facilities	
Street Design		
<i>3 and 4 way intersection density</i>	Total number of 3 and 4 way intersections per sq. mi.	Mecredy (2012)
<i>4 way intersections density</i>	Total number of 4 way intersections per sq. mi.	Mecredy (2012)
<i>Dead end density</i>	Total number of dead ends per sq. mi.	Mecredy (2012)
<i>*Percent of roadway classified as primary arterial</i>	Total number miles of primary arterial per total miles of roadway	Dumbaugh (2011)
<i>*Percent of roadway classified as arterial</i>	Total number miles of arterial per total miles of roadway	Dumbaugh (2011)
<i>*Percent of roadway classified as minor road</i>	Total number miles of minor roads per total mile of roadway	Dumbaugh (2011)

*Control variable

Control and test Variables

Control variables were determined from previous child pedestrian-vehicle collision studies. All demographic and socio economic variables are used as control variables. Also, schools, roadway classification, and transit access are used as control variables.

Test variables include percent of land area dedicated to single family residential, multifamily residential, and commercial in addition to land use mix and road network connectivity measurements.

Analysis Process

GIS

Using ArcGIS 10 child pedestrian-vehicle collisions were geocoded using latitude and longitude data and intersection data. Using a spatial join the collisions were added to the census tract that contained the crash points. The collisions were then divided by the total miles of roadway within each census tract to obtain the dependent variable.

Demographic variables were pulled from the census and joined to the census tracts using ArcGIS join table feature. Demographic variables were downloaded from the new American Fact Finder from the census bureau website.

Built environment variables were calculated in ArcGIS 10. Land use types were isolated from the parcel data shapefile using select by attribute, selecting one land use at a time and exporting the data to its own shapefile. This process was repeated for single family residential, multifamily residential, and commercial. Note industrial uses were left out because little pedestrian activity is associated with industrial uses. Once each shapefile was created a spatial join was used to assign land uses to the census tract they fell within. Total square feet of each land use type was then divided by total land area within the census tract, this established a percent of specified land use of the total land area.

The calculation of land use mix used total square footage of single family residential, multifamily residential, commercial, and recreational facilities to calculate a dissimilarity index. The equation used is shown below.

$$\text{Land use mix} = (-1) * [(b_1/a)\ln(b_1/a) + (b_2/a)\ln(b_2/a) + (b_3/a)\ln(b_3/a) + (b_4/a)\ln(b_4/a)] / \ln(n)$$

Where:

a=total square feet of all land uses

b₁=total square feet of single family residential

b₂=total square feet of multifamily residential

b₃=total square feet of commercial

b₄=total square feet of recreational facilities

n=4

Schools and recreational facilities were also mapped and spatially joined to the census tracts.

Recreational facilities were converted from polygons to points, joined to the census tract they fell within, and then divided by total land area to achieve a measurement of recreational facility density. Only elementary, middle, and high schools were considered. Post high school educational facilities were not considered. Note private schools are included in the dataset. The dataset was then further divided into middle schools, elementary schools, and high schools as defined in the shapefile attributes table.

Street design variables were calculated using the street center lines shapefile in ArcGIS 10. The shapefile provided street type as primary arterial, arterial, and minor roads. Highways and freeways were not considered since these road types were solely accessible by motorized vehicle. The streets were joined to the census tracts using spatial join. Then each street type was calculated as a percent of total streets within each census tract.

Street connectivity used ArcGIS 10 network analysis to convert intersection points to nodes. Using definition queries 1 way intersection, 3 and 4 way intersections, and 4 way intersection nodes were selected and then spatially joined to the census tracts. One way intersections represent dead ends. Each intersection type selected was then divided by total land area to assess the street network connectivity density.

When all data was collected, processed, and converted into an excel spread sheet I conducted multivariate linear regression models using IBM SPSS v. 20.

Statistical Analysis

The multivariate linear regression uses adjusted R squared to measure the correlation between the dependent variable and independent variables. Two models were created one containing only control variables and a second containing both the control and test variables. The difference of R squared was measured to assess the effect the test variables, land use mix and street network connectivity, on the frequency of child pedestrian vehicle collisions.

The regression form used is $Y=F(X_1, X_2, X_3 \dots)$ where Y equals the dependent and X represents the independent variables.

Not all variables considered were used in the final model. A stepwise process was used to select only variables that are statistically significant and have the most predictive power. Parameters were set at $p < .05$ (selection) and $p > .15$ (removal). Next, variables were assessed in univariate models to ensure the quality and accuracy of the data. Variables selected for the final model are shown in table 3.

Table 3: Independent Variables Selected for the Final Model

Independent Variables	Measurement	Author
Demographics <i>*Percent of population 17 and younger density</i>	Total population 17 and younger per sq. mi.	LaScala, Greuenwald et. Al. (2004)
Socio Economic Factors <i>*Percent of population Hispanic</i>	Population Hispanic by total population	Cottrill (2010)
<i>*Percent of population at or below the poverty line*</i>	Population at or below the poverty line by total population	Cottrill (2010)
Built Environment <i>*Middle schools density</i> <i>*Elementary school density</i> <i>*Recreational facility density</i> <i>Land use mix</i>	Total number of middle schools per sq. mi. Total number of elementary schools per sq. mi. Total number of recreational facilities per sq. mi. Dissimilarity index using four land uses single family residential, multifamily residential, commercial, and recreational facilities	LaScala, Greuenwald et. Al. (2004) LaScala, Greuenwald et. Al. (2004) Clifton & Kreamer-Fults (2007) Frank et. al. (2005)
Street Design <i>Dead end density</i>	Total number of dead ends per sq. mi.	Mecredy (2012)

**Control Variable*

Once the final variables were selected each variable was graphed on a scatter plot to determine its linear model fit. Transformations were then applied where appropriate to improve the model fit. Transformations were applied to four of the 8 variables. Land use mix used a squared transformation, middle schools per sq. mi. used a log transformation, percent of population as Hispanic used a categorical transformation and total dead ends per sq. mi. also used a categorical transformation.

Hot Spot Investigation

Model variables in the final model were then tested for their presence at specific hot spots for child pedestrian-vehicle collisions. Hot spots were determined using a kernel density feature in ArcGIS 10. The two highest incident areas were identified.

Next, a quarter mile pedestrian catchment zone was created from the center of the high incident areas. A quarter mile is chosen because it has been commonly used in other walkability

research. Within the quarter mile it is assessed whether each built environment variable identified in the linear regression model is present. Socioeconomic factors were not considered in the onsite investigation because the priority focus is on the built environment. Population 17 and younger per sq. mi. is assessed as a control variable. Population 17 and younger per sq. mi. is assessed at the block group level. Block groups that fell within the pedestrian catchment zone were selected.

Finally walk audits of two high incident areas were completed using Dr. Kelly J. Clifton Pedestrian Environment Data Scan (PEDS). This walk audit is chosen because of its proven use in academic research on walkability (Clifton, Livi Smith et al. 2007; Zhu and Lee 2008; Shay, Rodriguez et al. 2009).

IV. Results

Descriptive Statistics

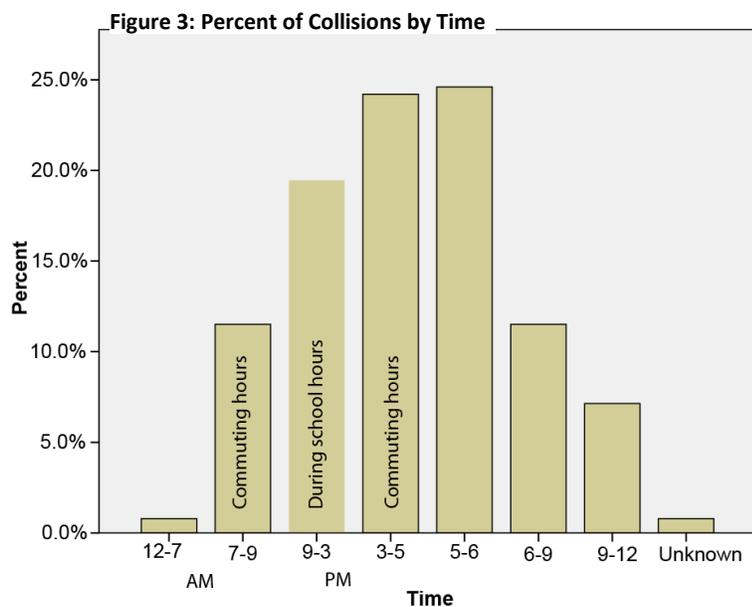
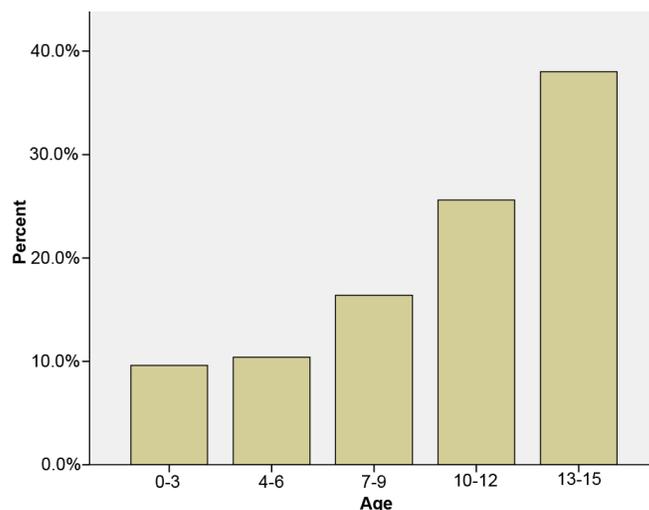
Between January 1, 2000 and December 31st, 2010 252 pedestrian-vehicle collisions involving children ages 15 and younger were recorded. Average age of injured child pedestrians is 10.4 years old.

Figure 2 displays the percent of total collisions by age group. Early teen years, 13-15, were recorded most frequently marking 95 crashes in eleven years or 38 percent of the 252 collisions.

Generally, collisions occurred when children are most likely to be outside and traffic volumes are at

their peak. The average time of collisions occurred at 4pm. Figure 3 displays the percent of collisions by

Figure2: Age Distribution of Child Pedestrian-Vehicle Collisions



time. The hour when most collisions occurred is between 5pm and 6pm.

Weather and driving conditions were generally nonhazardous. Most

collisions occurred on clear dry days, 66 percent, and during light hours, 72

percent. A small percentage, 6,

occurred during twilight. The month

with the most collisions occurring

within is July. Most collisions occurred during the week day with the most occurring on Tuesdays and

Fridays. Mondays were the lowest occurrence day. Figure 4 shows percent of collisions by month and

figure 5 shows percent of collisions by day.

Figure 4: Percent of Collisions by Month

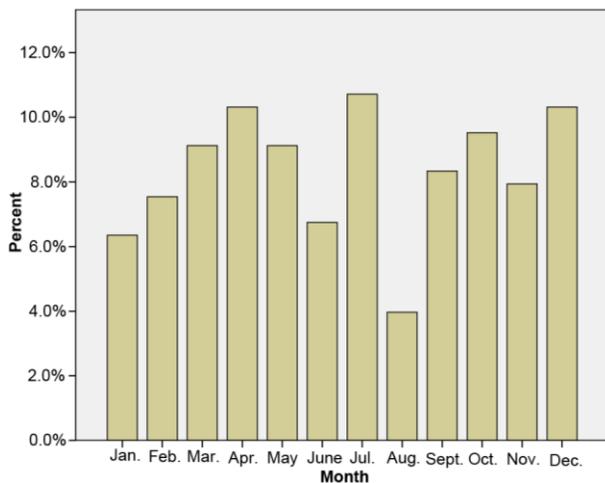
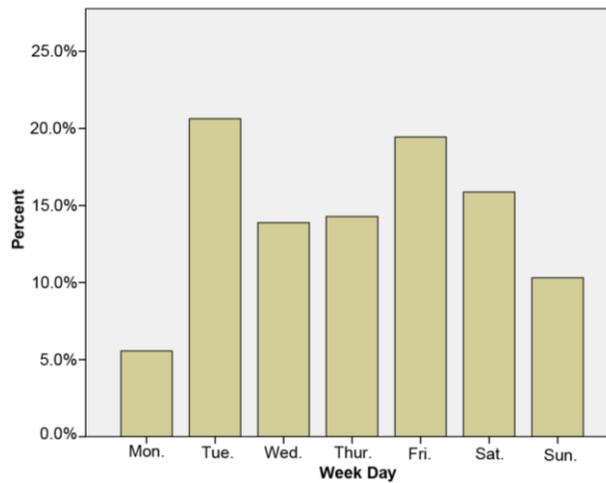


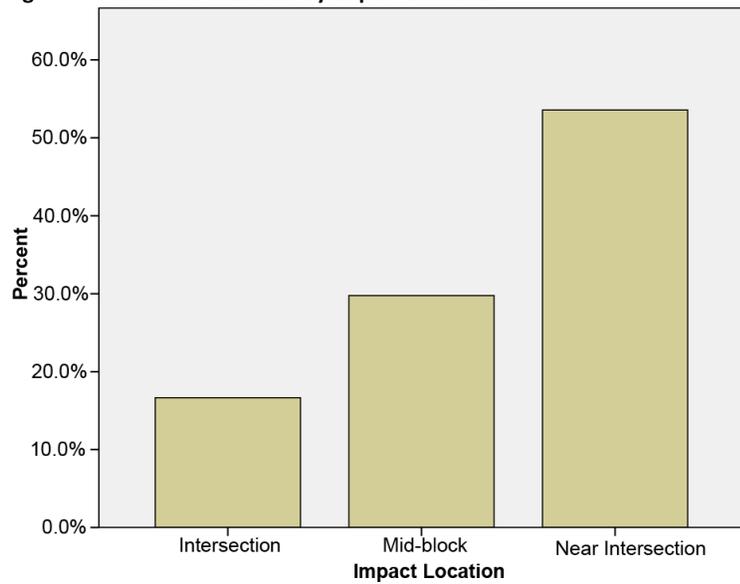
Figure 5: Percent of Collisions by Day of the Week



Collisions occurred most often within 50 feet of intersections, 50 percent. Nearly 32 percent of all collisions occurred at mid-block while 18 percent occurred at the intersection. Figure 6 displays

percent of all collisions by impact location. Primary arterial roads also had the largest share of child

Figure 6: Percent of Collisions by Impact Location

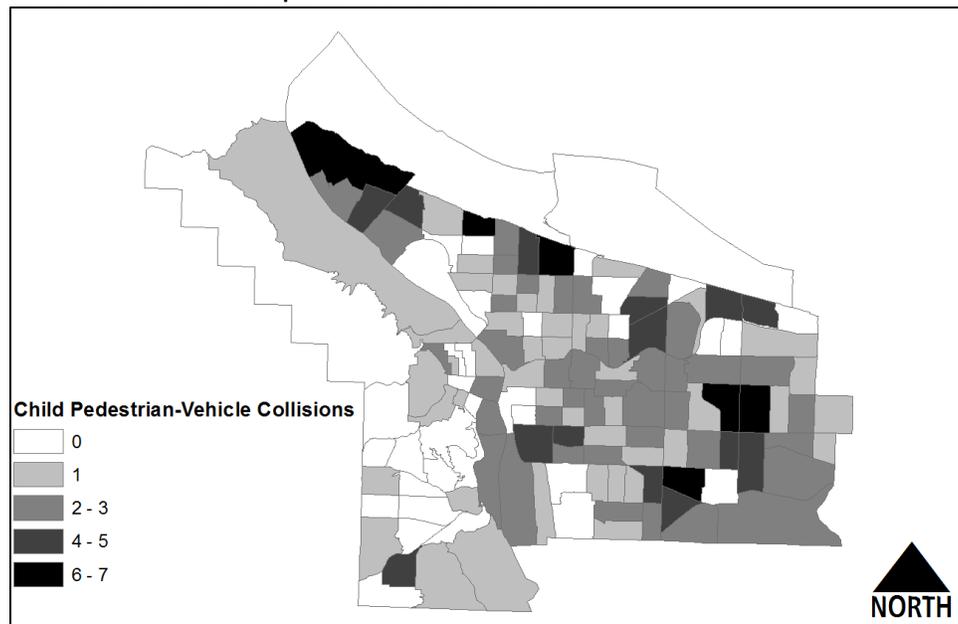


pedestrian-vehicle collisions, 49 percent. Arterials and minor roads (residential streets) split the remaining 51 percent, 25.5 percent each.

Collisions occurred most frequently in residential neighborhoods. The average distance from a school was .35 mi and from a recreational facility .30 mi.

Aggregate Analysis

Figure 7: Total Child Pedestrian Collisions per Census Tract 2000-2010



No child pedestrian-vehicle collisions occurred in 22 percent of the census tracts. The highest number of incidents within a census tract is 7, which occurred in four census tracts. Most census tracts had a single child pedestrian-vehicle collision, 32 percent. The average number of child pedestrian vehicle collisions per census tract is 1.73. Table 4 provides the descriptive statistics of the dependent variable.

Table 4: Dependent Variable Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
<i>Total child pedestrian injuries</i>	142	0.00	7.00	1.73	1.71
<i>Total length of roadway in mi</i>	142	4.47	93.79	19.68	12.59
Dependent variable					
<i>Child pedestrian injuries per mi of roadway</i>	142	0.00	0.46	0.10	0.10
Valid N (listwise)	142				

Concluding the stepwise process and a close analysis of each variable eight variables were shown to have the most statistical significance and predict the frequency of child pedestrian-vehicle

collisions with the highest percentage. Table 5 provides the descriptive statistics for the independent variables considered in the final model.

Table 5: Descriptive Statistics of Independent Variables

Independent Variables	N	Minimum	Maximum	Mean	Std. Deviation
Demographics					
<i>Population 17 and under per sq. mi.</i>	142	0.00	3377.46	1178.86	628.98
<i>Percent of population Hispanic</i>	142	0.00%	30.91%	8.63%	5.71%
<i>Percent of population at or below the poverty line</i>	142	0.00%	40.00%	12.68%	9.41%
Land use					
<i>Total recreational facilities per sq. mi.</i>	142	0.00	26.09	5.30	4.43
<i>Middle schools per sq. mi.</i>	142	0.00	3.64	0.22	0.67
<i>Elementary schools per sq. mi.</i>	142	0.00	4.52	0.89	1.12
<i>Land use mix</i>	142	0.12	0.98	0.69	0.19
Street network connectivity					
<i>Total dead ends per sq. mi.</i>	142	0.00	95.37	31.92	22.03
Valid N (listwise)	142				

As mentioned in the methods section transformations were applied to four of the eight variables to improve their model fit. The descriptive statistics for the variables after applying transformations are shown in table 6.

Table 6: Independent Variable Transformation Descriptive Statistics

Independent Variables	N	Minimum	Maximum	Mean	Std. Deviation
Percent of population Hispanic (categorical transformation)	142	1	4	2.15	1.010
Middle schools per sq. mi. (log transformation)	142	0.0000	1.5339	.117690	.3379294
Land use mix (squared transformation)	142	.0156	.9604	.507301	.2328506
Total dead ends per sq. mi. (categorical transformation)	142	0	3	1.53	.750
Valid N (listwise)	142				

The Control Model

Two multivariate models were completed the control model and the test model. The control model used variables found significant in previous child pedestrian-vehicle collision literature while the test model tested the addition of two new variables, intersection density and land use mix. Table 7 shows the outcome of the control model. The model predicted 38.4 percent of child pedestrian-vehicle collisions in Portland, Oregon.

Table 7: Control Model Output

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
Literature	.620 ^a	.384	.357	.0770514

a. Dependent Variable: Total collisions per mi. of roadway

Variables considered in this model include youth population density, percent of population at or below the poverty line, percent of population Hispanic, density of middle schools, and density of elementary schools. Table 8 shows the outcomes for the coefficients and their significance. Note all variables are significant at $p < 0.05$ except for elementary schools per sq. mi. and population at or below the poverty line. These variables are significant at $p < 0.1$.

Table 8: Control Model Coefficients

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Literature (Constant)	-.047	.019		-2.495	.014
Population 17 and under per sq. mi.	.072	.014	.474	5.268	.000
Percent of population at or below the poverty line	-.002	.001	-.164	-1.873	.063
Percent of population Hispanic	.025	.008	.261	3.163	.002
Total recreational facilities per sq. mi.	.006	.002	.285	3.921	.000
Middle schools per sq. mi.	.066	.019	.233	3.404	.001
Elementary schools per sq. mi.	-.011	.006	-.133	-1.780	.077

The most significant positively correlated variables in the control model are population 17 and under per sq. mi. and total recreational facilities per sq. mi.. These variables were significant below $P < .01$. Population 17 and under per sq. mi. had the strongest correlation ($R^2 = .171$) while total recreational facilities had the second strongest correlation ($R^2 = .102$). The third most significant model middle schools per sq. mi., showed a modest correlation to increased child pedestrian vehicle collisions ($R^2 = .079$). Each of these models is consistent with the literature.

Socio economic variables, however, show mixed results and were inconsistent with the literature. Percent of population Hispanic is significant at $P = .002$ with a positive of correlation ($R^2 = .069$).

This is expected based on the literature (Barton and Schwebel 2007; Cottrill and Thakuriah 2010). However, percent of population at or below the poverty line shows a negative correlation, though modest ($R^2 = .025$). Conversely, past studies show a positive correlation between areas with fewer high income families and incidents of child pedestrian vehicle collisions (Lascale, Gerber et al. 2000; LaScala, Gruenewald et al. 2004; Cottrill and Thakuriah 2010). However when considered in a univariate model the correlation is positive between percent of population at or below the poverty line and increased rates of child pedestrian-vehicle collisions. Other variables considered for this study included, percent non-white, educational attainment, and percent unemployed. All were statistically insignificant in the present model. Additionally, an inverse relationship occurred between those variables and incidents of child pedestrian vehicle collisions (LaScala, Gruenewald et al. 2004).

Finally, the model showed a negative correlation between elementary schools per sq. mi. and increased incidences of child pedestrian vehicle collisions, though modest ($R^2 = .025$). This variable is consistent with the literature. An aggregate study focusing on the effects of schools on child pedestrian-vehicle collisions shows areas with more elementary schools and high schools have less child pedestrian vehicle collisions, while areas with more middle schools have increased rates of child pedestrian-vehicle collisions.

Test Model

The test model introduces two new variables to the model land use mix and total dead ends per sq. mi. The results show a modest increase in predictability with the addition of these variables. Table 9 displays the model summary for the test model. The test model predicts 42.9 percent of events, an increase of 4.5 percent predictability from the control model.

Table 9: Combined Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
Test	.655 ^a	.429	.395	.0747114

a. Dependent Variable: Total collisions per mi. of roadway

Table 10 displays the independent variables their unstandardized coefficients, standardized coefficients, and significance. Note all but two variables are significant at $p < .05$. Percent of population at or below the poverty line and elementary schools per sq. mi. are significant at $p < .1$.

Table 10: Combined Model Coefficients

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Test (Constant)	-.041	.023		-1.830	.070
Population 17 and under per sq. mi.	.069	.013	.454	5.161	.000
Percent of population at or below the poverty line	-.002	.001	-.168	-1.939	.055
Percent of population Hispanic	.023	.008	.242	2.927	.004
Total recreational facilities per sq. mi.	.004	.002	.204	2.733	.007
Middle schools per sq. mi.	.059	.019	.209	3.133	.002
Elementary schools per sq. mi.	-.011	.006	-.133	-1.823	.071
Land use mix	.085	.031	.205	2.703	.008
Total dead ends per sq. mi.	-.020	.009	-.157	-2.248	.026

a. Dependent Variable: Total collisions per mi. of roadway

Table 11 displays the partial correlation of the independent variables land use mix has the 5th most predictive power of the variables while dead ends per sq. mi. the sixth highest predictor. Population 17 and under per sq. mi. remains the most important variable in the model. This is not surprising given this is consistently found to be true in child pedestrian-vehicle collision studies (Sandels 1995; Agran, Winn et al. 1996; LaScala, Gruenewald et al. 2004; Clifton and Kremer-Fults 2007).

Table 11: Partial Correlation of Independent Variables in the test model

Independent Variable	Correlation	R Square
Population 17 and under per sq. mi.	Positive	0.167
Middle Schools per sq. mi.	Positive	0.069
Percent of Population Hispanic	Positive	0.061
Total recreational facilities per sq. mi.	Positive	0.053
Land use mix	Positive	0.052
Dead ends per sq. mi.	Negative	0.037
Percent of population at or below the poverty line	Negative	0.027
Elementary schools per sq. mi.	Negative	0.024

Land use mix is a relatively low predictor ($R^2=.052$). However, considered in a univariate model land use mix has a much stronger correlation ($R^2=.123$). Percentage of land dedicated to commercial, single family residential, and multifamily residential were also considered, however the results showed low or no correlation in addition to being statistically insignificant. Interestingly percentage of land dedicated to commercial was not linear. Studies assessing pedestrian-vehicle collisions among all age groups show central business districts have more pedestrian-vehicle collisions (Sebert Kuhlmann, Brett et al. 2009; Wier, Weintraub et al. 2009). My study revealed an initial increase in the rate of child pedestrian-vehicle collisions as percent of land area as commercial goes up, however once percent of land dedicated to commercial reaches 10 percent the rate of events begins to go down and once hits 50 percent goes down drastically. One possible reason for this phenomenon is simply because children are not present in areas with high amounts of commercial, such as central business districts. Land use mix, in this regard, is particularly helpful in explaining how the relationship between residential areas and commercial areas has an influence on child pedestrian-vehicle collisions wherein it is likely commercial land use is hazardous to child pedestrians when it exists near residential areas, and or recreational facilities.

Dead ends per sq. mi. had an even more modest influence on the rate of child pedestrian vehicle collisions. Results show having more dead ends per sq. mi. is associated with a lower rate of child pedestrian vehicle collisions ($R^2=.037$). This finding correlates with the general research on cul-de-sacs that are shown to be safer for children playing outside (Southworth and Ben-Joseph 2004). Additionally, a bivariate model illustrated number of intersections correlates with length of block. Meaning areas with higher number of dead ends tend to have longer blocks while areas with higher intersection connectivity had shorter blocks. For child pedestrians longer blocks may mean less streets to cross, a variable associated with decreased rates of child-pedestrian vehicle collisions. Several studies have found that a child's exposure to traffic, counted as number of streets needed to cross on their route to school, has a

significant impact on the likelihood of that child being struck by a car (Macpherson 1998; Posner, Liao et al. 2002). Still, the finding is contrary to recent research by Mecredy (2012) whose study revealed increased street network density had a positive effect on reducing child pedestrian and child cyclist's accidents. However, Mecredy attributes the increase safety mainly due to less child cyclists-vehicle collisions not reduced child pedestrian-vehicle collisions.

The addition of land use mix and dead ends per sq. mi. had effect on the partial correlation of the control variables. Specifically, in the control model population 17 and under per sq. mi. had a stronger correlation ($R^2=.171$ in the control model compared to $R^2=.167$ in the test model). Total recreational facilities per sq. mi. had the largest change in influence on child pedestrian-vehicle collisions. Total recreational facilities per sq. mi. fell from $R^2=.102$ to $R^2=.053$. This is likely due to the fact that the land use mix model is made up, partly, of recreational facilities. Though a bivariate test between the two variables only has a Pearson correlation of .297.

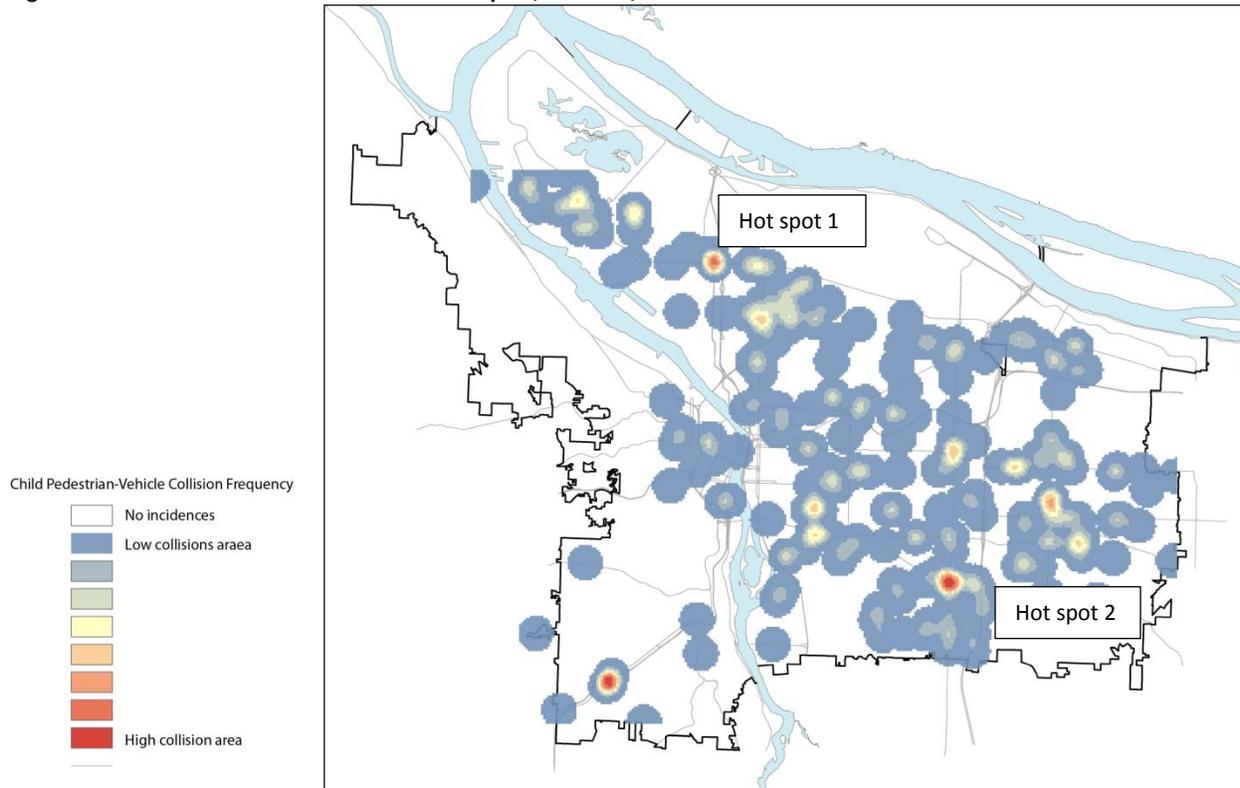
The remaining variables changed only slightly, .02 or less. In particular percent of population at or below the poverty line increased in predictability by .002 from $R^2=.025$ to $R^2=.027$. While elementary schools per sq. mi. fell from $R^2=.025$ to $R^2=.023$.

One nuance of the test model is the fact that many of the variables are correlated with increased incidences of child pedestrian activity. It is uncertain using this model alone to be certain that areas of higher land use mix, number of middle schools per sq. mi., increased street network density, higher percent of population Hispanic, and high density of children are in fact more dangerous or if it simply predicts higher rates of walking therefore more opportunities for child pedestrian-vehicle collisions to occur. That said, whether or not the latter is true this model still suggests that where child pedestrians are likely to be pedestrian safety infrastructure should be prioritized.

Still, to account for this factor the model was applied to localized areas that have the highest child pedestrian-vehicle collision frequency.

Local Analysis

Figure 8: Child Pedestrian-Vehicle Collision Hot Spots, Portland, Or.



The map above highlights high collision areas. Areas in red represent high incidences of child pedestrian collisions while the blue areas represent low incidences of child pedestrian-vehicle collisions. The hot spots used for analysis are identified as hot spot 1 and hot spot 2 on the map.

Table 11 displays the street location of the two hot spots, total child pedestrian vehicle collisions and traffic volumes. In hot spot 1 all collisions occurred within a single intersection. Collisions within hot spot 2 occurred mainly within the intersection as well. However, two collisions occurred at mid-block. Traffic volumes were generally high in these areas, average daily traffic above 12,000 vehicles. This is expected given the high correlation between traffic volumes and child pedestrian vehicle collisions in the literature (Agran, Winn et al. 1996; LaScala, Gruenewald et al. 2004).

Table 12: Collisions and Traffic Volume at Hot Spot

Hot Spot	Address	Collisions	ADT	Peak AM	Peak PM
1	N Lombard ST & N Interstate Ave	4	12057	4511	7546
2	SE Foster Rd & SE 82nd Ave	6	12358	4738	7283

Figure 9 displays the pedestrian catchment zone used for analysis of the hot spots. The onsite investigation revealed a close fit with the final model output in addition to revealing more nuances specific to land use patterns and geometric street design.

Figure 9: Quarter mile Pedestrian Catchment Zones of High Frequency Child Pedestrian-Vehicle Collisions Areas, Portland, Or.

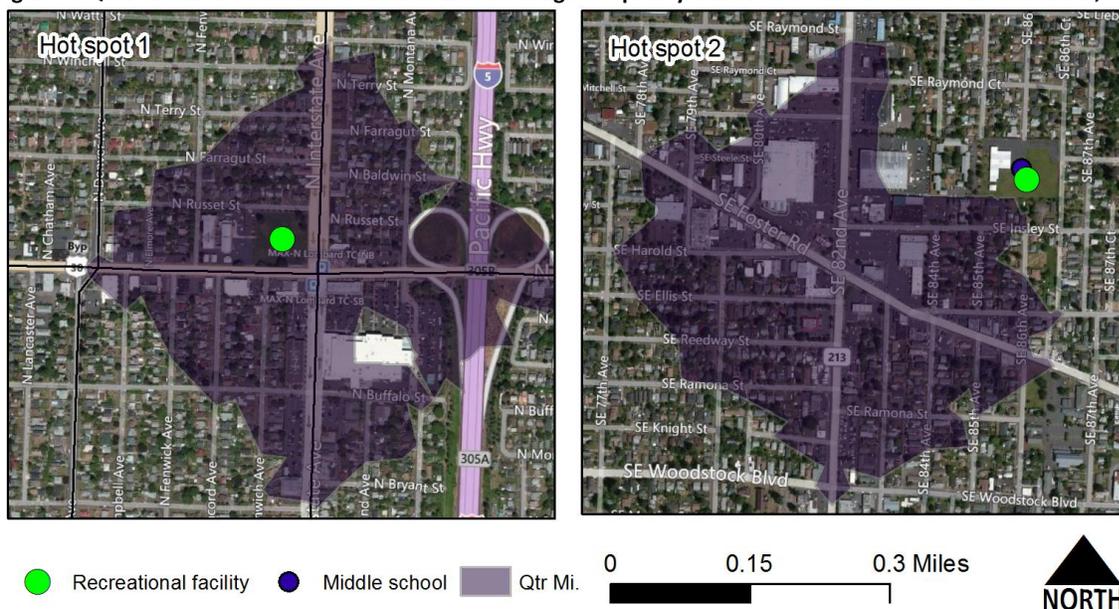


Table 13 displays the associated measurements of the final model output to the localized hot spots studied. Specifically highlighted are the land use types within the land use mix index in addition to presence of middle schools, recreational facilities, and a count of dead ends. Additionally population density of children 17 and younger was assessed. Socioeconomic factors were excluded because the assessment is to determine how well the built environment variables matched.

Table 13: Model Variables Applied to Local Child Pedestrian-Vehicle Collision Hot Spots

Hot Spot	Population 17 and younger per sq. mi.	Middle School	Recreational facility	Commercial	Residential	Dead ends
1	1,195	No	Yes	Yes	Single family and multifamily	3
2	2,080	Yes	Yes	Yes	Single family and multifamily	0

All land use types were found within the catchment zone or just outside. In hot spot 1 a recreational facility is adjacent to the center point of the analysis site while a recreation facility is located just outside of the pedestrian catchment zone in hot spot 2. Hot spot 2 has a middle school located just outside the catchment zone. However, hot spot 1 does not have a middle school within or near the catchment zone. It should be noted that adjacent to the recreational facility in hot spot 1 is a private high school. Though, the model did not find a correlation between high schools and increased incidences of child pedestrian-vehicle collisions. Additionally all commercial and residential types were within both catchment zones suggesting the land use mix variable does in fact fit these high incident areas.

In assessing the street connectivity related to these hot spots we find each have a low number of dead ends. Hot spot 1 had three dead ends while hot spot 2 had zero. These findings coincide with the final model output that showed a negative correlation between increased dead ends per sq. mi. and increased frequency of child pedestrian-vehicle collisions.

According to the final model output both hot spots should have a relatively high population 17 and younger per sq. mi.. This is true for Hot spot 2 which had a density of children higher than the average for all of Portland, Oregon (2,080 children 17 and younger per sq. mi. compared to Portland average 1,179 children 17 and younger per sq. m.). However, Hot spot 1 matches the average child density for all of Portland with a density of 1,195 children 17 and younger per sq. mi..

The two hot spots are similar except for a few key differences. They share similar traffic volumes, similar land use mix and presence of attributed land use types. However, hot spot 1 lacks a middle school, has more dead ends, and a lower density of children. Additionally hot spot 1 has fewer collisions as the model would suggest based on these attributes.

Walk Audits

The PEDS walk audit revealed interesting attributes of commercial design and geometric street design that should be considered more rigorously in future research. First, in both hot spots commercial buildings were primarily set back 20 feet or more in addition to having to walk through parking lots to access the commercial buildings. Second, both areas contained a big box retail store. Research has shown that big box retail and strip commercial development have higher incidences of pedestrian-vehicle collision, however no research has looked at big box retail and strip development and child pedestrian-vehicle collisions (Dumbaugh and Li 2011). Third, both areas had auto oriented retail located at the corners of intersections. In hot spot 1, gas stations were placed kitty corner from one another, while in hot spot 2 fast food drive-thrus and a gas station were found at the corners of the intersection. Fourth, both had operating speeds of 35 mph with five lanes of travel. It is likely the high operating speeds and wide streets play a particularly important role on the rate of child pedestrian vehicle collisions based on the literature that shows children have difficulty spotting looming objects at speeds higher than 25 mph and are vulnerable in high traffic areas (Posner, Liao et al. 2002; LaScala, Gruenewald et al. 2004; Wann, Poulter et al. 2011). Figures 10 and 11 display photographs of hot spot 1 and 2 demonstrating the commercial setbacks, auto-oriented retail at street corners, high number of parking lots and driveways, and wide streets.

Figure 10: Hot spot 1 N. Lombard and N. Interstate



Figure 11: Hot Spot 2 SE Foster Rd and SE 82nd Ave



V. Discussion

Results of this study need to be evaluated carefully. The study is not whether certain land use patterns or street connectivity is more dangerous than another type, rather it notes what land use patterns are street network connectivity exist where child pedestrian-vehicle collisions occur. In order to accurately determine one place safer than another accurate pedestrian counts are needed. Pedestrian counts would allow for a calculation of total number of pedestrian injuries per number of total pedestrians. This would allow for an assessment of what areas of higher rates of collisions versus simply higher number of incidents. The latter case can simply be caused by having more pedestrians in an area therefore more chances of a pedestrian-vehicle collision occurring.

Policy Implications

Lessons from this study support four policy implications

- Prioritizing pedestrian safety infrastructure in commercial zones in areas near middle schools, recreational facilities, and single family residential.
- Separating auto-oriented uses such as gas stations, drive-thrus, and big box retail from areas where, middle schools, recreational facilities, and residential areas are in close proximity to one another.
- Supports the use of engineering strategies that dead-end streets to motor vehicle traffic but still allow connectivity for pedestrian and cyclists such as full and partial closures.
- Improved accident reporting and data collection at the time of a child pedestrian-vehicle collisions namely more accurate reporting of the pedestrian actions and collision location.

Ultimately this study reveals two ways to improve safety of child pedestrians through separation of uses and design. In particular it is shown commercial zones are precarious to children when located within walking distance of residential areas, a recreational facility, and a middle school. However simply separating commercial zones from these areas is impractical. Moreover, greater land use mix is shown

to increase walking among children (Schlossberg, Greene et al. 2006; Panter, Jones et al. 2008). A more suitable policy suggestion is prioritizing pedestrian safety infrastructure in commercial zones.

Findings of the study reveal commercial zones are more suitable for pedestrian safety prioritization rather than school zones or recreational areas. For instance children are struck on average .35 miles from a school and .3 miles from a recreational facility. Also children are struck most often between 5pm and 6pm, after common school commuting hours. An aerial investigation of two child pedestrian-vehicle collision hot spots revealed that high incident areas are within commercial zones located near recreational facilities and middle schools.

Effective pedestrian infrastructure in commercial zones includes general traffic calming measures and reducing the number of lanes to cross. Previous studies have revealed children are most likely to be struck with increased exposure to traffic (Macpherson 1998; Posner, Liao et al. 2002). Additionally research on child cognitive ability shows children are unable to safely detect looming objects at greater speeds than 25 mph (Wann, Poulter et al. 2011). This suggests lowering speeds in commercial areas and using traffic calming measures to reduce speeding among motor vehicles. Furthermore, decreasing the distance crossing street distance will reduce child pedestrian exposure to traffic. Effective methods include reducing the total number of lanes, installing pedestrian refuge, or installing bulb-outs at crosswalks.

While general separation of uses is not recommended separating specific commercial types namely auto-oriented retail and big box retail from recreational facilities, and schools is suggested. A previous study has shown pedestrians are more at risk of being struck by a motor vehicle near big box retail and strip-commercial development (Dumbaugh and Li 2011). Given children have less developed cognitive ability than adults it is not a stretch to assume that these commercial developments put children at greater risk as well. My onsite investigation of two high child pedestrian-vehicle collision areas supports this finding as well. Both areas were characterized by auto-oriented retail at the corners, namely gas

stations and fast-food drive-thrus, and a big box retail store. Recreational facilities were located near these commercial uses.

Potentially, auto-oriented retail and big box retail can exist near schools and recreational facilities with proper pedestrian oriented design. However, a compounding factor unrelated to the design is auto-oriented and big box retail simply create large amounts of motor vehicle traffic. Regardless of design, previous research has shown where there is more traffic near higher density of children more child pedestrian-vehicle collisions will occur. Therefore, the most successful policy will be one that limits vehicle traffic and increases pedestrian traffic. Eliminating commercial uses that favor automobiles over pedestrians near areas where child pedestrians are likely to be—middle schools, recreational facilities and single family homes—is likely to indirectly reduce the number of child pedestrian-vehicle collisions most effectively.

The model also revealed decreased incidents of child pedestrian-vehicle collisions where there are more dead ends. However, research on increased active commuting amongst children show increased street network connectivity is correlated with increased walking. Engineering solutions that can meet both of these issues include partial and full closures.

Full and partial closures limit motorized vehicle traffic while providing permeable design for cyclists and pedestrians through the use of bollards or mounted curbs(Ewing and Brown 2009). Full closures completely dead end a street to motor vehicle traffic while still allowing pedestrian and cyclists to pass through. Full closures create a cul-de-sac like setting for children to play while also maintaining the walking benefits of higher street network connectivity. Partial closures limit traffic but not entirely. They may restrict travel to one-way while still allowing two-way travel by bike (Ewing and Brown 2009).

The final policy implication is related to how data is being collected at the time of reporting of a child pedestrian-vehicle collision. In particular data of pedestrian actions before the collisions and exact location of collision is needed. Understanding these attributes can supply useful information for

determining appropriate street design. The data provided by ODOT had a section for pedestrian actions; however the majority of events had no data. In terms of exact location the recent use of latitude and longitude data is extremely helpful for accurately geocoding the collisions. However, it is still uncertain exactly where they are located since GPS units have a margin of error often 3 feet or more. The data does provide such information but not in enough detail. For instance it provides a column to mark if collisions occurred off roadway, being in a parking lot, driveway, or alley. However it does not differentiate between the three or note whether they occurred within the parking lot or on the sidewalk crossing the entrance. Additionally data is provided whether the event occurred mid-block, near intersection, or in the intersection but the definition for near intersection is too large, within 50 feet or less of the intersection. This should be broken into “near intersection” six feet or less, and outside intersection 50 feet to six feet from the intersection.

On a final note general care needs to be taking to ensure all data is provided. Many of the collisions lacked data in important fields. For instance, sections such as number of lanes, number of turning legs, and intersection type often had no data or marked by a zero where inappropriate. For data such as number of lanes a notation of zero is impossible. Being able to quickly assess the number of lanes streets had where child pedestrian-vehicle collisions would help to provide support for certain types of street design.

Limitations

The study took steps to reduce bias and increase accuracy. However, several limitations still exist in terms of data and tools available to conduct analysis. These include likely underreporting of child pedestrian-vehicle collisions, using census tracts to define study boundaries, limited number of collisions and sites studied, and the lack of motor vehicle and pedestrian traffic counts.

First, it is likely that not all child pedestrian-vehicle collisions studied represent total number of collisions that occurred between 2000 and 2010. Collisions were collected by ODOT through police

reports, meaning for collisions to have been recorded it would need to have been reported to the police. Often collisions where no injury is sustained by the pedestrian go unreported.

Second, conducting an area level analysis at the census tract level can be problematic. For one census tracts are not evenly drawn. They are based on populations of roughly 4,000 people. Tracts at the edges of city boundaries tend to be largest while those concentrated in the center, typically around downtown, are the smallest. Due to this factor certain census tracts may pick up more child pedestrian collisions because of its sheer size. Additionally, arterial roadways tend to border census tracts. A majority of the collisions occurred on arterial roadways, 74.4 percent. Collisions that occur on the periphery may be influenced equally as much by the neighboring census tract as by the census tract the event occurred within. In order to address these issues collisions were divided by the total miles of roadway within each census tract to account for the size differences. Still this is not a perfect solution but the best use of what tools are available.

Third, a potential limitation is the relatively small sample size of 252 child pedestrian vehicle collisions. Other studies of this nature have used much larger samples, between 1,100 and 4,000. It is likely the results would be profoundly stronger had more points been available, fortunately however Portland, Oregon averages roughly 12 child pedestrian-vehicle collisions a year a number still too big but relatively small compared to other communities.

Finally, the model lacks motor vehicle and pedestrian traffic counts. Traffic flow is an important variable found in many other studies. Previous studies have found significant positive correlations between traffic flow and the rate of child pedestrian vehicle collisions (Agran 1996; LaScala, Greuenwald et. al. 2004). It is likely the model would have a much higher predictability rating had I been able to assess traffic flow as a variable. Additionally, given its importance in predicting child pedestrian vehicle collisions, this would be a particularly important variable to be considered with the two test variables, land use mix and dead ends per sq. mi..

Child pedestrian counts are needed to better understand the rate of accidents that occur in specified areas. Having the total number of child pedestrians would allow a calculation of rate of pedestrian-vehicle collision. This data can be helpful in determining if an area is in fact more dangerous or if more collisions are occurring simply because there are more pedestrians.

Future Research

The onsite investigation revealed further research opportunities understanding how commercial type, commercial building design and street design effect child pedestrian-vehicle collisions. Specifically future research should focus on design attributes of commercial space and street design on child pedestrian-vehicle collisions. Specifically assessing micro attributes of streets such as sidewalk width, presence of street trees, traffic calming infrastructure, crosswalk design, and more. In addition to assessing micro attributes of commercial building design such as setbacks, parking lot layouts, and placement of entrances. Understanding these attributes can lead to better street design and building codes to increase the safety of child pedestrians.

One suggestion to identify these design attributes is to focus on environments where child pedestrian-vehicle collisions do not occur. Most studies have looked either in high pedestrian-vehicle collision areas or the environment immediately surrounding a child pedestrian-vehicle collision. Few studies have conducted aggregate analysis and no studies have focused on where collisions have not occurred. This model and other variables associated with pedestrian-vehicle collisions can be used to assess areas that should have high pedestrian-vehicle collisions but do not. These areas can then be systematically studied to assess variables associated with street design and commercial building design to identify street design and building designs associated with improved safety for child pedestrians.

Conclusion

This study assessed the impact of land use patterns and street design on the frequency of child pedestrian-vehicle collisions. Using an aggregate analysis at the census tract level I found land use mix and dead ends per sq. mi. provided an additional 4.5 percent predictability. In all, areas with higher children density, higher percentage of Hispanic population, higher density of middle schools, higher land use mix, positively correlate with increased frequencies of child pedestrian vehicle collisions. A negative correlation is found between density of elementary schools, percent of population at or below the poverty line and frequency of child pedestrian vehicle collisions. The latter correlation is converse to previous research where a positive correlation is shown between areas of fewer high income homes and frequency of child pedestrian-vehicle collisions.

An onsite investigation of two child pedestrian-vehicle collision hot spots in Portland, Oregon reveals the model is an appropriate fit. Both areas had relatively high number of child pedestrian-vehicle collisions and had a mix of land uses, presence of recreational facilities, and few dead ends. Additionally, hot spot 2 had a middle school, higher density of children, and fewer dead ends in addition to greater number of child pedestrian-vehicle collisions. This is consistent with the model wherein the presence of these attributes correlates with greater frequency of child-pedestrian vehicle collisions. The onsite investigation also revealed future research opportunities namely the effect of big box retail, auto-oriented retail, large parking lots, and commercial buildings set back greater than 20 feet, and street width on child pedestrian-vehicle collisions.

Implications of the study suggest prioritization of pedestrian safety infrastructure at commercial centers in areas with greater land use mix, higher density of middle schools, higher percentage of Hispanic population, high density of recreational facilities, and high street network connectivity. Additionally, findings suggest a separation of auto-oriented and big box retail from areas near recreational facilities and schools. Potential design solutions to increasing safety of child pedestrian

safety collisions include full and partial closures, bulb outs, and traffic calming measures. On a final note better data collection is needed on child pedestrian-vehicle collisions namely information on pedestrian actions and better accuracy of collision locations.

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