ABSTRACT

Title of thesis: AN ANALYSIS OF PEDESTRIAN-VEHICULAR CRASHES NEAR PUBLIC SCHOOLS IN THE CITY OF BALTIMORE, MARYLAND.

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In previous research, children have been shown to be involved in pedestrian-vehicular crashes in high numbers due to improper pedestrian behaviors. Little research has been conducted to examine the relationship between schools and pedestrian crashes. This study analyzes pedestrian-vehicular crashes in the City of Baltimore, Maryland to determine any relationships that may exist between crashes near public schools and the physical and social attributes of these schools. It was found that the presence of a driveway decreases crash occurrence and severity. A setback from the road will decrease crash occurrence but increase the severity of the crashes. The presence of off-street parking was shown to increase the severity of a crash, particularly for children ages 16-18. Recreational facilities are shown to increase the crash occurrence and severity of crashes. This study however, is limited as it does not include pedestrian demand data and the results should be interpreted as such.

AN ANALYSIS OF PEDESTRIAN-VEHICULAR CRASHES NEAR PUBLIC SCHOOLS IN THE CITY OF BALTIMORE, MARYLAND

by

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DEDICATION

This thesis is dedicated to my amazing husband and best friend, Dan. Without his patience and balance I would not be here. So it’s finally finished and now I will start running with you.

Also to my parents, Jim and Kathy, who have always encouraged me to succeed and supported my ambitions.

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I would like to thank Dr. Kelly Clifton for all of her advice and insight over the past couple years.

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CHAPTER ONE: INTRODUCTION

1.1 Motivation

Every year numerous child pedestrians are killed or injured in pedestrian-vehicular collisions. Children 15 years and under are involved in almost one-third of all pedestrian-vehicular crashes. In 2001, over 500 children, 15 years and under, died and 24,000 children were injured in pedestrian-vehicular crashes (National Highway Traffic Safety Administration, 2002). Previous research has shown children's involvement is correlated with improper pedestrian behaviors, such as midblock darting, intersection dashing and playing in the road (Federal Highway Administration, 1996). Because most child-pedestrian crashes have been attributed to these behaviors, little research has been conducted to examine the relationship between the environments around schools and the pedestrian crash.

Although the number of children who actually walk to school has been steadily decreasing, in 1970 sixty-six percent of students walked to school and in 2000 only thirteen percent of students walked to school (Department of Health Services Centers for Disease Control and Preventions, 2000), many programs and initiatives have been established in an attempt to encourage children to commute to school using non-vehicular modes. Encouraging students to walk to school has many potential benefits. Fewer children being driven to school by automobile lessens the number of cars around schools, decreasing congestion and decreasing crash odds. Walking to school also provides children, and possibly parents, with physical activity. Finally, walking to school gives children a sense of their community and a comfort with their surroundings.

Understandably, many parents are reticent or even unwilling to allow their children to walk to school. Some parents are satisfied with the time they are able to spend with their child when driving them to school and are too busy, or otherwise, to walk them to school. However, the two most common reasons that parents will not allow their child to walk to school are harm to their child from strangers or ill-intentioned persons, or harm to their child from vehicular traffic (National Highway Traffic Safety Administration, 2004).

This paper addresses the second concern. Fundamentally, if the environmental factors that influence pedestrian-vehicular crashes could be identified and addressed, pedestrian crashes could be reduced. This thesis will examine pedestrian crashes in the City of Baltimore, Maryland within a quarter-mile of public schools. The analysis includes characteristics of the school, characteristics of the surrounding built environment and characteristics of the pedestrian involved in the crash. This thesis attempts to identify relationships between pedestrian-vehicular crashes, involving persons of various ages and severities, and the environmental influences of their surroundings.

1.2 Organization

Chapter 2 provides a history of previous research on pedestrians, their behaviors and what influences their travel choices. This review addresses children as pedestrians, pedestrian characteristics and demographics and the interaction of land use and personal travel.

Chapter 3 discusses the methodology employed in the analyses. Incorporated with the methodology is documentation of the data sources and their manipulation.

Chapter 4 presents an overview of pedestrian crashes and the built environment in the City of Baltimore. This section provides descriptive statistics on the behaviors and personal characteristics of pedestrians involved in pedestrian-vehicular crashes in the City of Baltimore and descriptive information regarding public schools in the City of Baltimore and their surroundings.

Chapter 5 organizes the results of the regression analyses. There are, in total, 19 multivariate models that are interpreted and explained. These models vary by dependent variable (including number of crashes and crash severity) and by sample size, which varies by age grouping (all ages, children less than 18 and only children within the age range appropriate to the school).

Chapter 6 discusses the implications of the analyses results and directions for future research.

CHAPTER TWO: BACKGROUND REVIEW

2.1 Pedestrian Travel

Pedestrian trips are made for a variety of reasons; commuting to work, commuting to transit, performing neighborhood errands, or for leisure and recreation. Three percent of the nation's employment population walks as their primary mode of commuting. This number increases significantly for more urban areas, 22 percent of New York City's and almost 12 percent of Washington, DC's employees walk to work. But, not all urban areas see this kind of trend; Los Angeles reports only three percent of employees walking to work and Dallas less than two percent. This study focuses on the City of Baltimore, Maryland, which reports just over a seven percent walk to work mode share (US Census Bureau, 2000).

Additionally, many commuters who use public transit as their primary mode to travel to work also complete a walking trip in order to access the transit mode. In some cities, similar trends are observed between transit commute trips and walk to work commute trips. Table 1 gives a few of these examples and explains how the City of Baltimore compares to other national urban areas. Walking to work numbers also indicate the walkability of the area, or the ability of the built environment to support walking trips.

AREA (by county)	Total Population	Poverty Level	Transit to Work	Walk to Work
United States	281,421,906	12.38%	4.73%	2.93%
Austin, Texas	812,280	12.53%	3.67%	2.25%
Baltimore, Maryland	651,154	22.92%	19.48%	7.11%
Chicago, Illinois	5,376,741	13.49%	17.25%	3.98%
Dallas, Texas	2,218,899	13.43%	3.55%	1.67%
District of Columbia	512,059	20.22%	33.15%	11.80%
Los Angeles, California	9,519,338	17.91%	6.58%	2.93%
New Orleans, Louisiana	484,674	27.94%	13.67%	5.21%
New York City, New York	1,537,195	20.00%	59.62%	21.90%
Salt Lake City, Utah	898,387	8.00%	3.50%	2.00%
Seattle, Washington	1,737,034	8.35%	9.58%	3.63%

Table 1: Socio-economic Statistics for Select US Cities, 2000 US Census

Walking, in some cases, may be the only mode of transportation available. Low-income populations and those without driver's license rely heavily on their ability to walk. As evidenced in Table 1, areas with higher levels of poverty also show higher levels of walk to work mode share. The four cities with poverty levels over 20 percent show the highest percent of walk to work mode share.

The sociodemographic trends are similar for nonwork walk trips, including shopping trips. Rajamani et al (2003) found that high-income households in Portland, Oregon are more likely to drive alone to nonwork activities. Likewise, as vehicle ownership per household increased, the likelihood of walking nonwork trips decreased. Handy and Clifton (2001) found that income does have a significant negative effect on frequency of walking trips to the store. Similarly, of the neighborhoods of Austin, Texas included in the study, the neighborhood with lowest median income also had the highest tendency to walk to shopping as the usual mode of transportation. In Florida, NHTS data reveal that the walk share of personal trips per household is significantly higher for households at or below poverty level. The walk share of personal trips decreases with increased income until the middle-income range where it slightly increases again (Florida Department of Transportation, 2003). Rajamani et al. (2003) theorize that this trend may be attributable to an increase in the availability of time for middle-income households for recreational walking and socializing with neighbors.

2.2 Children as Pedestrians

Children have different pedestrian needs and behaviors than adults. They are not likely to be making household shopping trips or commuting to work; rather children as pedestrians are more likely to be commuting to school or recreating. In contrast to adult pedestrians, children may be in the street with no trip-taking purpose in mind. Children may be recreating within the street, including cycling, playing sports or games, or just socializing with other children. As such, child pedestrians expose themselves to riskier pedestrian behaviors; midblock crossing, disregard of traffic laws and negligence in pedestrian responsibilities.

Children ages 14 years and under account for very high percentages of pedestrian-culpable crashes. Forty-seven percent of crashes resulting from working or playing in the road, involved children 14 and under. Sixty-four percent of crashes resulting from intersection dashes and seventy-two percent of crashes resulting from midblock darts involved children 14 and under (Department of Transportation, 2004).

Hospital records evaluated for the location and severity of injury found that child-pedestrian-involved crashes resulting in an injury are twice as likely to occur in a midblock location versus an intersection (Argan, 1994). The study also found that children are more likely to be playing when hit midblock and more likely to be within one block of their home if hit midblock. Pertaining to school commute trips, children who are hit within 1-2 miles from home are equally likely to be crossing midblock or at an intersection. There were twice as many fatalies resulting from midblock crashes than intersection crashes.

Although it is customary for children to be taught pedestrian responsibility in school or by their parents, it has a limited effect on a child's behavior (MacGregor, et al., 1999). Parents tend to overestimate the cognitive abilities of children to safely address vehicular traffic. Forty-two percent of parents who made unobserved checks on their children as pedestrians found that they were not following the basic pedestrian rules taught to them. The study also found that 33% of children do not conduct a visual search for traffic at non-signalized intersections and 48% of children do not search for traffic at signalized intersections.

However, children are also exposed to environmental inequalities with regard to pedestrian crashes. Children in a lower socioeconomic status area are more susceptible to pedestrian-vehicular crashes and a resulting more severe injury (Macpherson, 1998). Children walking to school in lower income areas are more likely to sustain a more severe injury than their counterpart in higher income areas. Correspondingly, children in lower income areas tend to travel twice as far to get to school as their more affluent counterparts and are more likely to be required to cross a major road during that commute.

To address these issues facing young pedestrians, more attention has been devoted to educating and planning for them. Safe Routes to School, a program originating out of Denmark, encourages students, through both education and planning, to walk or bicycle to school. The goals of this program are supported by the US Department of Transportation and the Centers for Disease Control and Prevention, as both see potential benefits for the children and the community. Children commuting to school by foot or bike reduce congestion around schools and provide students with physical activity, way-finding abilities and independent mobility.

The Safe Routes to School objectives have been categorized into the “Four E’s” framework; encouragement, education, enforcement and engineering. Encouragement comes from both planning special events and activities within the student community and beautifying the routes to make them more attractive to pedestrians/cyclists and improving safety to encourage parents to permit their children to walk. Education encompasses teaching children traffic laws and safety and also the health and environmental benefits of the physical activity. Enforcement is achieved at the judiciary level by creating laws or greater enforcement of existing laws to increase the safety of pedestrians and cyclists. Finally, safe pedestrian and cycling routes require informed and effective engineering (National Highway Traffic Safety Administration, 2004). Engineering a safer and more attractive environment to attract pedestrians will need to consider previously observed and documented pedestrian behaviors and trends. This includes pedestrian counts to identify where pedestrians are choosing to walk but also, evaluations of pedestrian crashes to determine what environmental elements are unsafe for pedestrians.

This thesis is a contribution to the engineering component of this framework. It identifies where pedestrian crashes are occurring and what environmental issues tend to influence those crashes. Per the discussion in the following section, travel behaviors have been specifically linked to characteristics of the built environment. Identifying relationships between the built environment and pedestrian crashes will provide specific engineering goals to address when considering pedestrian safety for future transportation and civic design. Specifically contributing to the Safe Routes to School initiative, this study addresses child pedestrian crashes near public schools and the built environment surrounding those schools.

2.3 Relationship of the Built Environment on Personal Travel Behaviors

A long line of research has been conducted relating personal transportation choices to the built environment. These relationships have been well researched and reported (for complete reviews, see Crane (2000); Ewing and Cervero (2001)). To address the specific scope of this study, a succinct review of the relationships involving pedestrian behaviors only is provided.

Not only have frequent walking patterns been related to sociodemographic factors, as discussed previously, walking can be influenced by the surrounding built environment. Walking trips tend to increase with higher population densities (Rajamani et al., 2003; Frank and Pivo, 1994). High levels of residential and commercial densities also increase the frequency of walking trips for work and nonwork purposes (Dunphy and Fisher, 1996; Cervero, 1994).

Rajamani et al. (2003) provided the framework for many of the built environment variables addressed in this study. These include: park area per housing unit, land use mix (diversity), and transit access. The study found that higher densities considerably increase the walk mode share of trips. Likewise, park area and land use mix increased walking mode share, while presence of cul-de-sacs decreased walking mode share. Interestingly, it was found that access to transit (bus stops) decreased walk mode share.

This thesis will discuss many of these built environment characteristics and determine the relationship with child pedestrian crashes or crashes near schools. This creates a new perspective on inducing walking trips and influencing pedestrian behaviors. As shown in this review, much attention has been devoted to determining the walking environment that attracts pedestrians. In this thesis, the focus is to address the environments that are unsafe and how to increase pedestrian activity by recognizing the influences of pedestrian crashes and making those environments safer.

CHAPTER THREE: METHODOLOGY

3.1 Introduction

This study draws on multiple sources of data that span a three-year period. Data included in this study describe the pedestrian crash and personal characteristics of the pedestrian, the built environment surrounding public schools and characteristics of the public schools in the City of Baltimore. Figure 1 shows a conceptual diagram of the variables included in the analysis to understand the relationships between personal characteristics and behaviors, school attributes and built environment attributes.

3.2 Data and Data Sources

This study relied primarily on pedestrian-vehicular crash data for the City of Baltimore, Maryland from 2000-2002. These data were compiled and supplied by the State of Maryland Motor Vehicle Accident Report and includes 3,009 crash records with spatial information. All records are coded from police reports, and as such are limited in scope and detail to the police narrative provided. For the purposes of this study, the data provided in the report on injury severity will be used, however these data are limited without the inclusion of hospital records. Often pedestrian-vehicular collisions are

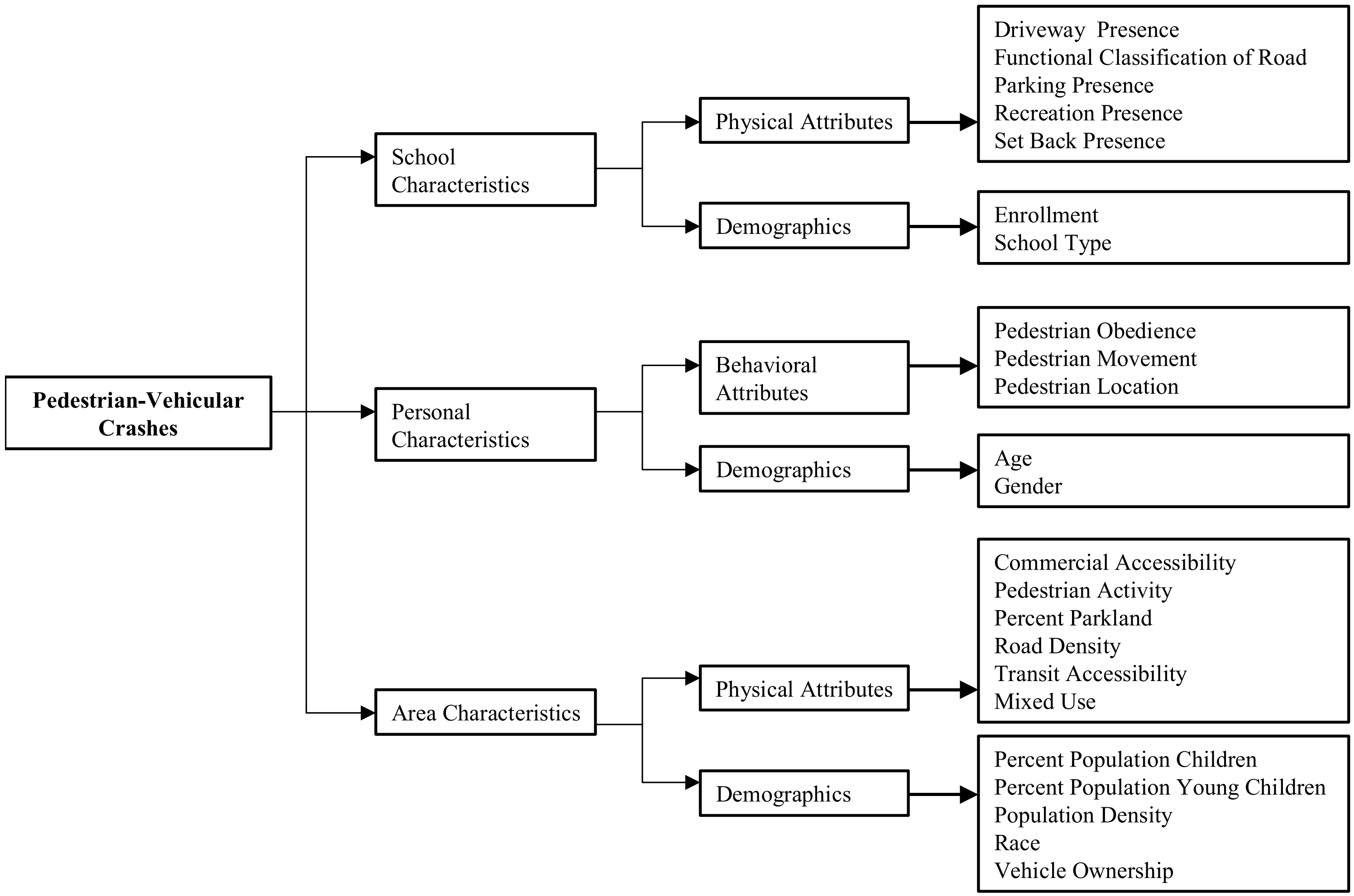

Figure 1: Concept Diagram for Crash Analysis

unreported and the victim (pedestrian) will later seek medical attention for an injury without filing a police report. The Motor Vehicle Accident Report provided all personal characteristics of the pedestrian discussed in this paper, such as pedestrian age, gender, condition and obedience. The report also includes crash characteristics such as time of crash and pedestrian movement.

The severity of crash was considered in multiple criterion variables for regression analysis. The severity was applied as a weight to the individual crash. It was weighted as follows:

- 1 = No injury
- 2 = Possible injury
- 3 = Non-incapacitating injury
- 4 = Incapacitating injury
- 5 = Fatality

The second component to the analysis is public school information. This information was obtained using the City of Baltimore's online resources. School names, locations and enrollment data were collected from the school district (http://www.baltimorecityschools.org/). There are 163 public schools in the City of Baltimore; 116 elementary, 23 middle schools and 24 senior high schools. Enrollment data for most schools were obtained for all three years of pedestrian crash data (2000-2002). In some cases when previous enrollment data were not available, current enrollment numbers were used. As the final enrollment measure, an average of all three years and current enrollment was taken for each school, and in the case where there is only current enrollment data, that datum was used. See Figure 2 for the pedestrian-vehicular crashes and public school distribution in the City of Baltimore.

To further define the schools' attributes, physical characteristics of the school were obtained from site inspection of aerial photographs. These data include: presence of a driveway for student drop-off, presence of recreational facilities, presence of off-street parking, and presence of school set back from the road (http://maps.baltimorecity.gov/imap/). This site provides orthographic overlays of the address or intersection given. Additionally, it will clearly identify schools and after-school recreation centers.

Notably, because all data measures are indicative of a presence of some built environment element, they are binary terms (1= present and 0 = not present). The presence of a driveway is defined as a throughway (or loop) directly addressing the school building, located on the property and not including or congested with parking spaces. Presence of recreational facilities is defined as a playground, courts, fields, pools or tracks. Additionally, after-school recreation centers (located indoors) are identified with the mapping tool and are also included. Off-street parking is defined as parking lots or parking spaces located on school property, exclusive of street or curbside parking. The criterion was to include a set back presence if the school had a substantial yard, numerous sidewalks with buffers or gardens, or a driveway at the main entry way or address of the school. The front of the school is defined as the side of the building that faces the road of the address. This definition was employed because there was no scale or measurement option available with the mapping tool. In general smaller elementary schools had no set back from the road except for the sidewalk with no or little green space (or yard). In contrast, high schools were large complexes with multiple buildings and facilities, driveways and green space. However, there were exceptions to these generalizations, and because of this the data were included in the analysis.

Finally, each school was supplemented with road classification data. The data were collected from the TIGER enhanced street file. The classification data were assigned to each school based upon their address. The road classification data is a composite for road width, speed limit and volume. All road classifications were aggregated into four definitions: (1) separated and (2) unseparated primary roads (interstate, state roads and highways) and (3) separated and (4) unseparated local roads. Table 2 describes all school attribute data.

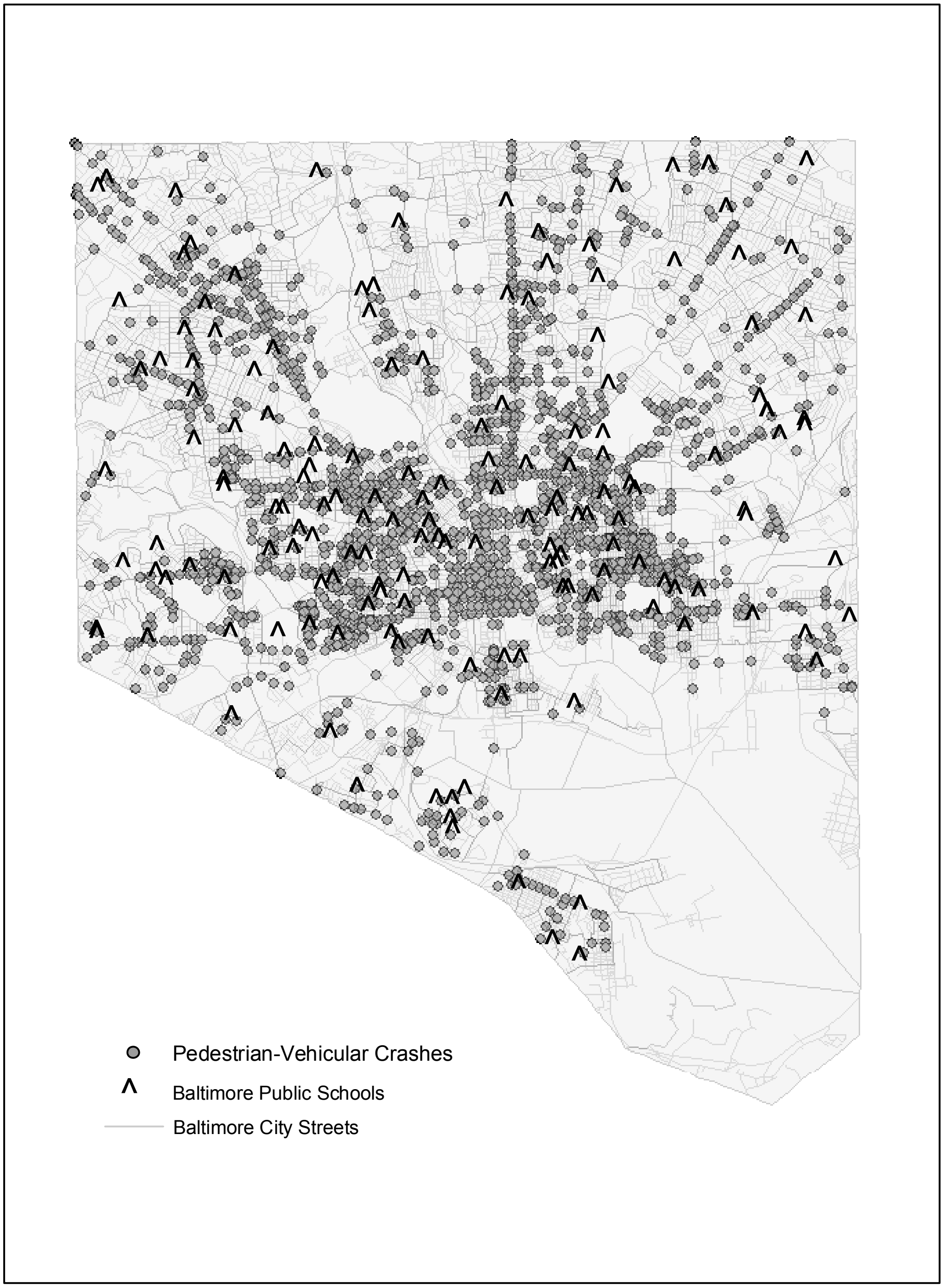

Figure 2: Pedestrian-Vehicular Crashes for 2000-2002
and Public School Distribution in Baltimore City

Independent Variables School Attributes	Definition	Source
Driveway Presence	presence of off-street drop-off facility or driveway	Baltimore City iMap
Enrollment	average school enrollment years 2000-2003	Baltimore City Public School System
Functional Class of Road	aggregated by separated and unseparated and primary and local	TIGER Enhanced Road File
Parking Lot Presence	presence of off-street parking	Baltimore City iMap
Recreation Presence	presence of recreation (courts, tracks, playgrounds, etc.)	Baltimore City iMap
School Type	elementary, middle, and senior high school	Baltimore City Public School System
Set Back Present	presence of school set back	Baltimore City iMap

Table 2: School Attributes Aggregated to the School Level

Socio-demographic and land use data for the surrounding neighborhood were included. For this study, socio-demographic and urban form measures were calculated at the blockgroup level. The socio-demographic measures were obtained from the 2000 US Census. All area measures are defined in Table 3. The City of Baltimore, through a cooperative agreement, supplied the park data that provided parkland area. Commercial parcel data and household location data were obtained from Maryland Property View provided by the Maryland Department of Planning. Bus stop location data was available from Transit View 2000, supplied by the Maryland Department of Transportation. Road density data were calculated from the TIGER enhanced street network file. All total areas used for measures in Table 3 (parkland, road density, population density and mixed use) indicate the total area of the blockgroup.

It should be noted that the mixed use measure is not a percentage, rather a ratio. In some cases, the value is greater than 1. The reason for this is the commercial data are based on individual commercial entities; one building's footprint may be double or multi-counted because multiple commercial entities cohabit that same building but on different floors. For consistency, the commercial footprint was determined by summing all "first floor" square footages for all commercial entities located in the blockgroup.

Geographic Information System (GIS) was used for data manipulation and organization. The crashes were assigned a specific geographic location using the intersection data provided by the Motor Vehicle Accident Report and schools were georeferenced using the street address. Both of these GIS data sets consist of specific point data to identify

Independent Variables Area Attributes	Definition	Source
Socio-demographic		
Race	percentage of population non-white	2004 US Census
Young Children	percentage of population under 5 years of age	2004 US Census
Children	percentage of population between the ages of 5 and 15	2004 US Census
Vehicle Ownership	percentage of households who own a vehicle	2004 US Census
Population Density	total population of blockgroup divided by total area of blockgroup	2004 US Census
Physical		
Pedestrian Activity	population who walk to work divided by total population that is employed	2004 US Census
Parkland	area of parkland divided by total area of blockgroup	Baltimore City, Department of Planning
Commercial Access	percentage of households within quarter mile buffer of commercially zoned property	2004 Property View, State of Maryland
Transit Access	percentage of households within quarter mile buffer of public bus stops	2000 Transit View, State of Maryland
Road Density	linear roadway mileage divided by total area of blockgroup	2004 US Census
Mixed Use	footprint of commercial property divided by total area of blockgroup	2004 Property View, State of Maryland

Table 3: Area Attributes Aggregated to the Blockgroup Level

each crash or school. Each point was then associated with the proper Census-defined blockgroup and blockgroup characteristics.

Using these spatial data and GIS, a quarter-mile buffer was created around each school. Only crashes that occurred within the quarter-mile buffer were included in the crash analysis. The buffers also captured the crash count, and similarly severities and age groupings, associated with each school. See Figure 3 for crash distribution within the public school quarter-mile buffer.

To determine transit and commercial access, buffers were generated around residential land parcels and identified any commercial building or bus stop located within the quarter-mile radius. Roadway density by blockgroup was also calculated using GIS.

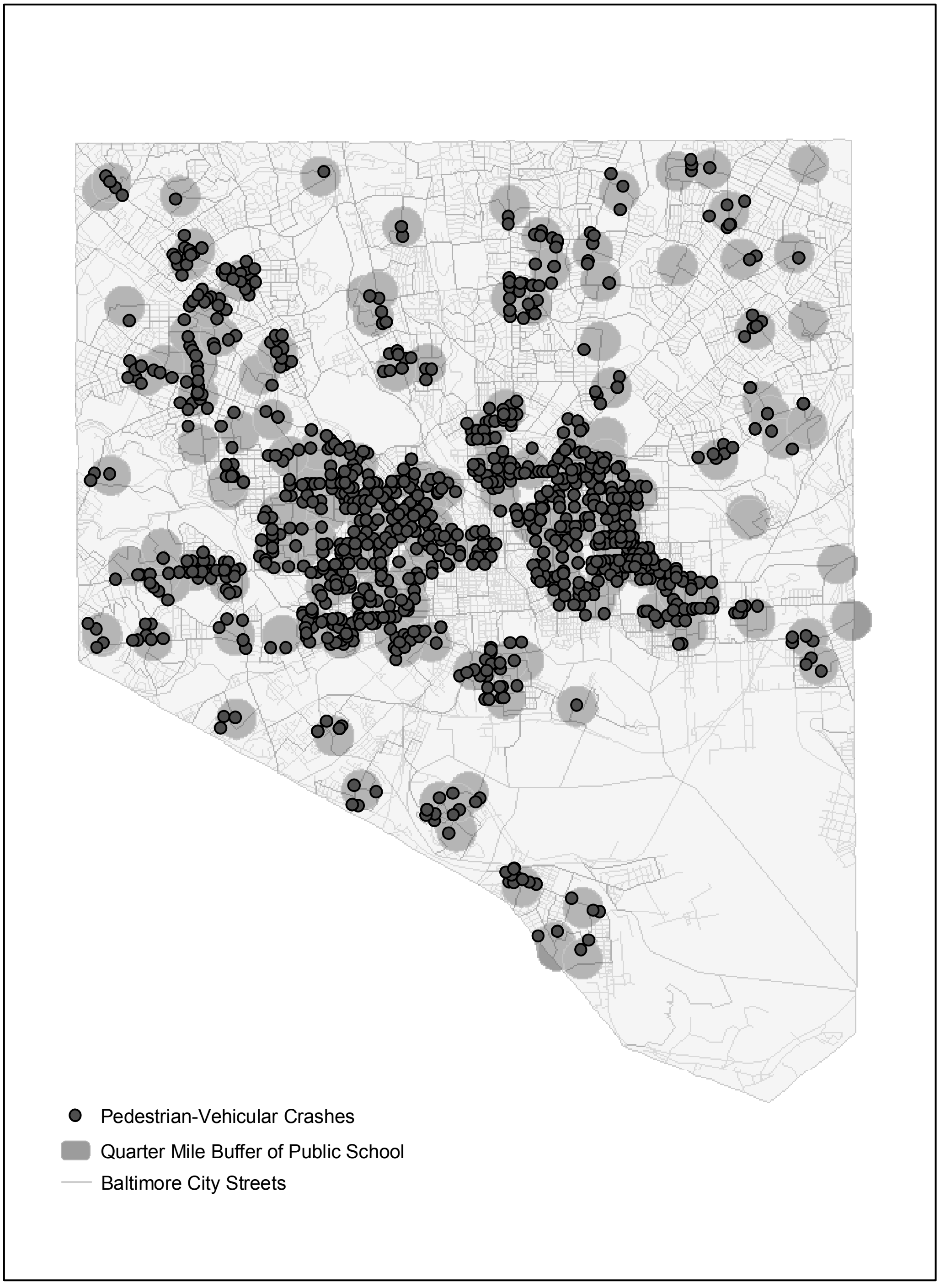

Figure 3: Pedestrian-Vehicular Crashes for 2000-2002 located within quarter mile buffer of Baltimore City public schools

The processes in GIS created two master databases for analysis, one at the individual crash level and one aggregated to the school level. The crash database includes 1621 crashes within the quarter-mile buffer.

3.3 Methods of Analysis

First descriptive statistics were used to define the crash data by age. This analysis was run for all crashes (crashes in the school buffer and outside of the buffer) and only crashes inside the school buffer. This analysis identifies the distribution of crash characteristics, such as severity of injury, presence of alcohol or other substance, pedestrian obedience to traffic signals, time of day and land use grouped by age. Additionally, schools were analyzed by school type (elementary, middle and senior) to define the distribution of land use characteristics by school.

For further analysis, five multivariate analyses were employed; all models were created using ordinary least squares (OLS) linear regression analysis. The purpose of the analysis was to determine the effects of the built environment characteristics and school characteristics on five dependent metrics (the spatial unit of analysis was the school level):

- Aggregate severity of crashes ($\sum$ crashes * weight by severity)
- Number of crashes (crashes)
- Average severity of crash

  (($\sum$ crashes * weight by severity) / number of crashes)

- Crashes per enrollment (number of crashes / average enrollment)
- Severity per enrollment

  ((∑ crashes * weight by severity) / average enrollment)

The model was segmented by age of pedestrian involved in a crash within the quarter-mile buffer of a public school:

- All ages
- Ages 18 years old and under
- Ages appropriate to school

The model was also segmented by school type. This analysis identifies the relationships between the independent variables and crash severity and count for each school.

The resulting equation was specified for all dependent variables (y_i) as follows:

$$(y_i) = \beta_o + \beta_1(enrollment)_i + \beta_2(elementary)_i + \beta_3(middle\ school)_i + \beta_4(set\ back)_i + \beta_5(recreation)_i + \beta_6(driveway)_i + \beta_7(parking)_i + \beta_8(primary\ unseparated\ roads)_i + \beta_9(primary\ separated\ roads)_i + \beta_{10}(pedestrian\ activity)_i + \beta_{11}(parkland)_i + \beta_{12}(commercial\ accessibility)_i + \beta_{13}(transit\ accessibility)_i + \beta_{14}(race)_i + \beta_{15}(population\ under\ 5)_i + \beta_{16}(population\ 5\text{-}15)_i + \beta_{17}(road\ density)_i + \beta_{18}(population\ density)_i + \beta_{19}(median\ income)_i + \beta_{20}(mixed\ use)_i + \xi_i$$

Finally, tests for collinearity were conducted. Collinearity occurs when two or more independent variables have linear relationships. Collinearity is detected by running bivariate correlations or could be suspected if the R-square value is very high with only a few statistically significant explanatory variables. Results of these analyses are presented in Chapter 5.

3.4 Data Distribution

In order to understand the data sets to greater detail, Table 4 and 5 provide distribution statistics for all independent and dependent variables. The statistics include the highest and lowest value datum for each variable and the mean of all data. This is specifically telling for the binary terms, it can be determined from the mean what percentage of schools apply to that characteristic.

	Range		Mean
	Low	High	
Dependent Variables			
Aggregate severity weight			
all ages	0	167	33.29
18 years or under	0	64	14.67
age appropriate	0	50	7.8
Average severity of crash			
all ages	0	4	2.37
18 years or under	0	4	2.21
age appropriate	0	4	1.96
Crash count			
all ages	0	71	13.31
18 years or under	0	29	5.93
age appropriate	0	21	3.17
Crashes per enrollment			
all ages	0	0.2222	0.0381
18 years or under	0	0.1111	0.0163
age appropriate	0	0.0704	0.0086
Aggregate severity per enrollment			
all ages	0	0.56	0.0955
18 years or under	0	0.28	0.0404
age appropriate	0	0.18	0.0209
N = 163			

Table 4: Distribution of Data for Dependent Variables

All data were aggregated to the school level, as such it is understandable why all low values of the dependent variables are zero; some schools have no pedestrian-vehicular crashes located in a quarter-mile radius.

	Range		Mean
	Low	High	
Independent Variables			
Area Attributes			
Socio-demographic			
Race	1.0%	100.0%	72.1%
Young Children	0.0%	20.0%	8.3%
Children	0.0%	33.0%	16.5%
Vehicle Ownership	7.0%	97.0%	60.4%
Population Density	913	36731	12444
Pedestrian Activity	0.0%	48.0%	6.7%
Parkland	0.0%	65.0%	6.7%
Commercial Access	0.0%	100.0%	65.9%
Transit Access	0.0%	100.0%	73.4%
Road Density	3.47	77.39	24.94
Mixed Use	0.00	2.94	0.09
School Attributes			
Driveway Presence	0	1	0.43
Enrollment	45	2059	543.41
Functional Class of Road			
primary separated	0	1	0.06
primary unseparated	0	1	0.28
local separated	0	0	0.00
local unseparated	0	1	0.66
Parking Presence	0	1	0.85
Recreation Presence	0	1	0.72
School Type			
elementary	0	1	0.71
middle school	0	1	0.14
senior high school	0	1	0.15
Set Back Present	0	1	0.62
N = 163			

Table 5: Distribution of Data for Independent Variables

CHAPTER FOUR: DESCRIPTIVE STATISTICS

4.1 Introduction

Descriptive statistics were computed to identify significant relationships between the behavioral and personal characteristics of the pedestrians involved in pedestrian-vehicular crashes in the City of Baltimore. To better understand the relationship between pedestrian-vehicular crashes in the City of Baltimore and their proximity to public schools, cross-tabulations were calculated for all crashes of all ages occurring within a quarter-mile buffer of a pubic school and for all crashes involving children 15 years and under for all of the City of Baltimore. Built environment characteristics were analyzed for all public schools to ascertain correlations between the attributes of the schools' location in the City of Baltimore and the built environment but were not found to be statistically significant.

4.2 Pedestrian-Vehicular Crashes Near Public Schools

Tables 6 and 7 show pedestrian crash characteristics for five age groupings: ages 0-4, ages 5-15, ages 16-18, adults and elderly. The child age groups are segmented to represent preschool, school-aged and non-driving-aged, and school-aged and driving-

	Total N	Total %	Age 0- 4	Age 5-15	Age 16-18	Age 19- 64	Age 65 +	X^2 p-values
Pedestrian Crash Characteristic								
Number of Crashes	1513	100.0%	3.3%	38.3%	5.0%	49.6%	3.8%	
Gender								0.201
male	907	60.2	76.0	60.4	57.3	59.6	56.1	
female	599	39.8	24.0	39.6	42.7	40.4	43.9	
total	1506	100.0	100.0	100.0	100.0	100.0	100.0	
Injury Severity								0.000
not injured	240	15.9	24.0	16.4	17.1	15.2	10.5	
possible injury	469	31.0	24.0	29.3	32.9	32.8	28.1	
non-incapacitating injury	611	40.3	44.0	43.3	42.1	37.8	38.6	
incapacitated	165	10.9	6.0	9.8	6.6	12.7	8.8	
fatal	28	1.9	2.0	1.2	1.3	1.5	14.0	
total	1513	100.0	100.0	100.0	100.0	100.0	100.0	
Pedestrian Location								0.000
shoulder	70	4.9	2.1	4.7	4.3	5.1	7.1	
curb	63	4.4	8.3	4.1	4.3	4.3	5.4	
sidewalk	79	5.5	6.3	2.3	14.3	6.8	8.9	
outside of right-of-way	50	3.5	6.3	3.2	2.9	3.5	3.6	
in crosswalk	284	19.7	14.6	14.7	12.9	23.1	41.1	
not in crosswalk	892	62.0	62.4	71.0	61.4	57.2	33.9	
total	1438	100.0	100.0	100.0	100.0	100.0	100.0	
Pedestrian Obedience								0.000
no pedestrian signal	1069	79.7	88.4	82.4	91.9	77.1	64.2	
obeyed pedestrian signal	96	7.2	2.3	4.3	1.6	8.8	26.4	
disobeyed pedestrian signal	176	13.1	9.3	13.3	6.5	14.1	9.4	
total	1341	100.0	100.0	100.0	100.0	100.0	100.0	

Table 6: Pedestrian Crash Characteristics by Age

	Total N	Total %	Age 0- 4	Age 5-15	Age 16-18	Age 19- 64	Age 65 +	X^2 p-values
Pedestrian Crash Characteristic								
Number of Crashes	1513	100.0%	3.3%	38.3%	5.0%	49.6%	3.8%	
Pedestrian Movement								0.000
cross at intersection	318	26.0	23.8	18.9	27.6	29.2	53.8	
cross not at intersection	552	45.2	45.2	50.0	56.9	41.8	26.9	
walking with traffic	56	4.6	0.0	3.8	3.4	5.8	1.9	
walking against traffic	85	7.0	11.9	7.7	5.2	6.7	1.9	
playing in road	90	7.4	14.3	16.6	0.0	0.7	3.8	
standing in road	131	9.9	4.8	3.0	6.9	15.8	11.7	
total	1222	100.0	100.0	100.0	100.0	100.0	100.0	
Legal/Illegal Substance Present								0.000
no substance detected	624	91.9	100.0	99.6	97.1	85.0	96.2	
substance present	41	6.0	0.0	0.4	2.9	11.0	3.8	
substance contributed	14	2.1	0.0	0.0	0.0	4.0	0.0	
total	679	100.0	100.0	100.0	100.0	100.0	100.0	
Time of Day								0.000
morning rush hour	137	9.1	2.0	11.9	10.5	7.5	5.3	
midday	310	20.5	20.0	13.4	18.4	24.3	45.6	
afternoon school release	445	29.4	44.0	38.3	34.2	21.2	28.1	
afternoon rush hour	300	19.8	20.0	24.7	17.1	16.7	15.8	
late night/ early morning	321	21.2	14.0	11.7	19.8	30.3	5.2	
total	1513	100.0	100.0	100.0	100.0	100.0	100.0	

Table 7: Pedestrian Crash Characteristics by Age, Continued

aged children. Only crashes that occurred within a quarter-mile of a school were included in this analysis.

Pedestrian location information was provided by the police report regarding where the pedestrian was at the time of impact and aggregated to the nearest intersection. Ages 0-4 are overrepresented among those hit on the curb. This may be synonymous with pedestrians ages 0-4 traveling in a stroller. While the pedestrians are waiting at the curb to cross (with the stroller being closest to the street), the stroller's occupant may be the first victim of a curb pedestrian-vehicular crash. Also, the person operating the stroller may not be aware of the impending collision and not react as quickly with the stroller as a pedestrian on foot would.

Ages 5-15 are underrepresented and ages 16-18 are overrepresented in sidewalk pedestrian-vehicular collisions. Not surprisingly, ages 5-15 are more likely to be involved in crashes located in the roadway but not in a crosswalk.

As discussed in earlier chapters, children are unique pedestrians because they may be recreating directly in the street rather than having some trip-taking purpose in mind. This trend is observed in the pedestrian movement characteristic. It shows that children ages 0-4 and ages 5-15 are much more likely as pedestrians to be involved in a crash while playing in the road and interestingly, there are no records of ages 16-18 being involved in a crash while playing in the road. Ages 5-15 and ages 16-18 are overrepresented as being involved in a crash while crossing the road not at an intersection (midblock).

Similarly, ages 16-18 involved in pedestrian-vehicular crashes are most likely to be walking where there are no pedestrian signals. Of the crashes involving ages 16-18 with a pedestrian signal present, they are more than four times more likely to disobey that signal. Interestingly, the fact that all child age groups are underrepresented in crashes involving an obeyed pedestrian signal does not indicate an overrepresentation for disobeying a pedestrian signal. All child age groups are overrepresented for crashes occurring where there is no pedestrian signal.

It is not surprising that ages 0-4 had no presence or contribution of a controlled or uncontrolled substance involved in the crash. A small amount of children ages 5-15 and ages 16-18 had a controlled or uncontrolled substance present at the time and location of the crash however, there were no records of a substance contributing to a crash involving children. This may be an underrepresentation of substance involvement in a crash for all ages because it is well documented that substance contribution is discretionary to the responding officer and many times not tested (National Highway Traffic Safety Administration, 2005). For more accurate data regarding substance involvement hospital records would be necessary.

Time of day of which the crash occurred was aggregated into five ranges based on school traffic and rush hour commute traffic (Center for Urban Transportation

Research, 1997). The morning rush hour peak typically occurs concurrent with morning school traffic. School starts at various times depending on the school, and some schools have before-school programs. For purposes of this analysis the morning rush hour time range was defined as 6:30 am to 9:00 am. Midday was defined as 9:01 am to 2:29 pm. Afternoon school release varies from 2:30 pm to 3:30 pm and later for children involved in after-school activities so for this analysis, the afternoon school release time period was defined as 2:30 pm to 5:00 pm to include children leaving school late. Afternoon rush hour is from 5:01 pm to 8:00 pm and late night/early morning includes 8:01 pm to 6:29 am.

The analysis shows that ages 5-15 are least likely to be involved in crashes occurring during the midday. This is to be expected because they should be attending school during that time. Ages 16-18 have a slightly larger representation in crashes occurring during the midday. This may be because the kids are not attending school, have off-periods or scheduled half days or are allowed to leave for lunch periods. Most pertinent to this study is the overrepresentation of all children involved in pedestrian-vehicular crashes during the afternoon release time period. The high incidence of child pedestrian crashes near a public school during this time highlights the need to address children who commute to school on foot.

4.3 Built Environment Attributes of Child Pedestrian-Vehicular Crashes in the City of Baltimore

To determine where children are walking when they are involved in a pedestrian-vehicular crash, all crashes involving children 15 years and under were analyzed by area built environment characteristics. Figure 4 shows the spatial distribution of child pedestrian crashes related to public schools, however the analysis in Table 8 will describe the areas in which these crashes occur. Most relationships were not found to be statistically significant; however, it is interesting to see the environments in which children are being involved in pedestrian-vehicular crashes. Specifically, the analysis looked at transit accessibility, pedestrian activity, percent parkland and commercial accessibility.

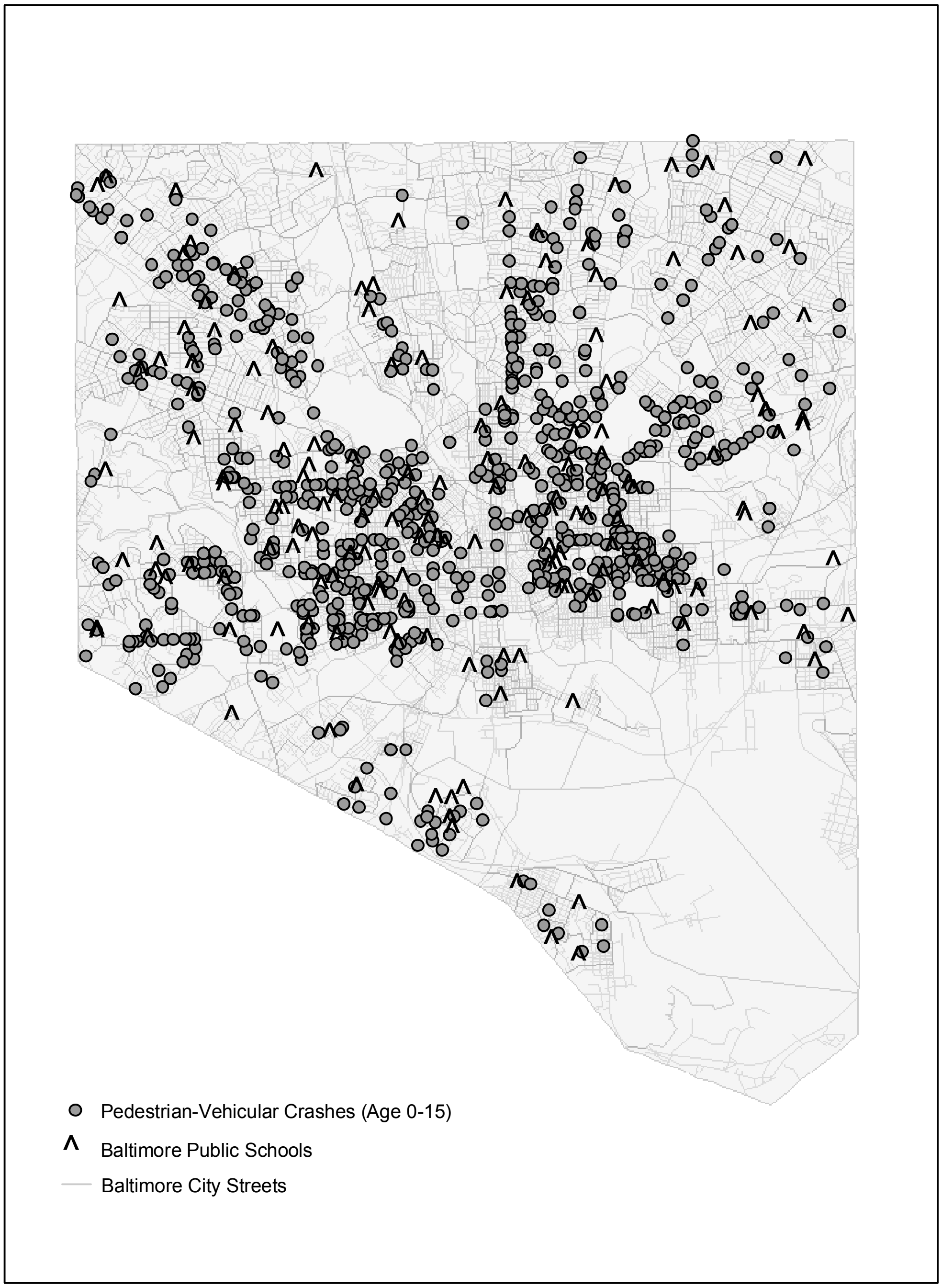

Figure 4: Spatial Distribution of Child (0-15 years) Pedestrian-Vehicular Crashes in Baltimore

Transit accessibility was the only characteristic found to be statistically significant; it shows that children involved in a pedestrian-vehicular crash are more likely to be in high transit-accessible blockgroups.

	Total N	Preschool Age (0-4)	Elementary School Age (5-11)	Non-Driving Middle and High School Age (12-15)	X^2 p-values
Pedestrian Crash Location					
Number of Crashes	1010	9.5%	60.7%	29.8%	
Transit Accessibility					0.037
Low (0%-30%)	35	8.6	2.4	3.9	
Medium (30%-85%)	154	21.4	14.9	14.0	
High (> 85%)	821	70.0	82.7	82.0	
Total	1010	100.0	100.0	100.0	
Pedestrian Activity					0.269
Low (0%-5%)	825	81.3	80.8	83.7	
Medium (5%-10%)	161	14.6	17.5	13.3	
High (> 10%)	24	4.2	1.8	4.0	
Total	1010	100.0	100.0	100.0	
Percent Parkland					0.505
Low (0%-10%)	816	84.4	80.6	80.0	
Medium (10%-40%)	135	8.3	13.4	15.0	
High (> 40%)	59	7.3	6.0	5.0	
Total	1010	100.0	100.0	100.0	
Commercial Accessibility					0.678
Low (0%-55%)	80	8.3	7.2	9.3	
Medium (55%-85%)	115	8.3	11.6	12.0	
High (> 85%)	815	83.3	81.2	78.7	

Table 8: All Child Pedestrian Crashes by Built Environment Characteristics

It is noteworthy that for all measures, the distribution includes one value representing approximately 80% of crashes. Most crashes involving children age 15 years and under are located in blockgroups with low pedestrian activity. Crashes involving children are most likely to occur in blockgroups with low percentages of parkland and high commercial accessibility (these statements are exclusive of each other). The low occurrence of crashes in high percentages of parkland appears counterintuitive because presumably parks are pedestrian generators. However, this may be attributable to motorists being more aware of the possibility of a pedestrian and driving with more caution. The same reasoning may be able to explain the low occurrence of crashes in areas of high pedestrian activity. This measure was defined by the percentage of employees who walk to work, so it is not an inclusive measure of all pedestrian activity, only a proxy. Motorists may anticipate pedestrians with high rates of employees walking to work and are therefore more cautious drivers.

4.4 Attributes of Public School Locations in the City of Baltimore

An analysis of the attributes of public school locations was performed to better understand where schools are located and what type of environment pedestrians must travel through to reach the school. Attributes included in the analysis are the built environment characteristics, percent nonwhite population and percent vehicle ownership, all calculated at the blockgroup level. The results are found in Table 9.

Most schools are located in areas with low percent parkland. This is similar to areas with high occurrences of child pedestrian crashes.

	Total N	Total %	Elementary	Middle School	Senior High School	X^2 p-values
School Site Characteristics						
Number of Schools	163	100.0%	71.2%	14.1%	14.7%	
Race						0.090
Low (0%-30%)	35	21.5	20.0	17.4	33.3	
Medium (30%-70%)	21	12.9	10.4	17.4	16.7	
High (> 70%)	107	65.6	69.6	65.2	50.0	
Total	163	100.0	100.0	100.0	100.0	
Percent Parkland						0.110
Low (0%-10%)	132	81.0	83.5	69.6	79.2	
Medium (10%-40%)	24	14.7	13.0	30.4	8.3	
High (> 40%)	7	4.3	3.5	0.0	12.5	
Total	163	100.0	100.0	100.0	100.0	
Commercial Accessibility						0.168
Low (0%-55%)	50	30.7	34.8	8.7	29.2	
Medium (55%-85%)	16	9.8	9.6	8.7	12.5	
High (> 85%)	97	59.5	55.6	82.6	58.3	
Total	163	100.0	100.0	100.0	100.0	
Transit Accessibility						0.310
Low (0%-30%)	39	23.9	27.8	4.3	25.0	
Medium (30%-85%)	12	7.4	7.0	13.0	4.2	
High (> 85%)	112	68.7	65.2	82.6	70.8	
Total	163	100.0	100.0	100.0	100.0	
Vehicle Ownership						0.358
Low (0%- 40%)	35	21.5	25.2	8.7	16.7	
Medium (40% -70%)	65	39.8	37.4	56.5	37.5	
High (> 70%)	63	38.7	37.4	34.8	45.8	
Total	163	100.0	100.0	100.0	100.0	
Road Density						0.379
Low (0-17 mi/sq mile)	92	56.4	50.4	69.6	70.8	
Medium (17-31 mi/sq mile)	54	33.1	37.4	21.7	25.0	
High (> 31 mi/sq mile)	17	10.4	12.2	8.7	4.2	
Total	163	100.0	100.0	100.0	100.0	
Pedestrian Activity						0.752
Low (0%-5%)	95	58.3	55.7	69.6	58.3	
Medium (5%-10%)	28	17.2	20.0	8.7	12.5	
High (> 10%)	40	24.5	24.3	21.7	29.2	
Total	163	100.0	100.0	100.0	100.0	

Table 9: Attributes of Public School Locations in Baltimore

Most schools were found to be in areas with a high nonwhite population, this is especially true for elementary schools and middle schools. Only half of high schools are located in areas with a high nonwhite population and a small number of high schools located in areas with a medium nonwhite population. Campos-Outcalt (2002) found that nonwhite populations have a higher likelihood of being involved in a pedestrian-vehicular crash. This may indicate that student pedestrians are further susceptible to being involved in a pedestrian-vehicular crash near their school.

Additionly, most public schools in the City of Baltimore are located in traditionally pedestrian-aware areas, such as areas with high transit accessibility and high commercial accessibility. Presumably, motorists in these areas are more cautious of pedestrians crossing. However, this additional caution from the motorists may not benefit student pedestrians if they are crossing illegally or walking on less pedestrian-friendly streets. Students involved in a pedestrian crash near schools are crossing illegally 45% of the time and are culpable for the crash 55% of the time (Center for Urban Transportation Research, 1997).

There are no compelling relationships between school location and vehicle ownership. As mentioned before many schools are located in areas with high transit accessibility. Additionally, the City of Baltimore provides yellow bus service to any child living greater than 1.5 miles from their school. Because of the density of elementary schools in the City of Baltimore, most households are not located greater than 1.5 miles from their school. However, it is interesting to note that over a quarter of elementary schools are located in areas with low vehicle ownership.

CHAPTER FIVE: MULTIVARIATE REGRESSION ANALYSIS

5.1 Introduction

To determine what relationships exist between pedestrian-vehicular crashes and the physical characteristics of a public school and its surrounding area, multiple regression analyses were employed. In order to adequately determine which independent variables are significant for various dependent variables segmented by age, all models retain all given independent variables, regardless of statistical significance. This type of analysis lends itself to policy interpretation so, although all relationships may not be statistically significant, they will still describe the relationship between the independent and dependent variables to some degree.

For purposes of discussion and presentation the dependent variables will subsequently be modeled in the follow scheme for all age segmentations:

- Model 1 = Aggregate Severity of Crash
- Model 2 = Average Severity of Crash
- Model 3 = Crash Count
- Model 4 = Crash Count per Enrollment

- Model 5 = Aggregate Severity per Enrollment

All independent variables were tested for multicollinearity. As expected, the binary variables for school type and road type were found to be highly correlated. This is acceptable for this type of variable. Correlations between two variables with an absolute value greater than 0.800 are considered inappropriate for inclusion of both in a regression analysis. All variables passed this criterion, however it is notable that median income and vehicle ownership, as well as transit accessibility and commercial accessibility are very close to being considered correlated.

5.2 Pedestrian Crashes of All Ages Near Public Schools

The model with the highest explanatory power for crashes of all ages had a dependent variable of aggregate severity of crashes (Model 1, Table 10 and Table 11). This model shows a statistically significant positive relationship between aggregate severity of crashes and recreation presence, commercial accessibility, race, population density and mixed use development. This may be interpreted in three ways, either the number of crashes are increasing with these variables or the severity of the crashes are increasing with these variables, or both.

Similarly, transit accessibility and driveway presence are shown to have a statistically significant negative relationship with the aggregate severity of crashes for a school. The negative relationship with driveway presence could be explained by the increased ease of dropping kids off at school with an automobile attracting less walking trips as a mode to school. Correspondingly, although not statistically significant, vehicle ownership also has a negative relationship to aggregate severity of crashes.

To further understand the previous model, average severity is used as the dependent variable in Model 2. Relationships determined from this model will indicate an association to crash severity specifically. The model maintains statistically significant positive relationships with recreation presence, commercial accessibility, race and population density. Different from Model 1, mixed use development is no longer significant and median income becomes significant.

Correspondingly, when the dependent variable is specified (from Model 1) to identify the relationships associated with number of crashes per school (Model 3), the statistically significant relationships that were lost in Model 2 are gained again. This is seen in the statistically significant negative relationship between driveway presence and transit access. Both of these variables indicate a mode shift from walking to automobile and transit, respectively, thus reducing the exposure rate of pedestrians at those schools.

Statistically significant positive relationships remain between number of crashes and race and population density. These variables have remained explanatory for all three model estimations. Additionally, mixed use development is regained as a statistically significant variable for number of crashes. Its positive relationship with number of crashes is indicative of pedestrian trips attracted by this type of development.

Dependent Variables	Model 1: Aggregate Severity of Crash	Model 2: Average Severity of Crash	Model 3: Crash Count
Independent Variables			
School Attributes			
enrollment	-0.0057 (-0.896)	-0.0002 (-0.942)	-0.0018 (-0.674)
elementary school	-1.1490 (-0.192)	-0.0768 (-0.427)	-0.0567 (-0.023)
middle school	2.3420 (0.345)	0.1155 (0.565)	1.2090 (0.431)
set back present	-4.0090 (-0.962)	0.0782 (0.627)	-2.0777 (-1.215)
recreation present	**7.0580 (1.737) ** **	**0.2165 (1.771) * **	2.4563 (1.465)
driveway present	**-7.6560 (-1.854) ** **	-0.1174 (-0.950)	**-3.1346 (-1.849) ** **
off-street parking present	-5.5940 (-1.037)	-0.1007 (-0.616)	-1.8221 (-0.813)
primary unseparated road	6.2590 (1.537)	-0.0631 (-0.517)	2.3040 (1.377)
primary separated road	10.4360 (1.178)	0.2143 (0.808)	3.5887 (0.987)
Area Attributes			
pedestrian activity	-7.1100 (-0.237)	0.1469 (0.156)	-3.2208 (-0.250)
parkland	13.1380 (0.942)	-0.2982 (-0.712)	5.6581 (0.986)
commercial accessibility	**14.5860 (1.771) ** **	**0.5297 (2.146) ** **	4.3054 (1.272)
transit accessibility	**-36.7850 (-4.270)*** **	-0.3263 (-1.254)	**-13.1554 (-3.685) *** **
race	**18.528 (2.799) *** **	**0.9257 (4.435) *** **	**6.5406 (2.285) ** **
population under 5 years	33.0030 (0.629)	2.3185 (1.471)	8.1317 (0.376)
population 5 and 15 years	52.5810 (1.488)	-1.7722 (-1.636)	22.5687 (1.519)
vehicle ownership	-5.772 (-0.346)	-0.2982 (-0.619)	-1.7171 (-0.260)
road density	18.3110 (1.261)	0.0213 (0.049)	6.8911 (1.1550)
population density	**1.0650 (3.460) *** **	**0.0162 (1.748) ** **	**0.4386 (3.445) *** **
median income	0.1710 (1.067)	0.0102 (1.683)	0.0786 (0.943)
mixed use	**43.3240 (1.968) * **	0.7504 (1.136)	**17.6465 (1.947) ** **
	N = 163 R^2 = .551	N = 163 R^2 = .267	N = 163 R^2 = .541

* Statistically significant at the 10% level
** Statistically significant at the 5% level
*** Statistically significant at the 1% level

Table 10: Models 1-3 Estimation Results for All Ages

Dependent Variables	Model 4: Crash Count Per Enrollment	Model 5: Aggregate Severity of Crash Per Enrollment
Independent Variables		
School Attributes		
elementary school	0.0077 (0.830)	0.0194 (0.826)
middle school	-0.0043 (-0.353)	-0.0103 (-0.335)
set back	0.0011 (0.151)	0.0045 (0.233)
recreation	0.0024 (0.325)	0.0068 (0.363)
driveway	-0.0095 (-1.273)	-0.0245 (-1.296)
off-street parking	-0.0024 (-0.242)	-0.0091 (-0.361)
primary unseparated road	0.0109 (1.478)	0.0296 (1.590)
primary separated road	0.0012 (0.076)	0.0075 (0.186)
Area Attributes		
pedestrian activity	0.0465 (0.810)	0.1133 (0.783)
parkland	0.0070 (0.275)	0.0145 (0.226)
commercial accessibility	0.0061 (0.412)	0.0246 (0.658)
transit accessibility	**-0.0285 (-1.809) ***	**-0.0828 (-2.087) ****
race	**0.0244 (1.916) ****	**0.0652 (2.031) ****
population under 5 years	-0.0613 (-0.638)	-0.1207 (-0.499)
population 5 and 15 years	0.0609 (0.921)	0.1489 (0.893)
vehicle ownership	-0.0134 (-0.455)	-0.0295 (-0.398)
road density	-0.0041 (-0.157)	-0.0110 (-0.166)
population density	**0.0015 (2.664) *****	**0.0037 (2.615) *****
median income	0.0002 (0.431)	0.0004 (0.424)
mixed use	-0.0040 (-0.099)	-0.0124 (-0.123)
	N = 163 R^2 = .338	N = 163 R^2 = .342

* Statistically significant at the 10% level
** Statistically significant at the 5% level
*** Statistically significant at the 1% level

Table 11: Models 4-5 Estimation Results for All Ages

Model 4 (see Table 11) introduces a density dependent variable, crashes per enrollment. The explanatory power of this model is less than the previous models (1 and 3) and has only three statistically significant relationships, all of which have been discussed in previous models. In all three of the previous models, average enrollment is used as an explanatory variable instead of being incorporated into the dependent variable. It is not surprising that this density variable does not increase the explanatory power; average enrollment is not significant in any of the previous models for all ages. The same explanation may be applied to the aggregate severity per enrollment measure (Model 5).

5.3 Crashes Involving Pedestrians Aged 18 Years and Younger

To capture all students, similar models segmented by age 18 years and younger were run in Tables 12 and 13. The results were slightly more explanatory for aggregate severity of crashes (Model 1), average severity of crashes (Model 2) and crash count (Model 3) than similar models run for ages 15 and under. Similar statistically significant relationships were observed for both 15 and under and 18 and under between transit accessibility, race, population between 5 and 15 and population density. The analysis for 18 and under reveals a new statistically significant positive relationship between aggregate severity of crashes and mixed use development. This may indicate a specific attractor to this type of development for children aged 16-18. This inference is further substantiated by the statistically significant positive relationship between crash count and mixed use development, not observed by ages 15 and under.

Commercial accessibility becomes statistically significant for average severity of crash. For 18 and under, parking presence is shown to have a statistically significant positive relationship with average severity of crash, but this is not true for ages 15 and under. This may indicate the presence of older students driving to school and having less safe driving habits than the parents who drop-off kids (speeding, disobeying traffic signs, etc.).

Contrary to the findings discussed in the previous literature review, crash count is shown to have a positive relationship with transit accessibility for children age 18 and under and for all ages analysis. This disparity may be attributable to the absence of walk to transit trips in the previous analysis. This study shows that people are most likely walking to transit and are therefore more exposed to crashes in those areas.

Dependent Variables	Model 1: Aggregate Severity of Crash	Model 2: Average Severity of Crash	Model 3: Crash Count
Independent Variables			
School Attributes			
enrollment	0.0013 (0.395)	-0.0003 (-1.110)	0.0004 (0.333)
elementary school	0.3831 (0.126)	-0.1554 (-0.662)	-0.0149 (-0.012)
middle school	1.8682 (0.543)	0.0130 (0.049)	0.7879 (0.580)
set back	-2.4185 (-1.153)	-0.0305 (-0.188)	-1.3091 (-1.580)
recreation	1.5193 (0.739)	0.1507 (0.946)	0.5605 (0.690)
driveway	-1.0698 (-0.515)	-0.1959 (-1.216)	-0.2606 (-0.317)
off-street parking	0.7024 (0.255)	**0.3621 (1.700) ***	-0.0463 (-0.043)
primary unseparated road	1.9592 (0.955)	-0.0991 (-0.623)	0.6533 (0.806)
primary separated road	1.3483 (0.302)	0.0035 (0.010)	0.7249 (0.412)
Area Attributes			
pedestrian activity	-14.7415 (-0.932)	1.0808 (0.882)	-5.8923 (-0.943)
parkland	4.5171 (0.642)	0.2601 (0.477)	2.5924 (0.932)
commercial accessibility	4.6718 (1.126)	**0.5542 (1.723) ***	1.2779 (0.780)
transit accessibility	**-10.3955 (-2.374) ****	-0.4768 (-1.405)	**-3.6197 (-2.093) ****
race	**11.0625 (3.152) *****	**1.2627 (4.641) *****	**4.1657 (3.005) *****
population under 5 years	-14.0616 (-0.530)	1.3676 (0.666)	-7.2148 (-0.689)
population 5 and 15 years	**37.9586 (2.084) ****	-0.8057 (-0.571)	**16.2114 (2.253) ****
vehicle ownership	4.4258 (0.546)	0.8768 (1.395)	1.2093 (0.378)
road density	7.0774 (0.967)	0.1672 (0.295)	3.8904 (1.346)
population density	**0.4781 (3.062) *****	**0.0308 (2.546) ****	**0.1987 (3.221) *****
median income	-0.0354 (-0.346)	-0.0044 (-0.551)	-0.0026 (-0.064)
mixed use	**19.1975 (1.728) ***	-0.0253 (-0.029)	**7.5067 (1.710) ****
	N = 163 R^2 = .432	N = 163 R^2 = .287	N = 163 R^2 = .448

* Statistically significant at the 10% level
** Statistically significant at the 5% level
*** Statistically significant at the 1% level

Table 12: Models 1-3 Estimation Results Segmented for Pedestrian Crashes 18 Years and Younger.

Dependent Variables	Model 4: Crash Count Per Enrollment	Model 5: Aggregate Severity of Crash Per Enrollment
Independent Variables		
School Attributes		
elementary school	0.0044 (1.126)	0.01203 (1.194)
middle school	0.0001 (0.011)	0.0000 (0.001)
set back	-0.0011 (-0.329)	-0.0013 (-0.155)
recreation	0.0001 (0.030)	-0.0008 (-0.100)
driveway	0.0001 (0.033)	-0.0011 (-0.141)
off-street parking	0.0018 (0.427)	0.0051 (0.468)
primary unseparated road	0.0032 (1.006)	0.0084 (1.055)
primary separated road	-0.0026 (-0.386)	-0.0065 (-0.377)
Area Attributes		
pedestrian activity	0.0045 (0.185)	0.0111 (0.179)
parkland	0.0042 (0.393)	0.0090 (0.329)
commercial accessibility	0.0007 (0.106)	0.0040 (0.252)
transit accessibility	-0.0059 (-0.882)	-0.0172 (-1.0087)
race	**0.0142 (2.635) *** **	**0.0373 (2.707) *** **
population under 5 years	**-0.0679 (-1.668) * **	-0.1636 (-1.573)
population 5 and 15 years	0.0416 (1.483)	0.1122 (1.568)
vehicle ownership	0.0017 (0.138)	0.0143 (0.448)
road density	0.0033 (0.296)	0.0029 (0.103)
population density	**0.0005 (2.272) ** **	**0.0013 (2.112) ** **
median income	-0.0001 (-0.331)	-0.0003 (-0.630)
mixed use	-0.0004 (-0.023)	0.0025 (0.057)
	N = 163 R^2 = .298	N = 163 R^2 = .292
* Statistically significant at the 10% level ** Statistically significant at the 5% level *** Statistically significant at the 1% level		

Table 13: Models 4-5 Estimation Results Segmented for Pedestrian Crashes 18 Years and Younger.

5.4 Pedestrian Crashes Involving Children Age-Appropriate to the School

In order to more specifically capture commute trips to school by students, the models were segmented to include only crashes involving pedestrians aged appropriate to the proximate school. In Table 14, it is shown that aggregate severity of crashes (Model 1) has a statistically significant positive relationship with race, population between 5 and 15 and population density. These are attributes that have been consistently significant for all segmented models.

Remarkably, in the models segmented for age appropriateness, variables not statistically significant in any of the previous models become so. These variables are the school type binary variables. To interpret these binary variables, one case must be excluded and the resulting coefficients are relative to that excluded variable. For this analysis the senior high variable was excluded. Consequently, the relationship between elementary and senior high school was significant for aggregate severity of crash (Model 1), crashes per enrollment (Model 4) and aggregate severity of crashes per enrollment (Model 5). In all cases, it shows a positive relationship; crash severity and crash occurrence are more likely at elementary schools than high schools.

Models segmented by age appropriateness and including a density dependent variable are presented in Table 15. These models are unremarkable; both maintain only two statistically significant positive relationships with race and population density.

Dependent Variables	Model 1: Aggregate Severity of Crash	Model 2: Average Severity of Crash	Model 3: Crash Count
Independent Variables			
School Attributes			
enrollment	0.0021 (0.954)	-0.0001 (-0.224)	0.0006 (0.726)
elementary school	**3.4625 (1.685) ***	-0.0084 (-0.028)	1.2938 (1.572)
middle school	2.0155 (0.863)	0.1264 (0.367)	0.8905 (0.953)
set back	0.1286 (0.090)	0.1126 (0.536)	-0.0136 (-0.024)
recreation	0.8863 (0.636)	0.2318 (1.126)	0.3616 (0.647)
driveway	0.0785 (0.056)	-0.2629 (-1.263)	0.1489 (0.264)
off-street parking	-0.9089 (-0.487)	**0.4672 (1.697) ***	-0.6000 (-0.884)
primary unseparated road	1.8431 (1.324)	-0.1083 (-0.527)	0.6306 (1.131)
primary separated road	-0.4375 (-0.145)	0.2294 (0.514)	-0.2391 (-0.197)
Area Attributes			
pedestrian activity	-12.6262 (-1.177)	-1.4244 (-0.899)	-3.6003 (-0.838)
parkland	2.6947 (0.564)	-0.0495 (-0.070)	1.1485 (0.601)
commercial accessibility	1.9016 (0.675)	**0.7637 (1.838) ***	0.2388 (0.212)
transit accessibility	-4.0379 (-1.360)	-0.5494 (-1.253)	-1.3495 (-1.135)
race	**5.0733 (2.131) ****	**0.8632 (2.456) *****	**2.0148 (2.113) ****
population under 5 years	-9.2830 (-0.516)	0.2332 (0.088)	-4.4186 (-0.613)
population 5 and 15 years	**22.2926 (1.804) ***	-0.3711 (-0.203)	**9.8954 (1.999) ****
vehicle ownership	1.1253 (0.205)	-0.5589 (-0.688)	0.3137 (0.142)
road density	4.3739 (0.881)	1.0691 (1.459)	1.6854 (0.848)
population density	**0.3055 (2.884) *****	0.0225 (1.437)	**0.1242 (2.927) *****
median income	-0.0433 (-0.624)	-0.0024 (-0.232)	-0.0102 (-0.368)
mixed use	11.2612 (1.494)	0.2030 (0.182)	3.6837 (1.220)
	N = 163 R^2 = .361	N = 163 R^2 = .237	N = 163 R^2 = .365
* Statistically significant at the 10% level ** Statistically significant at the 5% level *** Statistically significant at the 1% level			

Table 14: Models 1-3 Estimation Results Segmented for Crashes Involving Children Age Appropriate to School

Dependent Variables	Model 4: Crash Count Per Enrollment	Model 5: Aggregate Severity of Crash Per Enrollment
Independent Variables		
School Attributes		
elementary school	**0.0047 (2.071) ** **	**0.0124 (2.145) ** **
middle school	0.0013 (0.433)	0.0032 (0.424)
set back	0.0013 (0.709)	0.0036 (0.766)
recreation	-0.0007 (-0.387)	-0.0016 (-0.341)
driveway	0.0008 (0.440)	0.0012 (0.253)
off-street parking	-0.0006 (-0.227)	-0.0002 (-0.034)
primary unseparated road	0.0019 (1.044)	0.0051 (1.114)
primary separated road	-0.0034 (-0.860)	-0.0075 (-0.754)
Area Attributes		
pedestrian activity	-0.0023 (-0.163)	-0.0179 (-0.503)
parkland	0.0018 (0.286)	0.0039 (0.244)
commercial accessibility	0.0008 (0.221)	0.0056 (0.612)
transit accessibility	-0.0038 (-0.989)	-0.0115 (-1.171)
race	**0.0071 (2.261) ** **	**0.0177 (2.236) ** **
population under 5 years	-0.0353 (-1.490)	-0.0771 (-1.291)
population 5 and 15 years	0.0251 (1.544)	0.0569 (1.385)
vehicle ownership	0.0021 (0.285)	0.0077 (0.424)
road density	0.0037 (0.577)	0.0093 (0.569)
population density	**0.0003 (2.165) ** **	**0.0007 (2.0437) ** **
median income	-0.0001 (-0.599)	-0.0002 (-0.802)
mixed use	-0.0002 (-0.017)	0.0077 (0.311)
	N = 163 R^2 = .303	N = 163 R^2 = .293
* Statistically significant at the 10% level ** Statistically significant at the 5% level *** Statistically significant at the 1% level		

Table 15: Models 4-5 Estimation Results Segmented for Crashes Involving Children Age Appropriate to School

5.5 Aggregate Severity Weight for All Ages By School

To determine what specifically influences crashes and severity at each school type, three models were run segmented by school type in Table 16. This series of analyses show that race consistently remains statistically significant with a positive relationship with aggregate severity of crash. Combined with the previous analyses, this highlights the disparity in equity for nonwhite populations in the City of Baltimore.

Contrary to previous models, the aggregate severity of crashes has a statistically significant negative relationship with transit accessibility for elementary schools. This could be attributable to a reduction in crash count or less severe crashes occurring in that area. Perhaps around elementary schools specifically, drivers are more cautious and more likely to obey the reduced speed limits, therefore reducing severity. Associated with transit accessibility, perhaps people are taking alternative modes of transportation to work (pedestrian activity has a negative relationship but is not statistically significant) via the transit accessibility, thus limiting the number of vehicles on the road especially during rush hour times.

Elementary schools are also shown to have a statistically significant positive relationship with mixed use. Again, motorists may be more aware of pedestrians because this type of development has been shown to specifically attract pedestrians.

Middle schools are shown to have a statistically significant negative relationship between school set back and aggregate severity of crash. This is most likely indicative of the type of neighborhood surrounding that school. Schools with set backs are typically in more suburban areas with space available and larger buffers between sidewalks and the street. In these areas, pedestrian travel is less due to increases in vehicle ownership and walking distances between the houses and schools. This observation may be confounded with typical walking rates in these neighborhoods; there are less pedestrians and as a result, less pedestrian crashes.

Further substantiating the previous point, the model for middle schools shows that pedestrian activity has a statistically significant positive relationship with aggregate severity of crash. More pedestrians in those areas increases the likelihood of a crash.

Finally, middle schools have a statistically significant positive relationship between road density and aggregate severity of crashes. This is also indicative of the type of development surrounding the school. More urban and densely populated areas (indicated by higher densities of roads) generate more pedestrian trips than their counterpart. It is expected to see an increase in the number of crashes in that area.

Dependent Variables	Model 1: Aggregate Severity of Crash - Elementary	Model 2: Aggregate Severity of Crash - Middle	Model 3: Aggregate Severity of Crash - Senior
Independent Variables			
School Attributes			
enrollment	0.0003 (0.034)	0.0054 (0.309)	-0.0070 (-0.696)
set back	-4.2970 (-0.825)	**-38.8080 (-2.656)****	42.7190 (1.294)
recreation	6.6940 (1.274)	-1.6880 (-0.132)	-22.7950 (-1.220)
driveway	-7.8910 (-1.540)	11.8010 (1.216)	-48.9910 (-1.881)
off-street parking	-5.1830 (-0.791)	-13.150 (-0.560)	-45.6890 (-1.301)
Area Attributes			
pedestrian activity	-32.2400 (-0.897)	**475.327 (3.363)****	354.1080 (1.788)
percent parkland	-2.2000 (-0.113)	-49.1130 (-1.007)	12.9570 (0.525)
commercial accessibility	15.383 (1.529)	29.720 (1.384)	-61.8570 (-1.559)
transit accessibility	**-37.800 (-3.569)*****	-12.8870 (-0.603)	51.5350 (1.281)
race	**19.4290 (2.290)****	**46.0160 (2.715)****	**63.6730 (1.959)***
population under 5 years	27.6470 (0.412)	301.345 (1.874)	-44.7370 (-0.228)
population 5 - 15 years	36.3120 (0.803)	-150.919 (-1.204)	192.9320 (1.398)
road density	24.3420 (1.356)	**171.4750 (2.865)****	75.4330 (0.996)
population density	**1.135 (3.129)*****	-3.4120 (-1.904)	-2.1100 (-1.455)
median income	0.0602 (0.271)	-1.3190 (-1.336)	0.4880 (1.120)
mixed use	**58.5410 (1.945)***	-133.774 (-1.727)	-78.3750 (-0.777)
	N = 116 R^2 = .558	N = 23 R^2 = .889	N = 24 R^2 = .798

* Statistically significant at the 10% level
** Statistically significant at the 5% level
*** Statistically significant at the 1% level

Table 16: Aggregate Severity of Crashes Segmented by School Type

This analysis is limited, however, by amount of schools representing each type (by grade). Specifically, there are only 23 middle schools and 24 high schools. Further, the inferences made in this analysis emphasize the need for the inclusion of a measure of pedestrian exposure.

5.6 Crashes Ages 15 and Under by Exposure Rates

As a proxy for exposure, a model was specified with the number of crashes age 15 and under in the school buffer zone divided by population 15 and under for the blockgroup. The model considered all variables similar to previous analyses in this study; however, to optimize the findings many variables were removed for the final models in Table 17.

Dependent Variable	Crashes Per Population (15 and under)	Crashes Per Combined Population (15 and under)
Independent Variables		
School Attributes		
driveway	**-0.011 (-2.198) ****	0.061 (0.534)
off-street parking	-0.008 (-1.187)	0.052 (0.329)
Area Attributes		
transit accessibility	**-0.020 (-3.373)*****	0.149 (1.068)
race	**0.024 (2.903)*****	**0.578 (3.006) *****
vehicle ownership	0.020 (1.465)	-0.204 (-0.622)
road density	**0.059 (3.529) *****	**1.079 (2.728) *****
mixed use	**0.062 (2.59)****	0.085 (0.152)
	N = 163 R^2 = .538	N = 163 R^2 = .132
* Statistically significant at the 10% level ** Statistically significant at the 5% level *** Statistically significant at the 1% level		

Table 17: Crashes per Population Age 15 and Under

Population determined from only one blockgroup (crashes per population) is not sufficient to describe crashes within the buffer of a school. Because the crashes used in the analysis are aggregated at the school buffer levels that tend to span multiple blockgroups, there is a mismatch at the analysis level when considering only population of the school blockgroup. To capture a more accurate demand measure based on population, the combined population of all blockgroups whose centroid is located within the school buffer was considered in Table 17 (crashes per combined population).

Two significant relationships, race and road density, remain the same. Interestingly, the more specific population count changes the relationship between crash occurrence and driveway presence, parking presence, transit accessibility and vehicle ownership. Although the model has low explanatory power, it does give rise to a concern that previous models, which do not include an exposure rate, could be imprecise.

It is seen from this analysis that rather than a proxy measure, such as population, actual pedestrian counts are necessary to determine pedestrian exposure rates. It was expected that crashes would increase with environments that encourage more pedestrian trips; therefore, to apply these findings in policy-based decisions would be inaccurate. In order to properly address pedestrian safety policy it is necessary to consider pedestrian demand in the analysis.

CHAPTER SIX: IMPLICATIONS AND FUTURE NEEDS

6.1 Implications of the Study

The evidence presented in this paper suggests there are many links between school attributes and pedestrian crashes near schools. The most consistent relationship found was between crash occurrence and severity and race. This is not a new finding; however, it is clear that this is an equity issue that should be addressed for children walking to school.

Relationships between land use and pedestrian travel near schools were varied. In most cases, a positive relationship was observed between crash count and severity, and recreation presence, commercial accessibility, population density, and mixed use. It has been established previously that these built environments attract pedestrian trips, so it is not surprising that the crash numbers are higher in these areas.

Regarding the physical attributes of the school, it was found that the presence of a driveway did reduce crash numbers and crash severity. This may be interpreted in a variety of ways; the driveway aids in minimizing bus and drop-off congestion in the immediate area or it facilitates higher numbers of auto-driven students thereby lessening the number of pedestrians.

School set back and was shown to decrease pedestrian crash counts but increase the severity of the crashes. This may indicate that schools with set backs are typically located in a more suburban area with more available land but, less pedestrian-friendly streets.

An increase in severity of crash by parking lot presence was significant for children 18 and under and not children age 15 and under. This may indicate that high schools may be increasing the severity of crashes by facilitating the parking allowing new drivers to drive to school. These drivers tend to be less responsible than older drivers and more reckless.

Recreation presence was shown to increase pedestrian-vehicular crash counts and severity, particularly for elementary schools. This relationship with regard to crash count seems intuitive; children will be attracted to recreation, especially within the neighborhood at walking distances. Regarding severity, children may be less cautious because they are playing in the area and may be with other children and be less observant of traffic. Perhaps the speed limits directly around schools should be permanently lowered, not only during commuting hours, to help reduce the severity of crashes near these areas.

6.2 Future Research Needs

This study is limited in its interpretation because it does not contain pedestrian count data. Inclusion of this type of data would further explain the relationships between the built environment characteristics and crash counts.

Greater detail in describing the built environment surrounding the schools would further address design needs for increased safety. These variables could include: presence of a pedestrian signal, presence of a traffic signal and school location, such as midblock or intersection.

Finally, this study has further substantiated the relationship between race and pedestrian crashes. This study determined that blockgroups with higher nonwhite populations significantly increased both crash occurrence and crash severity. To further address this difference, ethnicity data regarding the pedestrian and the schools should be obtained.

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