How Differences in Roadways Affect School Travel Safety

Chia-Yuan Yu

Problem, research strategy, and findings: Three children 14 and younger are killed daily in the United States and almost 500 more are injured in traffic crashes, often while traveling to or from school. Previous studies examine the effect of built environmental characteristics on school travel safety, but are limited. I simultaneously evaluate the impact of street segment–level and neighborhood-level design characteristics on crashes involving elementary school–aged child pedestrians during school travel time around 78 elementary schools in Austin (TX). I find that more school travel–related collisions happen on highways and interstates and arterial roads and where there are traffic-generating land uses and transit stops. Fewer crashes occur on local roads and when there are connected sidewalks. Unfortunately, I do not consider microlevel features of the built environment; moreover, the crash data may include children's crashes not related to school travel.

Takeaway for practice: Planners should collaborate with a wide variety of agencies and organizations at different levels of government as well as with parents and neighborhood residents to create pedestrian-friendly schools that reduce or overcome current barriers to safe, human-powered school travel. Planners should address both current school safety problems at existing schools and help ensure better school siting and complementary planning and transportation decisions in the future.

Keywords: school travel safety, built environment, school siting, traffic safety, neighborhood planning.

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Children are a particularly vulnerable group for traffic-related injuries and fatalities (National Highway Traffic Safety Administration [NHTSA], 2012). Motor vehicle collisions are the leading cause of death for children under 15 in the United States (NHTSA, 2012). In 2013, an average of three children aged 14 and younger were killed, and an additional 470 were injured, each day in traffic crashes in the United States (NHTSA, 2015). A significant number of collisions involving school-aged children occur on their journey to and from school (Warsh, Rothman, Slater, Steverango, & Howard, 2009). Schools experience substantial traffic during the morning and afternoon peaks as motorists drop off or pick up their children while other children arrive or depart by walking, using public transit or school buses, cycling, or skateboarding. In 2009, 6.6 billion vehicle trips, covering 30 billion vehicle miles, were made to take or pick up children to and from school in the United States (McDonald, Brown, Marchetti, & Pedroso, 2011). A study in Toronto (Canada) finds that the crash rates of children aged 5 to 9 years are three times higher when they travel to or from school than at other times (Warsh et al., 2009). Not surprisingly, parents often report that traffic concerns are a major determinant in the choice of their children's travel mode to and from school (D'Haese, De Meester, De Bourdeaudhuij, Deforche, & Cardon, 2011; McDonald & Aalborg, 2009). For these very reasons, Congress established the Safe Routes to School (SRTS) program in 2005 to fund a variety of approaches to increase school safety, from educating and training school children to avoid risks to traffic engineering improvements near schools. However, we have little information on the impacts of the built environment, particularly the kinds and types of roadways surrounding schools, on school travel safety.

Researchers have not paid sufficient attention to the impacts of community design and the built environment on the travel safety of young children, or differences by the age of the children and the type of school they are attending. Previous studies on crashes involving school-aged children investigate

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children in a wide age range, including those attending elementary, middle, and high schools (Desapriya et al., 2011; Warsh et al., 2009). Yet, there are wide variations in the abilities of children of different ages and the size and siting of schools encompassing different grades.

To address these concerns, I examine a wide range of attributes of the built environment around elementary schools, including both road and neighborhood environments, for their potential links to crashes involving elementary school–aged (5 to 12 years) child pedestrians on their travel to school. I focus on crashes involving elementary school children because elementary school children are relatively more vulnerable than middle and high school children (Abdel-Aty, Chundi, & Lee, 2007). In addition, I go beyond current studies on school travel safety that consider only the influence of street segment–level or neighborhood-level variables (Abdel-Aty et al., 2007; Clifton & Kreamer-Fults, 2007) by considering both factors.

I analyze the risk of a car striking a child aged 5 to 12 years around 78 elementary schools in the Austin (TX) Independent School District (AISD) by using two-level (street segment–level and neighborhood-level) binomial logistic models. I find more elementary school travel–related crashes occur on highways/interstates and arterial roads, while fewer crashes happen on local roads. Connected sidewalks along street segments decrease the probability of crashes involving elementary school children traveling to school, while commercial uses and transit stops along street segments increase the probability of crashes. Roads with higher speed limits also increase the probability of crashes involving children traveling to elementary schools.

Planners can use these results to improve and enhance the safety of children walking or cycling to school, whether part of formal SRTS plans, or increasingly as part of ongoing city planning processes (McDonald et al., 2014). My research reinforces previous recommendations that planners should work with a wide variety of stakeholders and public agencies at all levels of government to ensure pedestrian-friendly access to schools (Cooner, Fitzpatrick, Wooldridge, & Ford, 2003). Planners should address both current school safety problems at existing schools and help ensure better school siting and complementary planning and transportation decisions in the future.

In this study, I review the literature on the causes of crashes involving pedestrians, both children and those of all ages. I then describe my research and methods and summarize the relationship between traffic speeds, pedestrian infrastructure, and land uses on one hand, and pedestrian crashes involving elementary school children traveling to or from school on the other. I conclude with three recommendations for planners to help create pedestrian-friendly and safe access to school: Work with traffic engineers to prioritize improvements and reduce speeds around existing schools; collaborate with a wide range of stakeholders to identify hot spots or sites of auto–pedestrian conflicts; and work with school districts to better incorporate sound planning principles into school siting decisions in the future.

Community Design and School Travel Safety

Schools serve as the center of daily activities for school-aged (5 to 12 years) children. Researchers have identified schools as high-risk crash locations (Clifton, Burnier, & Akar, 2009; Clifton & Kreamer-Fults, 2007; LaScala, Gruenewald, & Johnson, 2004) because they experience regular, concentrated, and congested traffic flows that create safety threats to children traveling to and from school (Abdel-Aty et al., 2007; Clifton & Kreamer-Fults, 2007; LaScala et al., 2004). School siting might be a key factor in influencing children's school travel behaviors and traffic safety around school areas, and was the source of much discussion among early urbanists.

Early urban designers focused on community-centered schools, which were inspired by the 1929 Perry concept of the neighborhood unit, a significant planning paradigm that influenced many local planning and subdivision design practices prior to World War II (Lawhon, 2009; McDonald, 2010). These schools are designed to be surrounded by well-connected infrastructure for nonmotorized modes and by local roads with low speed limits and traffic volumes (National Governors Association Center for Best Practices, 2007). In this model, commercial uses are located on arterial roads served by automobiles, while residential uses are placed on disconnected local roads and cul-de-sacs to separate pedestrians from that vehicle travel (National Governors Association Center for Best Practices, 2007). Such patterns were advanced supporting a safe pedestrian environment for school children and all pedestrians. Perry's (1929) model has largely been discredited (Talen, Menozzi, & Schaefer, 2015), and its importance in school siting decisions faded with the advent of school buses (making it unnecessary to site schools within walking distance of residences).

The more common type of school is often seen in suburban areas. In 1953, the Council of Educational Facility Planners (CEFPI) suggested that elementary school sites should be a minimum of 10 acres, plus one additional acre per 100 students. This standard was adopted in most states and resulted in large elementary schools on less expensive lands, comparatively far away from the residential areas they serve (National Governors Association Center for Best Practices, 2007). These suburban schools are designed primarily for motorist convenience; they are often located near highways and arterial roads, a characteristic that increases traffic exposure while failing to promote safe spaces with reduced traffic conflicts and pedestrian injuries (National Governors Association Center for Best Practices, 2007).

Where elementary schools are located, as well as the design of the surrounding environment, create different travel patterns with different safety impacts. Elementary schools surrounded by safe built environments for walking (e.g., low-speed roads, connected sidewalks, etc.) may make parents feel it is safe to allow their children to use human-powered modes to travel to school (McMillan, 2005; Nelson & Woods, 2010). Conversely, schools near major arterials in neighborhoods with cul-de-sac designs may encourage parents to drive children to school to keep them safe (McMillan, 2007; Timperio et al., 2006; Trapp et al., 2012).

Built environments at different scales—macro versus micro—may provide different incentives or barriers to walking to school. I define the macro elements to include community environments such as street connectivity and mixed land use; I define microenvironments to include detailed neighborhood elements such as nonmotorized infrastructure and traffic speed. These types of elements may have differential or even contradictory impacts on traffic safety. For example, an Austin (TX) study finds that macroenvironments with higher density, street connectivity, and mixed land uses in low-income and Hispanic neighborhoods are more walkable than high-income and mostly non-Hispanic White communities. However, at the same time, those neighborhoods face poor microenvironments because they have worse sidewalk maintenance and esthetics and higher crash and crime rates (Zhu & Lee, 2008). Another study in New York City also illustrates the conflict between the macro- and microenvironments in low-income neighborhoods; Neckerman et al. (2009) find that low-income neighborhoods have higher macrolevel walkability but poorer microlevel environments than higher-income neighborhoods because the streets are poorly maintained and lack amenities such as street trees.

Table 1 shows different street segment–level (micro) and neighborhood-level (macro) built environments around two elementary school paradigms: community-centered schools and suburban schools. Community-centered schools are surrounded by local roads with low speed limits and nonmotorized infrastructure (street segment level) and connected street networks, residential uses, and low traffic volume (neighborhood level). Suburban schools are located near highways or arterial roads with high speed limits (street segment level) and cul-de-sac designs, commercial uses, and high traffic volume (neighborhood level).

The Safe Routes to School Program and School Travel Safety

In 2005, Congress created the Safe Routes to School (SRTS) program, which funds both infrastructure projects, such as adding sidewalks and traffic signals near schools, and non-infrastructure projects, such as education, training, and incentive programs (Stewart, 2011). Most researchers find that SRTS programs are effective in increasing the use of human-powered modes for the school commute. McDonald et al. (2014) report on a large-scale study at 801 schools in the District of Columbia, Florida, Oregon, and Texas, finding that walking and biking to school increase after local implementation of SRTS programs: an 18% increase due to engineering improvements and a 25% increase due to education and enforcement programs.

However, fewer studies have looked directly at the traffic safety impacts of these mode changes on students. A California study examining the safety impacts of SRTS projects finds that there is a significant decline in the total number of pedestrian- or bicycle-involved collisions within 250 feet of 47 schools with SRTS projects (Ragland, Pande, Bigham, & Cooper, 2014). A New York City study also shows that the rates of school-aged pedestrian injuries during school travel hours decreased by 44% in census

Table 1. Different types of school surrounding by different community designs (street segment level and neighborhood level).

Built environments at different scales	Community-centered school	Suburban school
Neighborhood-level environment	Connected street network	Cul-de-sac design
	Residential use	Commercial use
	Low traffic volume	High traffic volume
Street segment–level environment	Local road	Highway/arterial road
	Low speed limit	High speed limit
	Nonmotorized infrastructure	Motorized convenience

tracts with SRTS programs and remain unchanged for those census tracts without SRTS projects (DiMaggio & Li, 2013). Boarnet, Anderson, Day, McMillan, and Alfonzo (2005) find that traffic conflicts and crash risk decrease after the implementation of a sidewalk gap closure project because more students are using sidewalks rather than walking or biking in the street or on the shoulder of the road. In contrast, Orenstein, Gutierrez, Rice, Jill, and Ragland (2007) report that the rates of child-related collisions are not dramatically different for schools with and without SRTS construction projects, although crash rates do not increase as the number of students walking to school increases.

However, SRTS projects focus primarily on incentive, education, enforcement, and training programs or relatively marginal physical changes to the school environment. Most do not focus on aspects of the built environment or explicitly consider the safety effects of the design of the surrounding community. In fact, SRTS projects cannot directly address neighborhood designs or the extent to which schools are located near high-volume roads.

Evidence of the Impacts of Community Design on School Travel Safety and Pedestrian Safety

Several descriptive studies of school-aged child pedestrian collisions are informative. For example, Warsh et al. (2009) explore the characteristics of child (younger than 18) pedestrian collisions in school zones in Toronto (Canada); they find that more crashes occur at midblock than at intersections (as is true of all pedestrian crashes). Desapriya et al. (2011) report that almost 86% of child (younger than 19) pedestrian fatalities in British Columbia (Canada) occur in roads with a speed limit of 30 miles per hour or higher.

Few studies have linked factors in the built environment, such as land uses and road types, to crashes involving school-aged children, although many studies show that total crashes are significantly affected by all these factors (Shawsky, Garib, & Al-Harthei, 2014). However, Clifton and Kreamer-Fults (2007) explore the impacts of neighborhood-level environments on pedestrian–vehicle crashes involving school-aged children (5 to 18 years) around 163 public schools in Baltimore (MD). They report that areas with a higher non-White population and a higher population density experience more school-aged children (5 to 18 years) pedestrian–vehicle crashes. Areas with great commercial access and mixed land uses also have higher school-aged children (5 to 18 years) pedestrian–vehicle crashes. Abdel-Aty et al. (2007) examine the effects of road environments at the street segment level on crashes involving children aged 4 to 18 around schools in Orange County (FL). They find that these students are more likely to be involved in crashes on high-speed, multilane roads.

These studies use statistical analyses to examine the relationship between built environments and crashes involving school-aged children, but have limitations. First, these studies do not account for traffic volumes and school enrollment, important exposure factors affecting crashes involving school-aged children. Second, these studies tend to group crashes involving a wide range of school-aged children from 4 to 18 years attending elementary school, middle school, and high school. However, Abdel-Aty et al. (2007) report that elementary school children are more likely to be involved in school-related crashes than middle and high school children. Moreover, the designs of, and policies on, school siting also differ significantly for elementary, middle, and high schools (National Governors Association Center for Best Practices, 2007).

It is important to note that pedestrian crashes at specific sites are actually rare; thus, many studies are forced to rely on changes in factors or surrogate safety measures thought to influence crashes (Federal Highway Administration [FHWA], 2011). Surrogate measures include whether drivers slow down when approaching an intersection or pedestrian crossing or whether pedestrians refrain from crossing midblock, or when the traffic light is against them or there is insufficient time remaining to cross. Changes in these surrogate measures, or risk factors, may not actually be directly linked to changes in crash rates (FHWA, 2011).

There is a literature on the impact of the general built environment on child pedestrian and total pedestrian crashes that also informs my work (Aziz, Ukkusuri, & Hasan, 2013; Kim, Lee, Washington, & Choi, 2007; Mannering & Bhat, 2014; Mohamed, Saunier, Miranda-Moreno, & Ukkusuri, 2013; Ukkusuri, Hasan, & Aziz, 2011). In general, this research finds that traffic-generating uses such as commercial enterprises are linked to higher pedestrian crash rates because they attract both motorists and pedestrians, thus increasing the possibility for conflicts (Jemprapai & Srinivasan, 2014). Bennet and Yiannakoulis (2015) find that child pedestrian injuries at intersections are associated with land use characteristics, traffic volume, and intersection controls; however, they find that similar crashes at midblock locations are not associated with small-scale environmental features, suggesting that children's crash risks differ across locations. Di, Taquechel, Steward, and Strasser (2010) find that pedestrian crashes in Georgia are more frequent on road segments where streets are compact, where there are mixed land uses, and where density is high. Elias and Shiftan (2014) find that child pedestrian road crashes are affected by socioeconomic status, travel patterns, and land use.

There are also other consistent patterns in overall pedestrian crash data: Most crashes occur outside of intersections, and those crashes are more serious than those occurring in intersections. The FHWA (2013) reports that 68.1% of all pedestrian crashes are not in intersections; NHTSA (2015) finds, however, that more than 80% of child pedestrian traffic fatalities occur outside intersections. Moreover, most child pedestrian fatalities occur between 3 p.m. and 5:59 p.m., when most children would return home from school. Koopman, Friedman, Kwon, and Sheehan (2015) report that in Chicago, children are more likely to be involved in a pedestrian crash (per 100,000 people) than adults but are less likely to be involved in fatal pedestrian crashes. These researchers also find that younger pedestrians are more likely to be involved in midblock crashes; that is, there is an inverse relationship between age and the likelihood of being involved in a midblock crash.

Driveways are recognized hot spots for traffic crashes involving pedestrians of all ages (Gattis et al., 2013), even in residential areas (Box, 1969), although crashes occurring in private driveways and outside of public rights-of-way are usually not recorded in traffic safety data (NHTSA, 2014a, 2014b). Gattis et al. (2013) note that "Driveway connections create intersections, which in turn create conflicts with bicyclists, pedestrians, and other motor vehicles" (p. 38) and suggest that driveways should be conspicuous and clearly delineated for various road users. At the same time, they note that while driveway crashes constitute between 11% and 19% of all crashes, those involving pedestrians or cyclists account for a very small percentage (less than 3%) of all crashes (although they may be underreported, as is true of all pedestrian crashes).

In addition, the lack of marked crosswalks is also linked to higher pedestrian crash rates because neither pedestrians nor motorists realize the dangers involved; Haleem, Alluri, and Gan (2015) recommend placing standard crosswalks at unsignalized intersections. An FHWA (2010) study finds that raised pedestrian safety islands reduce pedestrian crashes at marked crosswalks by 47% and at unmarked crosswalks by 39%. Samuel et al. (2013) report that drivers approaching a pedestrian crosswalk are more likely to scan the environment in search of pedestrians when there are advanced yield markings, signs, or signals 20 to 50 feet before a marked crosswalk, coupled with removing parking spaces immediately adjacent to the crosswalk (thus increasing a driver's ability to see pedestrians starting to cross the street). Vasudevan, Pulugurtha, Nambisan, and Dangeti (2011) find that pedestrian-activated traffic signals (including flashing yellow lights and countdown signals) improve the behavior of both drivers and pedestrians. A Texas Transportation Institute (TTI; 2014) study at a number of sites in the state concludes that traffic control signals are the most effective at getting drivers to yield to pedestrians, but other flashing signals and beacons are almost as effective. Most important, TTI finds that the more widespread the use of a specific traffic control measure in the city they study, the greater the number of drivers that yield to pedestrians, possibly because they have a better understanding of how the device works because they have greater exposure to it.

However, there is some dispute about the actual and relative impact of crosswalks and a variety of traffic signals on all pedestrian crashes. Some studies conclude, for example, that marked crosswalks actually involve higher pedestrian crash rates (Zhao, Tian, & Herandez, 2013). A study in New York City finds that signal-related countermeasures are more effective in reducing pedestrian crashes than high-visibility crosswalks (Chen, Chen, & Ewing, 2012). An FHWA (2011) study reports that while advanced stop or yield lines with additional signing near marked crosswalks are a commonly recommended safety countermeasure, they are not widely used and may have limited effectiveness on high-speed, high-volume roads.

It is also important to recognize the impact of pedestrian behavior and compliance with traffic signals on crashes. Hussein, Sayed, Reyad, and Kim (2015) find that the main factor explaining a high number of conflicts between vehicles and pedestrians of all ages is pedestrians crossing the street when pedestrian signals are flashing or say "Don't Walk." They find that during a two-hour period at a major signalized intersection in New York City more than a third of pedestrians are either crossing outside the crosswalk or past the time they should have started to cross. This supports the focus of traffic safety experts on education as well as enforcement and traffic treatments in reducing pedestrian crashes.

Many traffic safety experts suggest the need for integrated and cooperative approaches to school safety and pedestrian safety overall, although they rarely see a role for planners. Haleem et al. (2015) comment that to improve pedestrian safety, "appropriate countermeasures should be organized through the coordination of law enforcement officers, safety engineers, and the public to integrate the components of the four E's: engineering, education, enforcement, and emergency response" (p. 22).

Evaluating Macro- and Microlevel Design Characteristics

To build on the existing literature and address gaps in prior work, I use actual crash data, not surrogate measures, on crashes involving elementary school–aged (5 to 12 years) children. I evaluate the impact of macro- and microlevel design characteristics on school travel safety. Moreover, in contrast to prior studies that examine the impact of built environments on school travel safety only at one scale—street segment level or neighborhood level—I simultaneously examine the impact of both street segment–level and neighborhood-level built environments on school-related crashes. My approach allows me to offer suggestions on how planners can improve school travel safety by better designing the road network and the environment around elementary schools. I examine the relationship between the built environments around schools and crashes involving elementary school–aged child pedestrians specifically during school travel time, which has not been examined in the urban planning literature.

I selected 78 elementary schools in the AISD, serving central Austin (TX), a 271.8-square-mile area with 60,263 children aged 5 to 12 in these 78 schools. The selected schools and their catchment areas feature diverse development patterns, ranging from inner-city neighborhoods with high densities, small parcels, and grid-like street networks on one hand, to suburban neighborhoods with low densities, larger parcels, and cul-de-sac street networks on the other hand. This sample provides enough variation to explore the association between built environments and school travel safety. Moreover, I use 0.5-mile buffers around each school, assuming that this is a feasible distance for elementary school–aged children to walk.

Measuring Street Segment–Level School Travel Safety

I use five-year (2008–2012) crash data from the Texas Department of Transportation (TxDOT). These data provide the age of people involved in the crash and time of the crash (e.g., the day of the week and the time of the day). I geocoded these collisions based on the longitude and latitude of the crash. To identify crashes involving elementary school–aged child pedestrians during school travel time, I use six criteria developed by Abdel-Aty et al. (2007) and McDonald et al. (2011). I identify and select crashes that involve:

- pedestrians and vehicles;
- people who were 5 to 11 years old for schools serving grades 1 through 5, or 5 to 12 years old for schools serving grades 1 through 6;
- weekdays (from Monday to Friday);
- school travel time (5 to 11 a.m. and 1 to 6 p.m.); and
- 0.5-mile buffers around each of the 78 AISD elementary schools.

Table 2. Number of crashes involving elementary school–aged child pedestrians during school travel time within 0.5-mile parcel buffers from elementary schools in the Austin (TX) Independent School District.

Year	Number	Percentage
2008	185	19.68%
2009	172	18.30%
2010	198	21.06%
2011	183	19.47%
2012	202	21.49%
Total	940	100.00%

Source: TxDOT (2008–2012).

I do not consider one of the six criteria used by Abdel-Aty et al. (2007) and McDonald et al. (2011)—the date of the crashes—because the data are not available. Thus, I do not know if the crash occurred while school was in session.

As Table 2 shows, using these criteria I identify a total of 940 crashes involving elementary school–aged child pedestrians during school travel time between 2008 and 2012 within the 0.5-mile parcel buffers of 78 elementary schools in the AISD.

I use the street segment as the unit of analysis to avoid the serious spatial autocorrelation issues that would arise if each single crash point is used as the unit of analysis and a buffer around the school is used for measuring built environments. I split street segments at intersections and at jurisdiction boundaries to ensure there are no major changes in road characteristics along each segment. I cut off street segments at the point where they intersect with the 0.5-mile buffer boundary around each school because the study area is limited to those buffers.

In total, 11,178 unique street segments are located within 0.5-mile school buffers around 78 elementary schools in the AISD. Of those, 2,072 segments are located within the buffers of two schools, and 247 segments are located within the buffers of three schools. I counted these segments two or three times for the analysis; that is, I reuse the same segment for all the schools with which it is associated, because crashes that occur on these segments are influenced by environments around the corresponding schools. As a result, the final sample size is 16,063 segments. To test whether this creates problems, I also calculated the average neighborhood-level characteristics of two or three schools for these street segments and ran the model to test the consistency of the results. The results for the model that use duplicate street segments ($N = 16{,}063$) and for the model using average neighborhood-level characteristics ($N = 11{,}178$) are consistent: Reusing the same segments two or three times do not bias the result.

Roughly 85% of the street segments had no crashes between 2008 and 2012. Because the data show there was no more than one crash per street segment, I measure the school travel safety performance of each street segment using a binary outcome variable in which "with crashes" equals 1 and "without crashes" equals 0.

I use three sets of factors as independent variables based on the research literature: risk exposure, sociodemographic factors, and characteristics of the built environment. Table 3 lists the dependent and independent variables, their measurements, data sources, and units of measurement. For risk exposure, I consider the average daily traffic count for each street segment in the 0.5-mile elementary school buffers (collected by the City of Austin) and school enrollment for each school. I do not have pedestrian volumes around schools and thus did not include them.

Sociodemographic characteristics include total population density, percentage of the population younger than 12 years, percentage of non-White population, percentage of the population with less than a high school education, percentage of male population, and percentage of the population below the poverty line within the 0.5-mile elementary school buffers. I use sociodemographic information for 2010 U.S. Census block groups, and I split the population in the census block group into the school buffers by the fraction of the area of the school buffer in each census block group.

As Figure 1 shows, I consider two types/levels of built environments: road environments around the street segment (level 1) and neighborhood environments around schools (level 2). The parcel-level land use, street centerline, and sidewalk data are from the City of Austin geographic information system (GIS) data sets.

I create 100-foot buffers around each street segment to stand for road environments. I determine buffer size based on several considerations. First, I refer to the minimum requirements on lane width, shoulder width, and median width for different road types (i.e., freeways, arterial roads, city collectors, and local roads) from the FHWA (TxDOT, 2014). For example, the minimum lane width of highways is 12 feet, and each highway has at least two lanes in each direction. The widths of both the outside and the inside shoulder for highways are 4 to 12 feet on average. If a highway is designed with two lanes, one outside shoulder, and one inside shoulder for both directions, the minimum total width would be 96 feet. Given these minimum requirements, I choose a slightly larger buffer size of 100 feet, which is wide enough to capture most of the land uses around the corresponding street segments while avoiding those along other street segments. Last, this buffer size is reasonably small or narrow to avoid excessive overlaps among the buffers that would cause serious spatial autocorrelations.

For road environments, I include the segment length, distance to school parcel, posted speed limit, road class (highways or interstates, arterials, local roads, city collectors, and ramps and turnarounds), nonmotorized infrastructure (sidewalk and bike lane completeness), transit service density, and the number of parcels for land use types (residential, commercial, office, industrial, and park) along the street segment.

For the neighborhood environment around schools, I include not only the just-described variables to measure road environments, but also additional variables such as the three-leg (T junction or Y junction) and four-or-more-leg (crossroad) street intersection densities, the percentage of busy roads (highways or freeways and arterial roads),

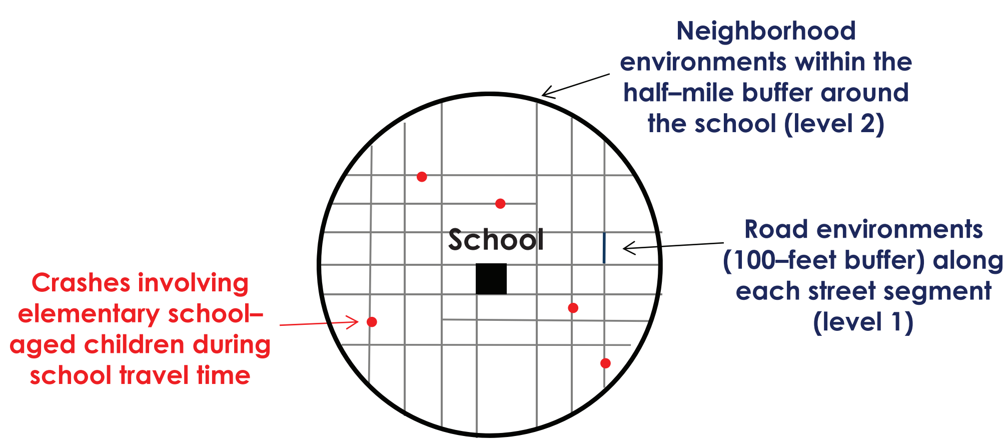

Figure 1. Hierarchical sturucture of road environments and neighborhood environments around schools.

Table 3. Variables, measurements, data sources, units of measurement, and bivariate analyses used in this study.

Variable	Measurement	Data source	Time	Unit of measurement	Descriptive statistics	Bivariate analysis Coefficient (p value)
Dependent variable (street segment–level)						
Occurrence of a collision involving elementary school–aged child pedestrians during school travel time	Yes (1), no (0)	TxDOT	2008–2012	Point	1: 139 (14.79%) 0: 801 (85.21%)	—
Control variables						
Risk exposures						
School enrollment[a]	Number of students enrolled for each school/area of the school parcel buffer (acres)	Academic Excellence Indicator System	2011	Each school	Mean: 2.38 S.D.[c]: 0.93 Min[d]: 0.74 Max[e]: 4.69	0.01 (0.872)
Average daily traffic	Average daily traffic for each street segment	City of Austin	2006	Point	Mean: 242.17 S.D.: 224.40 Min: 8.64 Max: 913.54	0.02*** (<0.001)
Sociodemographic characteristics[b] (neighborhood level)						
Population density	Total population/area of the school parcel buffer (acres)				Mean: 6.54 S.D.: 3.08 Min: 0.60 Max: 15.17	0.05** (0.003)
% of the population younger than 12 years	Population under age 12/total population	U.S. Census Bureau	2010	Census block group	Mean: 0.13 S.D.: 0.04 Min: 0.05 Max: 0.25	0.18** (0.003)
% of non-White population	Non-White population/total population				Mean: 0.32 S.D.: 0.17 Min: 0.07 Max: 0.73	0.13** (0.004)
% of the population with an education level less than high school	Population with an education level less than high school/total population				Mean: 0.12 S.D.: 0.08 Min: 0.01 Max: 0.29	0.31** (0.001)
% of male population	Male population/total population	U.S. Census Bureau	2010	Census block group	Mean: 0.51 S.D.: 0.06 Min: 0.39 Max: 0.79	0.11* (0.023)
% of the population below the poverty line	Population below the poverty line/total population				Mean: 0.20 S.D.: 0.10 Min: 0.02 Max: 0.55	0.22* (0.013)
Independent variables						
Road environments (street segment–level)						
Segment length	Continuous (mile)				Mean: 0.08 S.D.: 0.06 Min: 0.01 Max: 0.86	6.92*** (<0.001)
Distance to school parcel	Continuous (mile)				Mean: 0.24 S.D.: 0.20 Min: 0.01 Max: 0.48	0.45* (0.022)

Table 3. (*Continued*)

Variable	Measurement	Data source	Time	Unit of measurement	Descriptive statistics	Bivariate analysis Coefficient (*p* value)
Road environments (street segment–level, continued)						
Posted speed limit	Continuous (miles per hour)	City of Austin	2010	Street segment	25: 8529 (53.10%) 30: 200 (1.20%) 35: 4510 (28.10%) 40: 597 (3.70%) 45: 1441 (9.00%) 50: 684 (4.30%) 55: 11 (0.10%) 65: 91 (0.60%)	0.12*** (<0.001)
Road class						
Highways/interstates	1 = yes; 0 = no				122 (0.80%)	2.97*** (<0.001)
Arterials	1 = yes; 0 = no				2052 (12.80%)	2.06*** (<0.001)
Local roads	1 = yes; 0 = no	City of Austin	2010	Street segment	9379 (58.40%)	–1.81*** (<0.001)
City collectors	1 = yes; 0 = no				4235 (26.40%)	0.26** (0.002)
Ramps and turnarounds	1 = yes; 0 = no				275 (1.70%)	1.38*** (0.002)
Nonmotorized infrastructure						
Sidewalk completeness	(Sidewalk length)/(street length × 2) in the street segment buffer	City of Austin	2008	Line	Mean: 0.60 S.D.: 0.26 Min: 0 Max: 1.00	–2.47*** (<0.001)
Bike lane completeness	(Bike lane length)/(street length × 2) in street segment buffer	City of Austin	2008	Line	Mean: 0.20 S.D.: 0.30 Min: 0 Max: 1.00	0.24 (0.10)
Transit service						
Transit stops	# of transit stops/area of the street segment buffer (acres)	Capital Metro	2010	Point	Mean: 0.11 S.D.: 0.27 Min: 0 Max: 2.76	1.92*** (<0.001)
Land use types						
Residential use	# of residential parcels along the street segment	City of Austin	2010	Parcel	Mean: 9.21 S.D.: 5.32 Min: 4 Max: 13	-1.82*** (<0.001)
Commercial use	# of commercial parcels along the street segment				Mean: 6.35 S.D.: 4.35 Min: 0 Max: 10	2.24*** (<0.001)
Office use	# of office parcels along the street segment				Mean: 3.62 S.D.: 0.15 Min: 0 Max: 6	2.13** (0.003)
Industrial use	# of industrial parcels along the street segment				Mean: 0.78 S.D.: 0.63 Min: 0 Max: 5	1.02** (0.004)
Park	# of park parcels along the street segment				Mean: 0.14 S.D.: 0.21 Min: 0 Max: 2	0.19 (0.183)

(*Continued*)

Table 3. (*Continued*)

Variable	Measurement	Data source	Time	Unit of measurement	Descriptive statistics	Bivariate analysis Coefficient (*p* value)
Neighborhood environments around schools (neighborhood-level)						
Nonmotorized infrastructure						
Sidewalk completeness	(Sidewalk length)/(street length × 2) in the school parcel buffer	City of Austin	2008	Line	Mean: 0.80 S.D.: 0.14 Min: 0.28 Max: 0.99	–1.02* (0.021)
Bike lane completeness	(Bike lane length)/(street length × 2) in the school parcel buffer				Mean: 0.21 S.D.: 0.16 Min: 0 Max: 0.96	0.85 (0.042)
Street connectivity						
Three-leg intersection density	# of three-leg intersections/total miles in the school parcel buffer	City of Austin	2010	Point	Mean: 0.11 S.D.: 0.04 Min: 0.01 Max: 0.28	–0.57 (0.725)
Four-or-more-leg intersection density	# of four-or-more-leg intersections/total miles in the school parcel buffer				Mean: 0.05 S.D.: 0.03 Min: 0.02 Max: 0.22	1.86 (0.224)
Transit service						
Transit stops	# of transit stops/total miles in the school parcel buffer	Capital Metro	2010	Point	Mean: 0.05 S.D.: 0.04 Min: 0 Max: 0.15	–0.65** (0.008)
Busy roads						
Highways/freeways	The miles of highway/freeway/total miles in the school parcel buffer	City of Austin	2010	Street segment	Mean: 0.04 S.D.: 0.08 Min: 0 Max: 0.32	1.31* (0.041)
Arterials	The miles of arterial roads/total miles in the school parcel buffer				Mean: 0.12 S.D.: 0.10 Min: 0 Max: 0.39	1.82*** (<0.001)
Land use types						
Residential use	Residential area/total area in the school parcel buffer (acres)	City of Austin	2010	Parcel	Mean: 0.53 S.D.: 0.21 Min: 0.06 Max: 0.90	–0.45 (0.141)
Commercial use	Commercial area/total area in the school parcel buffer (acres)				Mean: 0.07 S.D.: 0.08 Min: 0 Max: 0.46	2.35*** (<0.001)
Office use	Office area/total area in the school parcel buffer (acres)				Mean: 0.04 S.D.: 0.08 Min: 0 Max: 0.44	2.13* (0.031)
Industrial use	Industrial area/total area in the school parcel buffer (acres)				Mean: 0.04 S.D.: 0.08 Min: 0 Max: 0.32	2.01* (0.012)
Park	Park area/total area in the school parcel buffer (acres)				Mean: 0.12 S.D.: 0.18 Min: 0 Max: 0.83	–1.18** (0.021)

Notes.
a. Downloaded from AEIS 2011–2012 (Academic Excellence Indicator System). b. Used 2010 Census block group data and area apportionment approach to estimate. c. Standard deviation. d. Minimum. e. Maximum.
*$p < .05$, **$p < .01$, ***$p < .001$.

and the percentages of five major land use types: residential, commercial, office, industrial, and park. I use the 0.5-mile buffer around each school as the unit of analysis to be consistent with the crash selection criteria.

I use a binomial logistic model for the analysis because the dependent variable is a binary measurement. I model the probability of a crash involving elementary school–aged pedestrians during school travel time as a function of three types of factors: risk exposures, sociodemographic characteristics, and characteristics of the built environment. I use a two-level model, as described in the Technical Appendix, to fit the data structure because I consider two types or levels of built environments: street segment level and neighborhood level. As a result, the reported odds ratios represent what impact a 1% change in the independent variable has on the probability of a crash involving elementary school–aged child pedestrians during school travel time on each street segment.

This study has some limitations. First, I do not consider microlevel features of the built environment such as trees and street amenities, the maintenance and quality of the road, or pedestrian and cycling infrastructure due to data limitations, nor do I have information on the type of traffic controls or the location of crosswalks. Second, some of the crash data may be incomplete or misleading; pedestrian crashes are underreported, and the crash data I do have may include children's crashes not related to travel to school. Third, the timeframes of the GIS data sets vary slightly, but urban patterns might differ at different times. Fourth, the results of this study may be subject to the scale effect (what is known as the modifiable areal unit problem [MAUP]) since I consider only a small buffer, a half-mile, around school sites. Future studies should examine the built environment–school travel safety relationship using different buffer sizes to test the consistency of the results (Mitra & Buliung, 2012).

Fifth, I do not know if crashes occurred while school was in session. Finally, this study only explores one aspect of school travel safety: the number and local of street segment–level school travel–related collisions. Future research should address other perspectives, such as crash severity and outcomes.

How Does the Built Environment Affect School Travel Safety?

Street Characteristics and Crash Risk

My research shows that the type and function of streets and roads near schools makes a difference in school travel safety. I find that street segments with higher traffic volumes have a higher probability of crashes involving school-aged child pedestrians during school travel time. Street segments with a higher speed limit are associated with a higher probability of crash risk for children traveling to school. Highways or freeways and arterial roads increase the crash risk for children traveling to school, while local roads have a lower crash risk. I also find that street segments with a higher density of transit stops increase the crash risk.

I show that more school travel–related crashes occur on highways/interstates and arterial roads and fewer crashes happen on local roads. The result show that the impact is significant: A 1% increase in arterial roads around schools led to a 186% increase in the likelihood of school travel–related crashes. Previous studies suggest that drivers have less time to react to unexpected hazards when traveling on arterial roads with high operating speeds. Highways and arterial roads are designed for high operating travel speeds with wide and straight lanes, while narrow local roads decrease vehicle speeds, reducing stopping sight distances and giving drivers more time to react to unforeseen hazards (Ewing & Dumbaugh, 2009).

In addition, I find that street segments with more sidewalk coverage decrease the likelihood of crashes involving elementary school pedestrians. This may be because, as others have noted (Boarnet et al., 2005), connected sidewalks around schools reduce the number of pedestrians who walk in the street or on road shoulders, decreasing traffic conflicts between pedestrians and motor vehicles.

Sociodemographic Characteristics and Crash Risk

Crash risks vary with sociodemographic characteristics, as previous research has demonstrated (Abdel-Aty et al., 2007; Clifton & Kreamer-Fults, 2007; LaScala, Gerber, & Gruenewald, 2000; LaScala et al., 2004). I show that neighborhoods around schools with a greater percentage of people with low education levels (less than high school) have an increased likelihood of crashes involving elementary school–aged child pedestrians during school travel time. For each 1% increase in the population with less than a high school education, there is a 28% increase in crash risk. These findings may be explained by higher exposure rates; that is, higher rates of walking in lower-income neighborhoods.

Land Uses and Crash Risk

Land use matters in traffic safety: Street segments with more residential parcels have lower probabilities of school travel crashes. More specifically, every 1% increase in

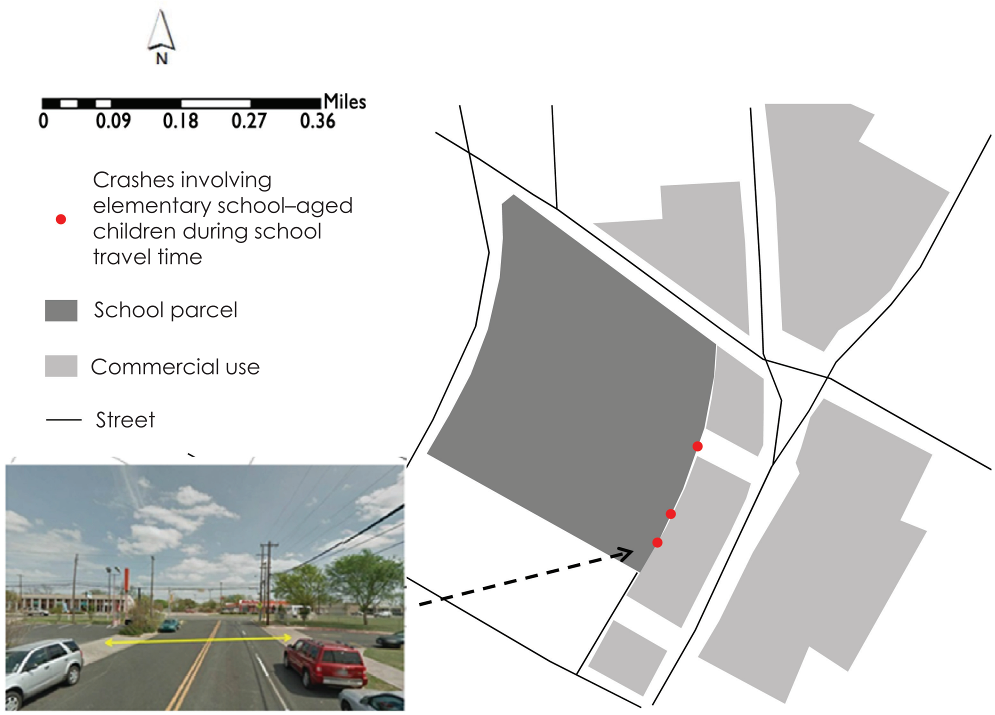

Figure 2. School site layout, its relationship with surrounding commercial uses, and relevant school travel–related crash locations.

residential parcels in the school catchment area is accompanied by a 38% decrease in the crash risk of elementary school pedestrians. Conversely, for every 1% increase in commercial parcels in the school buffer, there is a 148% increase in the probability of school travel–related crashes. Commercial land uses may increase traffic conflicts between pedestrians and vehicles; research clearly shows that such crashes are higher in commercial and industrial areas than in residential neighborhoods. A closer examination of the locations of Austin's school travel–related crashes reveals that 65% of all crashes occur on roads where there are adjacent commercial uses.

Figure 2 shows a school site layout, its relationship with surrounding commercial uses, and the location of adjacent school travel–related crashes. As the research suggests, several school travel–related crashes occurred on roads surrounded by commercial uses and the school. This may be because there are no midblock crossings for pedestrians (although some research suggests that formal midblock crosswalks do not reduce crashes) and because there are unmarked driveways that create confusion for both motorists and pedestrians (Haleem et al., 2015; Samuel et al., 2013).

Transit Stops and Crash Risk

Every 1% increase in the density of transit stops in the 100-foot buffer along street segments near schools is associated with a 92% increase in the probability of school travel–related crashes. This is due to three interrelated factors: transit stops independently act as focal points generating pedestrian activities; transit stops are usually placed along busy arterials; and land uses near transit stops usually involve commercial activities. In the study area, 68% of transit stops are located along arterial roads exposing transit commuters to high-speed traffic, especially at intersections. Moreover, as Figure 3 shows, more than 60% of land uses near transit stops within the 100-foot buffers around schools in the study area are commercial uses, which might generate even more pedestrian activities and attract more vehicle traffic.

A Role for Planning in School Safety

Schools are high-risk crash locations for elementary school–aged pedestrians. Unfortunately, researchers have not paid enough attention to the combined impacts of community design elements—adjoining land use, the location of transit stops, the existence and state of repair of pedestrian infrastructure and signalization, and the volume and speed of traffic on adjacent roadways—on the safety of school travel. This research shows that street segments with higher speed limits (e.g., highways/interstates and arterials) and traffic-generating land uses increase the probability of school travel–related crashes, while street segments with connected sidewalks decrease the school travel–related crash risk.

Figure 3. Land uses and road types around transit stops.

The results of this study confirm previous research but also offer important new insights to planning practitioners trying to increase human-powered travel to school. It is crucial that stakeholders from different levels of government and from different agencies, from the health department to school districts, from the planning department to law enforcement officials, collaborate to develop strategies to address traffic safety hazards around schools. These collaborative efforts need to address safety issues from a dual perspective, first by working to change the existing infrastructure and use of roads to better address the traffic problems that children currently face walking to school, and then to better site schools and better control the roadways and land uses around them in the future. I suggest three interrelated ways that planners can do so, collaborating with a wide range of stakeholders.

First, planners should work with traffic engineers to prioritize improvements around schools that improve school travel safety, including reducing speeds through enforcement and traffic devices and identifying and treating locations with high potential for conflicts between child pedestrians and vehicles, such as driveways, intersections, and crosswalks. As new information becomes available on the efficacy of various pedestrian treatments, particularly those geared to schoolchildren, planners should work with traffic engineers and law enforcement officials to incorporate those improvements into roadways and facilities around schools.

Second, planners, school officials, crossing guards, community leaders, and parents should work together to identify hot spots or places where conflicts between school-aged pedestrians and vehicles have often occurred. Current school site planning guidelines suggest locating schools near arterials to make it easier for buses to access the school (Cooner et al., 2003), which means that schools are often located near commercial areas on heavily trafficked streets, demonstrably increasing dangerous conflicts between vehicles and pedestrians. Planners should work with school districts to better coordinate existing automobile-oriented access to schools as well as pedestrian-friendly access. This might include reducing commercial uses around existing schools where possible and definitely when new schools are designed and built. Planners should also focus on reducing the width and speed of adjacent arterials, both initially for existing schools and over time as new schools are built. Moreover, planners should work to retrofit areas around current schools with connected sidewalk networks while ensuring that new schools have such sidewalk networks. Third, to focus on future needs, neighborhood planners must work with school districts to better integrate school siting into comprehensive planning processes.

Overall, planners should seek to create pedestrian-friendly schools that reduce or overcome current barriers to safe, human-powered school travel. To achieve all these objectives, planners must work collaboratively with a wide variety of agencies and organizations at different levels of government as well as with parents and neighborhood residents to improve school travel safety around current schools and to ensure that new schools are sited and planned in ways that avoid the many traffic safety problems that current schools face.

References

Abdel-Aty, M., Chundi, S. S., & Lee, C. (2007). Geo-spatial and log-linear analysis of pedestrian and bicyclist crashes involving school-aged children. *Journal of Safety Research, 38*(5), 571–579. doi:10.1016/j.jsr.2007.04.006

Aziz, H. A., Ukkusuri, S. V., & Hasan, S. (2013). Exploring the determinants of pedestrian–vehicle crash severity in New York City. *Accident Analysis & Prevention, 50*, 1298–1309. doi:10.1016/j.aap.2012.09.034

Bennet, S. A., & Yiannakoulis, N. (2015). Motor-vehicle collisions involving child pedestrians at intersections and mid-block locations. *Accident Analysis and Prevention, 78*(1), 94–103. doi:10.1016/j.aap.2015.03.001

Boarnet, M. G., Anderson, C. L., Day, K., McMillan, T., & Alfonzo, M. (2005). Evaluation of the California Safe Routes to School legislation: Urban form changes and children's active transportation to school. *American Journal of Preventive Medicine, 28*(2), 134–140. doi:10.1016/j.amepre.2004.10.026

Box, P. C. (1969). Driveway accident and volume study, Part I: General relationships. *Public Safety Systems, 34*(1), 18–22. Retrieved from http://trid.trb.org/view.aspx?id=107688

Chen, L., Chen, C., & Ewing, R. (2012, January). *The relative effectiveness of pedestrian safety countermeasures at urban intersections: Lessons from a New York City experience*. Paper presented at the 92nd Annual Meeting of the Transportation Research Board, Washington, DC.

Clifton, K. J., Burnier, C. V., & Akar, G. (2009). Severity of injury resulting from pedestrian-vehicle crashes: What can we learn from examining the built environment? *Transportation Research Part D-Transport and Environment, 14*(6), 425–436. doi:10.1016/j.trd.2009.01.001

Clifton, K. J., & Kreamer-Fults, K. (2007). An examination of the environmental attributes associated with pedestrian-vehicular crashes near public schools. *Accident Analysis and Prevention, 39*(4), 708–715. doi:10.1016/j.aap.2006.11.003

Cooner, S. A., Fitzpatrick, K., Wooldridge, M. D., & Ford, G. L. (2003). *Traffic operations and safety at schools: Recommended guidelines*. College Station: Texas Transportation Institute.

Desapriya, E., Sones, M., Ramanzin, T., Weinstein, S., Scime, G., & Pike, I. (2011). Injury prevention in child death review: Child pedestrian fatalities. *Injury Prevention, 17*(S1), i4–i9. doi:10.1136/ip.2010.026914

D'Haese, S., De Meester, F., De Bourdeaudhuij, I., Deforche, B., & Cardon, G. (2011). Criterion distances and environmental correlates of active commuting to school in children. *International Journal of Behavioral Nutrition and Physical Activity, 8*, 88–97. doi:10.1186/1479-5868-8-88

Di, D., Taquechel, E. P., Steward, J., & Strasser, S. (2010). The impact of the built environment on pedestrian crashes and the identification of crash clusters on an urban university campus. *Western Journal of Emergency Medicine, 11*(3), 294–301. Retrieved from http://escholarship.org/uc/uciem_westjem

DiMaggio, C., & Li, G. (2013). Effectiveness of a Safe Routes to School program in preventing school-aged pedestrian injury. *Pediatrics, 131*(2), 290–296. doi:10.1542/peds.2012-2182

Elias, W., & Shiftan, Y. (2014). Analyzing and modelling risk exposure of pedestrian children to involvement in car crashs. *Accident Analysis & Prevention*. 62(2): 397–405. doi:10.1016/j.aap.2013.06.035

Ewing, R., & Dumbaugh, E. (2009). The built environment and traffic safety: A review of empirical evidence. *Journal of Planning Literature, 23*(4), 347–367. doi:10.1177/0885412209335553

Federal Highway Administration. (2010). *Safety benefits of raised medians and pedestrian refuge areas* (Report FHWA-SA-10-020). Washington, DC: Author. Retrieved from http://safety.fhwa.dot.gov/ped_bike/tools-solve/brochure/medians_brochure.pdf

Federal Highway Administration. (2011). *Evaluation of pedestrian and bicycle engineering countermeasures: Rectangular rapid-flashing beacons, HAWKs, sharrows, crosswalk markings, and the development of an evaluation methods report* (Report FHWA-HRT-11-039). Washington, DC: Author. Retrieved from http://www.fhwa.dot.gov/publications/research/safety/pedbike/11039/11039.pdf

Federal Highway Administration. (2013). *Where pedestrians cross the roadway* (Report FHWA-HRT-13-099). Washington, DC: Author. Retrieved from www.fhwa.dot.gov/publications/research/safety/3099/index/cfm

Gattis, J. L., Gluck, J. S., Barlow, J. M., Eck, R. W., Hecker, W. F. J., & Levinson, H. S. (2013). Considering and applying driveway design for all users. *Transportation Research Record: Journal of the Transportation Research Board, 2348*, 38–46. doi:10.3141/2348-05

Haleem, K., Alluri, P., & Gan, A. (2015). Analyzing pedestrian crash injury severity at signalized and non-signalized locations. *Accident Analysis & Prevention, 81*, 14–23. doi:10.1016/j.aap.2015.04.025

Hussein, M., Sayed, T., Reyad, P., & Kim, L. (2015, January). *Automated pedestrian safety diagnosis and behavioral study at a signalized intersection in New York City*. Paper presented at the 94nd Annual Meeting of the Transportation Research Board, Washington, DC.

Jemprapai, K., & Srinivasan, S. (2014). Planning-level model for assessing pedestrian safety. *Transportation Research Record*, *2464,* 109–117. doi:10.3141/2464-14

Kim, D. G., Lee, Y., Washington, S., & Choi, K. (2007). Modeling crash outcome probabilities at rural intersections: Application of hierarchical binomial logistic models. *Accident Analysis & Prevention, 39*(1), 125–134. doi:10.1016/j.aap.2006.06.011

Koopman, J. M., Friedman, L., Kwon, S., & Sheehan, K. (2015). Urban crash-related pedestrian injury incidence and characteristics associated with injury severity. *Accident Analysis and Prevention, 77*(1), 127–136. doi:10.1016/j.aap.2015.02.005

LaScala, E. A., Gerber, D., & Gruenewald, P. J. (2000). Demographic and environmental correlates of pedestrian injury collisions: A spatial analysis. *Accident Analysis and Prevention, 32*(5), 651–658. doi:10.1016/S0001-4575(99)00100-1

LaScala, E. A., Gruenewald, P. J., & Johnson, F. W. (2004). An ecological study of the locations of schools and child pedestrian injury collisions. *Accident Analysis and Prevention, 36*(4), 569–576. doi:10.1016/S0001-4575(03)00063-0

Lawhon, L. (2009). The neighborhood unit: Physical design or physical determinism? *Journal of Planning History, 8*, 111–132. doi:10.1177/1538513208327072

Mannering, F. L., & Bhat, C. R. (2014). Analytic methods in accident research: Methodological frontier and future directions. *Analytic Methods in Accident Research, 1*, 1–22. doi:10.1016/j.amar.2013.09.001

McDonald, N. (2010). School siting: Contested versions of the community school. *Journal of the American Planning Association, 76*(2), 184–198. doi:10.1080/01944361003595991

McDonald, N., & Aalborg, A. (2009). Why parents drive children to school: Implications for Safe Routes to School programs. *Journal of the American Planning Association, 75*(3), 331–342. doi:10.1080/01944360902988794

McDonald, N., Brown, A. L., Marchetti, L. M., & Pedroso, M. S. (2011). U.S. school travel, 2009: An assessment of trends. *American Journal of Preventive Medicine, 41*(2), 146–151. doi:10.1016/j.amepre.2011.04.006

McDonald, N., Steiner, R. L., Lee, C., Rhoulac Smith, T., Zhu, X., & Yang, Y. (2014). Impact of the Safe Routes to School Program on

walking and bicycling. *Journal of the American Planning Association, 80*(2), 153–167. doi:10.1080/01944363.2014.956654
McMillan, T. (2005). Urban form and a child's trip to school: The current literature and a framework for future research. *Journal of Planning Literature, 19*(4), 440–456. doi:10.1177/0885412204274173
McMillan, T. (2007). The relative influence of urban form on a child's travel mode to school. *Transportation Research Part A: Policy and Practice, 41*(1), 69–79. doi:10.1016/j.tra.2006.05.011
Mitra, R., & Buliung, R. N. (2012). Built environment correlates of active school transportation: Neighborhood and the modifiable areal unit problem. *Journal of Transport Geography, 20*(1), 51–61. doi:10.1016/j.jtrangeo.2011.07.009
Mohamed, M. G., Saunier, N., Miranda-Moreno, L. F., & Ukkusuri, S. V. (2013). A clustering regression approach: A comprehensive injury severity analysis of pedestrian–vehicle crashes in New York, US and Montreal, Canada. *Safety Science, 54*, 27–37. doi:10.1016/j.ssci.2012.11.001
National Governors Association Center for Best Practices. (2007). *Integrating schools into healthy community design.* Retrieved from http://www.nga.org/files/live/sites/NGA/files/pdf/0705SCHOOLSHEALTHYDESIGN.PDF
National Highway Traffic Safety Administration. (2012). *Traffic safety facts 2010.* Washington, DC: Author.
National Highway Traffic Safety Administration. (2014a). *Not-in-traffic surveillance: Fatality and injury statistics in nontraffic crashes, 2008 to 2011* (National report, DOT HS 811 813). Washington, DC: National Center for Statistics and Analysis. Retrieved from http://www-nrd.nhtsa.dot.gov/Pubs/811813.pdf
National Highway Traffic Safety Administration. (2014b). *Traffic safety facts 2012 data: Pedestrians* (National report, DOT HS 811 888). Washington, DC: National Center for Statistics and Analysis. Retrieved from http://www-nrd.nhtsa.dot.gov/Pubs/811888.pdf
National Highway Traffic Safety Administration. (2015). *Traffic safety facts: Children* (National report, DOT HS-812-514). Washington, DC: Author. Retrieved from www-nrd.nhtsa.dot.gov/Pubs/812514.pdf
Neckerman, K. M., Lovasi, G. S., Davies, S., Purciel, M., Quinn, J., Feder, E.,…Rundle, A. (2009). Disparities in urban neighborhood conditions: Evidence from GIS measures and field observation in New York City. *Journal of Public Health Policy*, S264–S285. doi:10.1057/jphp.2008.47
Nelson, N. M., & Woods, C. B. (2010). Neighborhood perceptions and active commuting to school among adolescent boys and girls. *Journal of Physical Activity & Health, 7*(2), 257–266. Retrieved from http://journals.humankinetics.com/jpah
Orenstein, M., Gutierrez, N., Rice, T., Jill, C., & Ragland, D. (2007). *Safe routes to school safety and mobility analysis.* Berkeley, CA: Berkeley Traffic Safety Center.
Perry, C. (1929). The neighborhood unit: A scheme of arrangement for the family-life community. *Regional Plan for New York and Its Environs VIII, Neighborhood and Community Planning, Monograph 1.* New York: Committee on Regional Plan of New York and Its Environs.
Ragland, D. R., Pande, S., Bigham, J., & Cooper, J. F. (2014, January). *Ten years later: Examining the long-term impact of the California Safe Routes to School Program*. Paper presented at the Transportation Research Board 93rd Annual Meeting, Washington, DC.
Samuel, S., Romoser, M. R. E., Geradino, L. R., Hamid, M., Gomez, R. A., Knodler, M. A. J.,…Fisher, D. L. (2013). Effect of advance yield markings and symbolic signs on vehicle-pedestrian conflicts: Field evaluation. *Transportation Research Record: Journal of the Transportation Research Board, 2393*, 139–146. doi:10.3141/2393-16
Shawsky, M. A., Garib, A. M., & Al-Harthei, H. (2014). The impact of road and site characteristics on the crash-injury severity of pedestrian crashes. *Advances in Transportation Studies, 1*(1), 27–36. http://host.uniroma3.it/riviste/ats/
Stewart, O. (2011). Findings from research on active transportation to school and implications for Safe Routes to School programs. *Journal of Planning Literature, 26*(2), 127–150. doi:10.1177/0885412210385911
Talen, E., Menozzi, S., & Schaefer, C. (2015). What is a "Great Neighborhood"? An analysis of APA's top-rated places. *Journal of the American Planning Association, 81*(2), 121–141.
Texas Department of Transportation. (2014). *Roadway design manual.* Retrieved from http://onlinemanuals.txdot.gov/txdotmanuals/rdw/rdw.pdf
Texas Transportation Institute. (2014). *Characteristics of Texas pedestrian crashes and evaluation of driver yielding at pedestrian treatments* (FHWA/TX-13/0-6702-1). College Station: Texas A&M Transportation Institute. Retrieved from http://tamu.edu/documents/0-6702-01.pdf
Timperio, A., Ball, K., Salmon, J., Roberts, R., Giles-Corti, B., Simmons, D.,…Crawford, D. (2006). Personal, family, social, and environmental correlates of active commuting to school. *American Journal of Preventive Medicine, 30*(1), 45–51. doi:10.1016/j.amepre.2005.08.047
Trapp, G. S., Giles-Corti, B., Christian, H. E., Bulsara, M., Timperio, A. F., McCormack, G. R., & Villaneuva, K. P. (2012). Increasing children's physical activity: Individual, social, and environmental factors associated with walking to and from school. *Health Education & Behavior, 39*(2), 172–182. doi:10.1177/1090198111423272
Ukkusuri, S., Hasan, S., & Aziz, H. M. A. (2011). Random parameter model used to explain effects of built-environment characteristics on pedestrian crash frequency. *Transportation Research Record: Journal of the Transportation Research Board, 2237*(1), 98–106. doi:10.3141/2237-11
Vasudevan, V., Pulugurtha, S., Nambisan, S., & Dangeti, M. (2011). Effectiveness of signal-based countermeasures for pedestrian safety: Findings from pilot study. *Transportation Research Record: Journal of the Transportation Research Board, 2264*, 44–53. doi:10.3141/2264-06
Warsh, J., Rothman, L., Slater, M., Steverango, C., & Howard, A. (2009). Are school zones effective? An examination of motor vehicle versus child pedestrian crashes near schools. *Injury Prevention, 15*(4), 226–229. doi:10.1136/ip.2008.020446
Zhao, Y., Tian, Z. Z., & Herandez, A. (2013, January). *A multi-criteria-based guideline for marked and unmarked pedestrian crosswalks at unsignalized intersections*. Paper presented at the 92nd Annual Meeting of the Transportation Research Board, Washington, DC.
Zhu, X., & Lee, C. (2008). Walkability and safety around elementary schools: Economic and ethnic disparities. *American Journal of Preventive Medicine, 34*(4), 282–290. doi:10.1016/j.amepre.2008.01.024

Technical Appendix

This appendix provides additional detail on the model specification and model results.

Model Specification

Multilevel modeling is an effective approach to deal with the hierarchical data structure. Data are often nested or hierarchical. For example, students sampled from the same class or school may systematically differ from others due to some class- or school-related characteristics (e.g.,

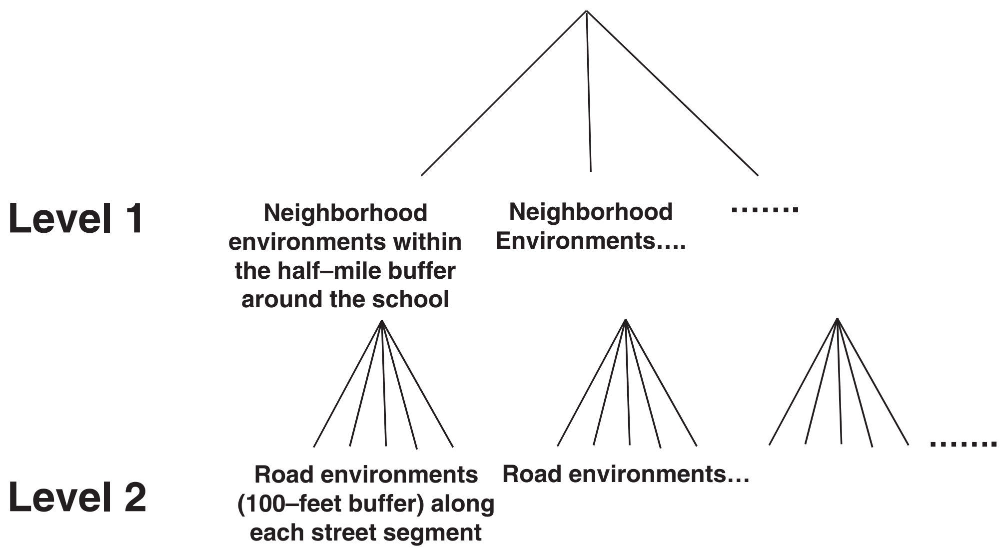

Figure A-1. Hierarchical structure of level 1 and level 2 variables.

school district, classroom atmosphere, etc.). If the researchers did not use the multilevel model to analyze the nested structure data, the estimated standard errors may be biased and lead to incorrect statistical inference (Snijders & Bosker, 2012).

For this study, I develop two-level (street segment level and neighborhood level) binomial logistic models to examine the impacts of road and neighborhood environments on the occurrence of collisions involving elementary school–aged child pedestrians during school travel time on street segments (Figure A-1).

Among the various types of multilevel analysis, random-intercept models have been commonly used in previous studies. For example, Kim, Lee, Washington, and Choi (2007) estimate random-intercept models to examine the probability that a type of crash will occur by using crash-level (level 1) and intersection-level (level 2) predictors. Huang, Chor, and Haque (2008) also use random-intercept models to explore driver injury severity and vehicle damage at signalized intersections. These models consider varying intercepts and assume that slope coefficients do not vary across level 2 units. Therefore, I also use random-intercept models to avoid the possibility of excess complexity and nonconvergence (Snijders & Bosker, 2012).

The variance of level 1 residuals for binomial logistic distribution is $\pi^2/3 = 3.29$, while the intercept variance of level 2 binomial logistic random-intercept model is τ_0^2 (Snijders & Bosker, 2012). The intraclass correlation coefficient (ICC) is calculated by these two variances to examine the average correlation between subjects within a group:

$$\mathrm{ICC} = \frac{\tau_0^2}{\tau_0^2 + \pi^2/3}. \qquad (1)$$

Maas and Hox (2005) suggest a design effect to examine whether the multilevel model is necessary. If the value of the design effect is higher than 2, the use of single-level analysis may lead to biased results.

$$\textit{Design effect} = \textit{1+ (average group size-1)* ICC.} \qquad (2)$$

A multilevel binomial logistic model is formulated as follows:

$$log\left(\frac{p_{ij}}{1-p_{ij}}\right) = \gamma_{00} + \textstyle\sum_{p=1}^{P} \beta_{pj} X_{pij} \text{ (level 1 model)} \qquad (3)$$

and

$$\beta_{0j}, = \gamma_{00} + \textstyle\sum_{q=1}^{Q} \gamma_{0q} W_{qj} + u_{0j} \qquad (4)$$

$$\beta_{1j}, = \gamma_{10} \text{ (level 2 model)} \qquad (5)$$

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$$\beta_{pj} = \gamma_{\mathrm{p}0}, \qquad (6)$$

where p_{ij} is the probability of the occurrence of a collision involving elementary school–aged children during school travel time on a street segment (i) within a given neighborhood environments around the school (j); γ_{00} is the intercept; W_{qj} is a vector of neighborhood-level variables; X_{pij} is a vector of street segment–level variables; γ_{0q} and γ_{p0} are regression coefficients of neighborhood-level variables and street segment–level variables, respectively; and u_{0j} is the random effect at level 2, where $u_{0j} \sim \mathrm{N}(0, \tau_0^2)$.

For the modeling procedure, I first test bivariate correlations between all control variables and the dependent variable. I include only those significant control variables from the bivariate analyses at the 95% level to generate the base model. Second, all independent variables (road environments and neighborhood environments) were added into the base model to generate the final model.

Because of the potential multicollinearity issue, I use the "grand mean center" approach for all independent variables by subtracting the grand mean of that independent variable from each observation for that variable (Aiken & West, 1991). I perform the estimation of the models using HLM 7.0.

Model Results

Table A-1 presents the final estimated results for the probability of a collision involving elementary school–aged

Table A-1. Final estimated results.

Variable	Coefficient	SE	Odds ratio	95% CI	*p* value
Fixed part					
Intercept (γ_{00})	–1.76**	0.04	0.17	(0.15, 0.18)	0.003
Control variable					
Average daily traffic (vehicles)	0.03**	0.03	1.02	(1.01, 1.03)	0.006
Population less than high school (%)	0.25*	0.08	1.28	(1.13,1.52)	0.032
Segment length (mile)	1.81*	0.36	6.11	(6.01, 6.23)	0.022
Road environments (street segment level)					
Highways/interstates (1 = yes, 0 = no)	1.24***	0.26	3.46	(2.20, 6.15)	<0.001
Arterials (1 = yes, 0 = no)	0.82***	0.08	2.27	(1.90, 2.54)	<0.001
Local roads (1 = yes, 0 = no)	–0.75**	0.06	0.47	(0.35, 0.59)	0.004
City collectors (1 = yes, 0 = no)	0.05	0.04	1.05	(1.01, 1.09)	0.075
Ramps and turnarounds (1 = yes, 0 = no)	0.12	0.09	1.13	(1.05, 1.22)	0.102
Sidewalk completeness (%)	–1.10**	0.11	0.33	(0.25, 0.40)	0.009
Bike lane completeness (%)	–1.32	0.13	0.27	(0.21, 0.32)	0.153
Transit stops (stops/acre)	0.65**	0.09	1.92	(1.81, 2.04)	0.002
Residential use (# of parcels)	–0.48**	0.08	0.62	(0.52, 0.75)	0.007
Commercial use (# of parcels)	0.91***	0.12	2.48	(2.01, 2.90)	<0.001
Office use (# of parcels)	1.32	0.14	3.74	(2.98, 4.50)	0.068
Industrial use (# of parcels)	0.35	0.15	1.42	(1.12, 1.74)	0.055
Park (# of parcels)	0.68	0.18	1.97	(1.72, 2.23)	0.132
Neighborhood environments around schools(neighborhood level)					
Sidewalk completeness (%)	1.52	0.85	4.57	(3.82, 5.32)	0.124
Bike lane completeness (%)	0.96	0.64	2.61	(1.85, 3.37)	0.153
Three-leg intersection density (intersections/acre)	–0.52	0.24	0.59	(0.25, 0.93)	0.211
Four-or-more-leg intersection density (intersections/acre)	2.05	1.52	7.77	(6.85, 8.69)	0.112
Transit stops (stops/acre)	–2.12	1.74	0.12	(0.002, 0.24)	0.053
Highways/freeways (%)	1.58	1.12	4.85	(3.95, 5.75)	0.094
Arterial roads (%)	1.05**	0.52	2.86	(1.18, 4.54)	0.006
Residential use (%)	–0.21	0.09	0.81	(0.68, 0.94)	0.112
Commercial use (%)	2.08	1.13	8.00	(6.81, 9.21)	0.067
Office use (%)	1.11	0.84	3.03	(2.52, 3.54)	0.083
Industrial use (%)	1.65	0.96	5.21	(4.35, 6.07)	0.105
Park (%)	0.88	0.74	2.41	(1.95, 2.87)	0.098
Random part					
Between-group intercept τ_0^2	0.73				
Within-group $\pi^2/3$	3.29				
ICC	0.18				
Design effect	37.89				

*$p < .05$, **$p < .01$, ***$p < .001$.

child pedestrians during school travel time on the street segment. To check whether multilevel analysis fits the data set, I calculate the ICC based on Equation 1 and the design effect from Equation 2. The ICC is 0.18, indicating that approximately 18% of the total variation is explained by between-school variations. In terms of the design effect, the average number of street segments in each school is 205.94. The value of design effect is 37.89, which is much higher than 2, suggesting that using single-level analysis for this study may lead to biased results. Therefore, the test results confirm that the multilevel analysis is an appropriate analytical method for this study. Moreover, I did not include the posted speed limit in the final model due to the high correlation with the road type variables.

For control variables, average daily traffic for each street segment, the percentage of population with less than high school education, and the segment length are significant. In terms of road environments, posted speed limit, road classes as highways/freeways and arterial roads, transit stop density, and the number of commercial parcels along street segments are significantly positive correlates, while the road class as local roads, sidewalk completeness, and the number of residential parcels along street segments are negatively related to crashes involving elementary school-aged child pedestrians during school travel time. For neighborhood environments around schools, the percentage of arterial roads is significantly related to the probability of a collision involving elementary school-aged child pedestrians during school travel time.

References

Aiken, L. S., & West, S. G. (1991). *Multiple regression: Testing and interpreting interactions*. Thousand Oaks, CA: Sage.

Huang, H., Chor, H., & Haque, M. (2008). Severity of driver injury and vehicle damage in traffic crashes at intersections: A Bayesian hierarchical analysis. *Accident Analysis & Prevention*, *40*, 45–54. doi:10.1016/j.aap.2007.04.002

Kim, D. G., Lee, Y., Washington, S., & Choi, K. (2007). Modeling crash outcome probabilities at rural intersections: Application of hierarchical binomial logistic models. *Accident Analysis & Prevention, 39*(1), 125–134. doi:10.1016/j.aap.2006.06.011

Maas, C. J. M., & Hox, J. (2005). Sufficient sample sizes for multilevel modeling. *Methodology*, *1*(3), 86–92. doi:10.1027/1614-2241.1.3.86

Snijders, T. A. B., & Bosker, R. (2012). *Multilevel analysis: An introduction to basic and advanced multilevel modeling* (2nd ed.). London, UK: Sage.