Research-Based Article

Planning for Safe Schools: Impacts of School Siting and Surrounding Environments on Traffic Safety

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Abstract

This study explores the impacts of school siting and surrounding built environments on rates of motorist and pedestrian crashes around public schools in the Austin Independent School District, Texas, by using log-linear regressions. The results show that a higher sidewalk coverage and a higher percentage of local roads reduce pedestrian crashes around schools, while higher percentages of highways and commercial uses and higher transit stop densities increase motorist and pedestrian crashes. It is desirable to locate schools in areas with higher percentages of local roads and lower percentages of highways and commercial uses.

Keywords

built environment, pedestrian crash, school siting, school travel safety, traffic safety

Introduction

Schools are important community facilities dedicated to children's education, and may also accommodate community residents' social and recreational activities. Studies have shown that schools increase the risk for traffic crashes in their vicinity because they generate regular, concentrated, and congested traffic flows (Abdel-Aty, Chundi, and Lee 2007; Clifton, Burnier, and Akar 2009; Clifton and Kreamer-Fults 2007; LaScala, Gruenewald, and Johnson 2004). School locations and development patterns of the surrounding neighborhoods also affect traffic safety. Traditional "neighborhood schools" are often located in the center of the neighborhood, featuring short home-to-school distances, walkable environments, and low-speed traffic that help ensure pedestrian safety (Ewing and Greene 2003). However, recent decades have witnessed a trend toward "sprawl," with schools being further away from the neighborhood center and often next to high-speed arterials or highways and auto-oriented environments lacking pedestrian infrastructure (NGA Center for Best Practices 2007).

Little attention has been devoted to the impacts of school locations and surroundings on traffic safety around schools. This study addresses this knowledge gap by reviewing relevant trends and literature, and then conducting an empirical study to identify environmental factors related to crash rates around public schools in Austin, Texas. The results provide insights about how to optimize traffic safety around schools through school siting and neighborhood planning.

School Siting and Its Implications on Traffic

In 1929, Perry proposed the influential concept of "neighborhood unit" as a planning model for creating functional, self-contained neighborhoods in metropolitan areas. A key principle of this model is to center the school in the neighborhood so that students can live within a half-mile, walkable distance from school. He also proposed to locate commercial areas and high-speed roadways (i.e., highways and arterials) on the periphery and to use curvilinear local streets inside the neighborhood to minimize through traffic and ensure low traffic speed and pedestrian safety. In such a neighborhood, traffic around schools is mostly limited to school travel and other within-neighborhood trips, supported by pedestrian infrastructure and away from high-speed traffic, and as a result, is relatively safe.

In reality, for much of the twentieth century, schools were mostly located in or near neighborhood centers and provided relatively good pedestrian access (NGA Center for Best Practices 2007). However, in recent decades, with growing

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	An example of neighborhood schools	An example of "spawl" schools
School location	Center of the neighborhood	Periphery of the neighborhood
Neighborhood density	Higher	Lower
Road types	Surrounded by local roads	Next to highways or arterials
Transportation infrastructure	Sufficient sidewalks, bike lanes, and crosswalks	Lacking sidewalks, bike lanes, and crosswalks

Figure 1. Examples of schools with different locations and surrounding environments.

student populations and increasing urban sprawl, larger schools away from neighborhood centers became increasingly popular (NGA Center for Best Practices 2007). This "sprawl" trend is partly driven by policies such as school funding formula that favor the construction of new and larger schools in peripheral areas over the renovation of existing schools in neighborhood centers (NGA Center for Best Practices 2007). As a result, these "sprawl" schools are often located near highways and/or arterial roads and designed for the convenience of automobiles, while ignoring the need of pedestrians and bicyclists.

Neighborhood environments around schools influence traffic volumes in the area and people's choices between motorized and nonmotorized transportation modes for travel to schools or other destinations. In terms of traffic volumes, it is reasonable to expect that traffic-generating land uses such as commercial areas will increase the volume of traffic in the area. As to mode choices for children's school travel, shorter distances consistently predict increases in active commute (walking and biking) and reductions of driving; other factors such as nonmotorized transportation infrastructure (sidewalks, bike lanes, crosswalks, etc.), street connectivity, and high density have shown similar positive impacts in some studies (Figure 1) (Stewart 2011). For general travel behavior among adults, research has shown that higher density, shorter distance to nonresidential destinations, and land use mix encourage walking for transportation (Ewing and Cervero 2001; Saelens and Handy 2008).

SRTS Program and Traffic Safety around Schools

In 2005, the U.S. Congress allocated $612 million in funding for the federal Safe Routes to School (SRTS) program to promote safe and active commute (walking and biking) to school through both infrastructure and noninfrastructure projects. Empirical studies on safety impacts of these projects are still limited yet promising. A New York City study examined the school-aged pedestrian injuries during school travel hours. Results showed that the rates decreased by 44% in census tracts with SRTS programs and remained unchanged for those census tracts without SRTS projects (DiMaggio and Li 2013). Another study reported that the total number of pedestrian- or bicycle-involved collisions significantly decreased within 250 feet of SRTS projects at 47 schools in California (Ragland et al. 2014). Moreover, the sidewalk gap closure project decreased the number of students walking/biking on streets and shoulders, which reduced traffic conflicts and crash risk (Boarnet et al. 2005).

Despite these initial positive results, the SRTS program cannot address more fundamental issues related to traffic safety around "sprawl" schools, such as the long distances that necessitate the dependence on motorized transportation and increased traffic volumes and the exposure to high-speed traffic due to adjacency to highways and arterials that lack pedestrian infrastructure. It is likely that more dramatic changes in school siting and surrounding environments are needed in order to encourage further improvements in traffic safety around schools.

Environmental Correlates of Traffic Safety

Environmental correlates of traffic safety have been studied by many researchers but the results are still inconclusive. Higher traffic volume and speed increase the risk of traffic exposure and crashes (Clifton and Kreamer-Fults 2007; de Guevara, Washington, and Oh 2004; Ewing and Dumbaugh 2009; Graham and Glaister 2003; Wier et al. 2009), and built environments influence traffic volumes. Studies have shown that development patterns with higher density, more employment or commercial areas, and more arterial lane miles are associated with increased traffic volumes per area and, in turn, more traffic crashes per area (Clifton and Kreamer-Fults 2007; Delmelle, Thill, and Ha 2012; Dumbaugh and Rae 2009; Hadayeghi, Shalaby, and Persaud 2010; Loukaitou-Sideris, Liggett, and Sung 2007). However, the relative risk on a per capita basis may be different. A literature review study actually concluded that traffic environments of dense urban areas are safer than the lower-volume environment of the suburbs on a per capita basis, because fewer miles are driven per capita and the traffic speed is generally lower in dense urban areas (Ewing and Dumbaugh 2009). Presence of transit stops is another safety-related factor. They are often focal points for pedestrian activities and may, therefore, generate traffic conflicts between pedestrians and vehicles (Ukkusuri et al. 2012). But it is possible that increased transit service may reduce vehicle miles traveled per capita. Street patterns also influence traffic safety, but the results are not consistent either. Relevant studies have shown both positive (de Guevara, Washington, and Oh 2004; Graham and Glaister 2003) and negative relationships (Clifton, Burnier, and Akar 2009) between street connectivity and traffic crashes. Four-or-more-leg intersections generally produce more conflicting traffic movements and crashes than three-leg intersections (Dumbaugh and Rae 2009).

Factors Influencing Traffic Safety around Schools

Despite previous studies on general traffic safety–built environment relationships, the corresponding risk factors for crashes around schools have been understudied. Clifton and Kreamer-Fults (2007) explored pedestrian–vehicle crashes for all traffic in 0.25-mile straight-line buffers around 163 public schools in Baltimore, Maryland. Results showed that commercial access and mixed land uses increased the number of pedestrian crashes, likely because of the increases in traffic volumes. Abdel-Aty, Chundi, and Lee (2007) examined crashes involving school-aged children (aged 4 to 18) in 0.5-mile straight-line school buffers in Orange County, Florida, and considered characteristics of drivers, pedestrians, cyclists, vehicles, and road environments. They found that middle and high school children were more likely to be involved in crashes on high-speed, multi-lane roads than elementary school students. Warsh et al. (2009) explored the factors related to child pedestrian collisions in school zones and found that more crashes occurred at midblock than at intersections. However, these studies did not control for the influence of traffic volumes or school enrollment. Larger schools with more students are expected to have more traffic exposure than smaller schools. The effects of neighborhood environments were not considered either.

Another issue in previous studies on this topic is that they used only one specific buffer size and might be subject to the Modifiable Areal Unit Problem (MAUP). MAUP relates to scale and zoning effects: a scale effect exists when the use of different sizes of spatial units generates different statistical inferences; a zoning effect is present when different zone configurations in a fixed scale lead to different results (Openshaw 1984). These two effects can lead to biased results and generate inaccurate information for relevant policy decisions.

Research Design

To address these knowledge gaps, this study examines how school siting and surrounding environments influence traffic safety around schools using multiple spatial units of analysis. The study sites are 120 public schools (including 77 elementary schools, 24 middle schools, and 19 high schools) in the Austin Independent School District (AISD), Texas, and their surrounding neighborhoods. The diverse school locations and neighborhood development patterns provide a unique opportunity to test the effects of school siting and neighborhood designs on crash rates.

A conceptual framework (Figure 2) was developed based on the previous literature to guide the selection of study variables. Three domains of determinants—risk exposure, neighborhood sociodemographic characteristics, and surrounding built environments—are hypothesized to be associated with traffic safety. This study focuses on built environments (the independent variables) and treats the other two domains as confounding variables.

School parcels' straight-line buffers were used as spatial units of analysis. In determining the appropriate sizes of the buffers, two issues were considered. First, to address the possible scaling effect of the MAUP issue, this study chose to use multiple units with different sizes. If the results from these different scales are relatively stable, this study will provide a greater level of confidence in the findings. Second, this study referred to thresholds of feasible distance for walking and biking to school (D'Haese et al. 2011; Van Dyck et al. 2010). As a result, 0.5-, 1-, 1.5-, and 2-mile straight-line buffers around the school parcel were identified as spatial units of analysis (Figure 3).

Data Sources

Seven-year (2004–2010) collision data were obtained from the Austin Police Department (APD), which provided the date that each crash occurred, the crash type (e.g., pedestrian–vehicle, cyclist–vehicle, vehicle–vehicle, etc.), and injury severity (e.g., fatal, serious, minor, and no injury). The GIS data sets for parcel-level land uses, streets, and sidewalks were obtained from the city of Austin. The land use data provided land use classifications including residential uses, commercial uses, office uses, parks, and others. The traffic volume data for major highways and regional arterials were collected from the Texas Department of Transportation

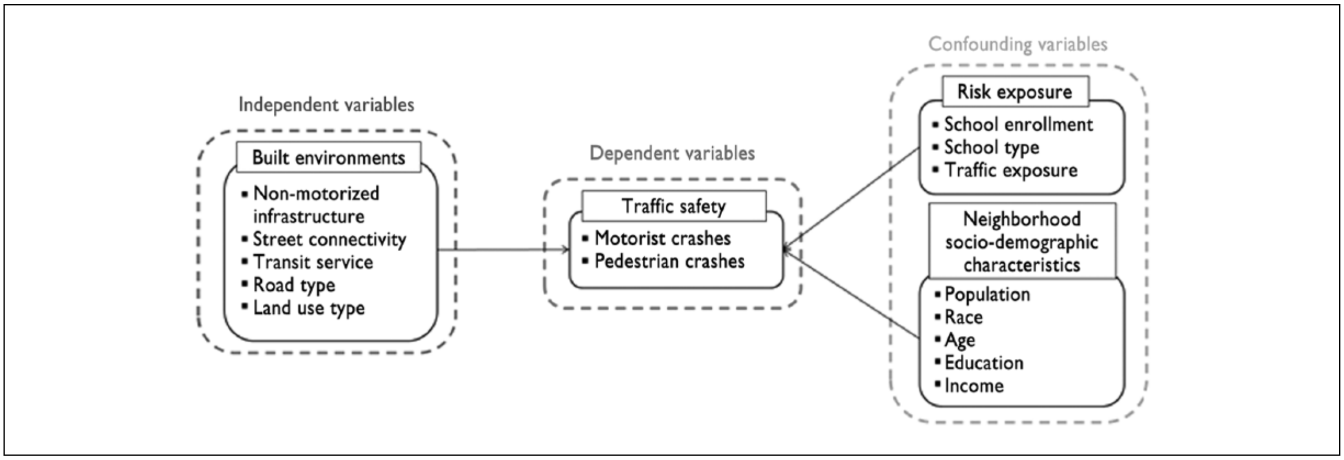

Figure 2. The conceptual framework for this study.

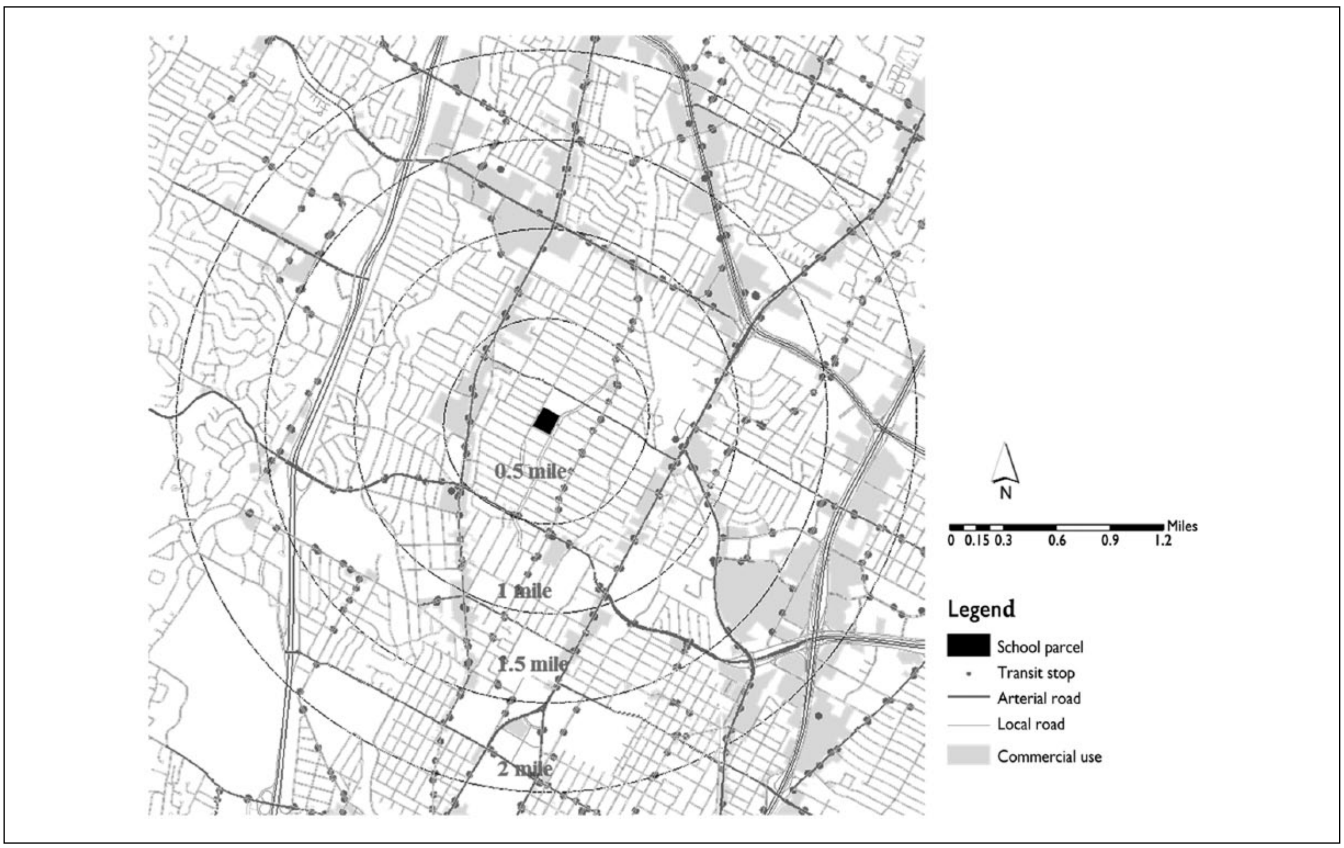

Figure 3. Four spatial units of analysis: 0.5-, 1-, 1.5-, and 2-mile airline buffers around the school.

(TxDOT) and the data for arterials and local roads were collected from the city of Austin. The point data for transit stop locations came from the Capital Metro–Austin Public Transit website. For the sociodemographic information, this study used 2010 census data and school enrollment information from the Texas Education Agency Academic Excellence Indicator System (AEIS) 2011–2012 report.

Because of limited data availability, some of the data sets used in this study have different time frames. For example, the crash data are from 2004 to 2010, while the school enrollment data are from the 2011–2012 academic year. However, since the school enrollments in the AISD do not dramatically change over years, it will not be a serious issue for the analysis.

Table 1. Study Variables and Their Measurements.

Variable	Measurement
Dependent variable	
Motorist crash rate	Number of motorist crashes (2004–2010) in the buffer / total miles of streets
Pedestrian crash rate	Number of pedestrian crashes (2004–2010) in the buffer / total miles of streets
Confounding variable	
Risk exposure	
School enrollment	Number of students enrolled in 2011–2012
Types of schools	
Elementary school	Elementary school (1) or not (0)
Middle school	Middle school (1) or not (0)
Traffic exposure	Vehicle miles traveled (2004–2010) / total miles of streets
Neighborhood sociodemographic characteristics	
Population density	Total population / buffer area (square miles)
% of nonwhite populations	Total nonwhite population / total population
% of population aged under 18	Population under age 18 / total population
% of population with education level lower than high school	Population with education level lower than high school / total population
% of population below the poverty line	Population below the poverty line / total population
Independent variable	
Built environments	
Nonmotorized infrastructure	
Sidewalk completeness	Total miles of sidewalks / (total miles of streets × 2)
Street patterns	
Density of three-leg street intersections	Number of three-leg intersections / total miles of streets
Density of four-or-more-leg street intersections	Number of four-or-more-leg intersections / total miles of streets
Transit service	
Density of transit stops	Number of transit stops / total miles of streets
Road type	
% of highways	Percentage of street length classified as highways
% of arterial roads	Percentage of street length classified as arterial roads
% of local roads	Percentage of street length classified as local roads
Land use type	
Density of residential use	Residential area / total area (square miles)
Density of commercial use	Commercial area / total area (square miles)
% of commercial use along local roads	Commercial area located along local roads / total commercial area
% of residential uses along local roads	Residential area located along local roads / total residential area

Variables and Measurements

Study variables were identified based on the systematic literature review and the proposed conceptual framework. Table 1 lists the dependent variables, confounding variables, and independent variables and their corresponding measurements.

Dependent Variables

Traffic safety in this study means crash rates for all traffic around schools, including both school trips and nonschool traffic. It is captured through rates of motorist crashes (i.e., vehicle–vehicle collisions) and pedestrian crashes (i.e., pedestrian–vehicle collisions). Because vehicles travel on roads and pedestrians move along the sides of streets, street-based measures (the number of crashes per unit of street length) (LaScala, Gerber, and Gruenewald 2000; LaScala, Gruenewald, and Johnson 2004) were preferred over area-based measures (the number of crashes per area) (Wier et al. 2009) in this study. As a result, the dependent variables were measured by the number of pedestrian crashes and the number of motorist crashes per unit of street length, respectively.

Independent and Confounding Variables

Built environmental attributes were independent variables for this study, including nonmotorized infrastructure (sidewalk completeness), street connectivity (three-leg and four-or-more-leg intersection densities), transit service (transit stop density), road types (percentages of highways, arterial roads, and local roads), land use types (percentages of areas designated for residential and commercial uses, the percentage of residential uses along local roads, and the percentage of commercial uses along local roads).

Two other domains—risk exposure and neighborhood sociodemographic characteristics—were considered as confounding variables. Risk exposure included school enrollment and types of schools (elementary, middle, or high school). Traffic exposure in the buffer were measured by (1) clipping the street layer by school buffers to get street segments inside the buffers; (2) multiplying the length of each street segment by its corresponding average daily traffic volume to get the number of daily vehicle miles traveled (VMT) for each street segment; (3) multiplying this daily VMT by 365 days and 7 years to estimate the VMT within the 7-year period, for which crash data are available; and (4) finally summing the VMTs in the buffer, and dividing it by total miles of streets in the buffer.

With respect to neighborhood sociodemographic characteristics, this study included population density, race (% of nonwhite population), age (% of population aged under 18), education level (% of population with an education level lower than high school), and income level (% of population below the poverty line). Since the sociodemographic data from 2010 Census was in census block group level, this study used area apportionment methods (splitting the population in the census block group into the school buffer by the fraction of the area of the school buffer in each census block group) to calculate the corresponding information for each school buffer.

Data Analysis

The descriptive statistics for dependent variables showed that they were not normally distributed. Therefore, this study used log-transformation to reach normal distributions and then used log-linear regressions—a widely applied method in traffic safety research (Abdel-Aty, Chundi, and Lee 2007; Lee and Abdel-Aty 2005; Miranda-Moreno, Morency, and El-Geneidy 2011)—to predict motorist and pedestrian crash rates. Four models with different spatial units of analysis (0.5-, 1-, 1.5-, and 2-mile school buffers) were run for each outcome variable (motorist crash rate and pedestrian crash rate).

Results

Table 2 presents the results of four regression models that predict motorist crash rates. The goodness of fit for these four models was consistently high (>0.731), but the individual results for some of the independent variables showed variations across the four spatial units.

School characteristics such as enrollment and type of school were not significant across the four models. Most neighborhood sociodemographic variables were not significant either, except population densities and the percentage of nonwhite populations. Built environmental variables showed some significant results. While three-leg intersections were insignificant in all four models, four-or-more-leg intersections showed positive associations with motorist crash rates in the 1- and 2-mile models. Surprisingly, sidewalk completeness showed a positive association with the motorist crash rate in the 0.5-mile model. Traffic exposure, transit stop density, the percentage of highways, the percentage of commercial uses, and the percentage of commercial uses along local roads showed consistent, positive associations with motorist crash rates across all four models. In contrast, the percentage of local roads showed consistent, negative associations in all four models.

In terms of pedestrian crash rates (Table 3), the goodness of fit for these four models was also consistently high (>0.746). School enrollment and type of school had no effect on pedestrian crash rates. Higher population density consistently increased the rate of pedestrian crashes in the four models, while the percentage of nonwhite populations only had positive effects in the 1- and 1.5-mile models.

Among built environmental variables, sidewalk completeness was negatively associated with pedestrian crash rates across the four models. The densities of three-leg and four-or-more-leg intersections showed insignificant results, except for the four-or-more-leg intersection density in the 2-mile model. The percentages of both highways and arterial roads had positive effects in the 1- and 1.5-mile models. Traffic exposure, the density of transit stops, the percentage of commercial uses, and the percentage of commercial uses along local roads were positively associated with the rates of pedestrian crashes in all models, while the percentage of local roads was a consistently negative correlate.

Discussion

This study considered four different spatial units of analysis in order to explore the potential scaling effect of the MAUP issue. Some variables (e.g., four-or-more-leg intersections, arterial roads, residential uses, etc.) showed inconsistent results across four units, and might be subject to this scaling effect. Some other variables (e.g., sidewalk completeness, highways, local roads, commercial uses, and transit stops) showed relatively stable results across the four models, providing more confidence for the interpretation of their impacts, which will be further discussed below.

Traffic Exposure and Density

Traffic exposure is positively associated with motorist and pedestrian crash rates. This finding is consistent with those from previous studies (Dumbaugh and Rae 2009). Population density, as a proxy measure of risk exposure, was also

Table 2. Coefficients from Log-Linear Regression Models Predicting the Motorist Crash Rate Using Different Spatial Units of Analysis.

Variable (unit)	0.5-mile model	1-mile model	1.5-mile model	2-mile model
Risk exposure				
School enrollment	0.064	0.056	0.035	0.014
Types of schools				
Elementary school (1 = yes; 0 = no)	0.004	0.004	0.006	0.005
Middle school (1 = yes; 0 = no)	0.043	0.035	0.022	0.014
Traffic exposure (vehicle miles traveled / mile of street)	0.104***	0.094*	0.091*	0.084*
Neighborhood sociodemographic characteristics				
Population density (persons/square mile)	0.074**	0.056	0.072	0.047***
Nonwhite populations (%)	0.086	0.095**	0.083***	0.079
Population aged under 18 (%)	0.022	0.018	0.019	0.020
Population with lower than high school education (%)	0.059	0.058	0.063	0.062
Population below the poverty line (%)	0.035	0.036	0.039	0.043
Built environments				
Nonmotorized infrastructure				
Sidewalk completeness (%)	0.019**	0.021	0.022	0.027
Street connectivity				
3-leg intersections (/mile of street)	0.072	0.076	0.082	0.084
4-or-more-leg intersections (/mile of street)	0.054	0.067***	0.078	0.093**
Transit service				
Transit stops (/mile of street)	0.254***	0.276**	0.365***	0.425***
Road type				
Highways (%)	0.143***	0.167**	0.203*	0.225***
Arterial roads (%)	0.063	0.078*	0.084	0.096
Local roads (%)	−0.194**	−0.215***	−0.262***	−0.295*
Land use type				
Residential uses (%)	0.053	0.064**	0.067*	0.073
Commercial uses (%)	0.256***	0.253***	0.242***	0.194*
Commercial uses along local roads (%)	0.120***	0.173***	0.201***	0.114**
Residential uses along local roads (%)	−0.023	−0.063	−0.046	−0.051
R^2	0.731	0.821	0.846	0.868
N	120	120	120	120

*p < 0.1, **p < 0.05, ***p < 0.01.

positively related to the rates of motorist and pedestrian crashes. This findings is consistent with results from some previous studies but differ notably from a proposition raised by previous studies (Ewing and Cervero 2001) and needed more critical analysis. Since the measure of crash rate was different between this study (crash per area) and Ewing's study (crash per person), the relationship between density and crash rate (per area vs. per person) may be different. It is possible that high-density areas with short links to destinations generated low numbers of vehicle miles traveled per capita (which decreased crash per person) but had more people commuting and led to more total traffic volumes in the area (which increased crash per area). Moreover, the relationship between density and traffic volume may not be linear. It is possible that traffic volume decreases when the population density reaches certain thresholds, and this threshold has not been reached in Austin.

Sidewalks

Higher percentages of sidewalk coverage were found to be associated with lower rates of pedestrian crashes. School areas with completed sidewalks offer connected nonmotorized infrastructure, which in turn increases pedestrian safety. Disconnected nonmotorized infrastructure may force pedestrians to walk on the street or the shoulder, which may cause traffic conflicts between vehicles and pedestrians. A California study asserted that a large number of pedestrians walked on sidewalks rather than on streets after sidewalk gap constructions resulting from the Safe Routes to School (SRTS) programs (Boarnet et al. 2005).

Highways

Highways are designed for high operating travel speeds with wide and straight lanes. Having these high-speed roads close

Table 3. Coefficients from Log-Linear Regression Models Predicting the Pedestrian Crash Rate Using Different Spatial Units of Analysis.

Variable (unit)	0.5-mile model	1-mile model	1.5-mile model	2-mile model
Risk exposure				
School enrollment	0.003	0.004	0.005	0.010
Types of Schools				
Elementary school	−0.003	−0.007	−0.012	−0.021
Middle school	−0.030	−0.034	−0.042	−0.045
Traffic exposure (miles traveled/ mile of street)	0.171**	0.173**	0.177***	0.211***
Neighborhood sociodemographic characteristics				
Population density (/square mile)	0.116***	0.136***	0.207**	0.364***
Nonwhite population (%)	0.157	0.267***	0.291***	0.187
Population aged under 18 (%)	0.264	0.245	0.232	0.217
Population with lower than high school education (%)	0.443	0.432	0.413	0.404
Population below the poverty line (%)	0.103	0.101	0.110	0.118
Built environments				
Nonmotorized infrastructure				
Sidewalk completeness (%)	−0.104**	−0.121**	−0.143**	−0.153***
Street connectivity				
3-leg intersections (/miles of street)	0.021	0.054	0.023	0.017
4-or-more-leg intersections (/miles of street)	0.011	0.015	0.027	0.036***
Transit service				
Transit stops (/miles of street)	0.343***	0.465***	0.441***	0.544***
Road type				
Highways (%)	0.033	0.103***	0.143**	0.186
Arterial roads (%)	0.045	0.046*	0.034**	0.025
Local roads (%)	−0.359***	−0.232***	−0.225***	−0.206*
Land use type				
Residential uses (%)	0.145	0.154*	0.165*	0.134
Commercial uses (%)	0.265***	0.224***	0.186***	0.202**
Commercial uses along local roads (%)	0.094**	0.072*	0.115***	0.124**
Residential uses along local roads (%)	0.012	0.006	−0.003	0.012
R^2	0.746	0.843	0.856	0.874
N	120	120	120	120

*$p < 0.1$, **$p < 0.05$, ***$p < 0.01$.

to schools may lead to traffic safety issues. One possible explanation is the speed differential between highways and local roads when vehicles enter or exit highways. Because 68% of the roads around schools (within 0.5 mile) are local roads in the study area, vehicles with high travel speeds on highways have to decelerate before they enter local roads. This speed differential may cause conflicts among vehicles entering/exiting highways or local roads, thus leading to more motorist crashes. Another possible reason is the large amount of traffic generated by highways, especially during the peak period, which increases the crash risk around the school area.

Local Roads

The benefit of local roads for traffic safety around schools was identified in this study, and may be due to their low traffic speeds. Narrow local roads decrease vehicle speeds, reducing stopping sight distances and giving drivers more time to react to unforeseen hazards (Ewing and Dumbaugh 2009). If roads around schools are designed for high operating speeds, it is difficult for drivers to avoid crashes in school areas, where vehicles and pedestrians are mixed in traffic during peak hours. A study in Orange County, Florida, reported that vehicles with higher speed ratios (estimated speed / speed limit) caused more crashes involving school-aged children (Abdel-Aty, Chundi, and Lee 2007).

Commercial Uses

A higher percentage of commercial uses was associated with more motorist and pedestrian crashes, which is consistent with the results of a previous study in Baltimore, Maryland (Clifton and Kreamer-Fults 2007). Commercial uses lead to more vehicle miles traveled (the correlation coefficient between commercial uses and travel volume in this study is

Figure 4. An example of pedestrian crashes in relation to commercial and school uses.

0.259, $p < 0.05$) and more pedestrian activities, which create a mixed traffic environment that would have multiple effects in school areas because schools also act as trip attractors.

In addition, locating more commercial uses along local roads instead of other road types around schools was associated with more crashes. One possible explanation is the typical auto-oriented design for access to commercial uses in the study area. Most commercial uses in the AISD are located in shopping plazas with large parking lots, which generate a large volume of vehicle traffic and increase the conflicts between pedestrians and vehicles. Future studies should examine the differences between auto-oriented and pedestrian-oriented commercial uses in terms of their impacts on traffic safety around schools. Another possible reason may be conflicts between traffic to/from commercial uses and traffic to/from schools. A closer examination of crash locations revealed that 65% of crashes occurred on road segments adjacent to commercial uses or schools. Figure 4 shows an example of pedestrian crash locations on a local road between a school site (right in the figure) and commercial uses (left in the figure). In this case, drivers in and out of commercial or school areas cannot quickly stop for pedestrian crossings, even if they drive on local roads with low travel speed, because there is (1) no clear driveway notification for drivers and (2) no crosswalks for pedestrian passing. Moreover, because commercial uses are usually set back from roads and parking lots, driveway access is a potential location for conflicts among different users (Dumbaugh and Li 2011).

Transit Stops

Transit services provide personal mobility to individuals traveling to and from school areas, especially for families who live outside of walking distance to schools and have no vehicles or school bus service. Transit stops also act as focal points of travel activities and generate pedestrian activities. This study found positive relationships between the density of transit stops and motorist and pedestrian crashes. This result is consistent with findings from two previous studies, one in New York City (Ukkusuri et al. 2012) and the other in Montreal, Canada (Miranda-Moreno, Morency, and El-Geneidy 2011). In checking the locations of transit stops around schools, this research found that 74% were located along arterial roads in order to provide greater accessibility. The possible problem associated with this design is the exposure of transit commuters to high-speed through traffic when pedestrians need to cross these arterial roads. Thus, planners need to use traffic-calming strategies such as the provision of buffers between transit stops and vehicle roadways to promote traffic safety.

Implications for Practice

Findings from this study have important implications for future planning of school and communities.

Planning a Low-Speed Environment around the School Area

Planners should provide a low-speed-road environment around the school area. Local roads placed around school areas offer low-speed environments, which would enable drivers to stop quickly for unexpected hazards.

To avoid safety threats from speed differentials among different road types around schools, highways should be located farther from schools. This road type emphasizes mobility, encourages relatively high travel speeds, and carries large traffic volumes, all of which increase pedestrian exposure to safety threats. If it is inevitable to have high-speed roads around school, planners should pay more attention to the design of these roads to ensure traffic safety.

Locating Commercial Uses Away from the School Area

Commercial uses, which produce greater traffic volumes and more pedestrian activities, should be located away from schools to avoid a mixed traffic environment. Moreover, commercial uses locating along local roads with low operating speeds also consistently increased motorist and pedestrian crash rates across the four spatial units. A possible solution is to provide pedestrian-friendly design instead of auto-oriented design for commercial uses along local roads to encourage walking and improve traffic safety around schools.

Connected Nonmotorized Infrastructure and Pedestrian-Friendly Environments around Transit Stops

School safety can be enhanced by providing connected nonmotorized infrastructure around schools. Offering a pedestrian-friendly environment could help manage traffic conflicts and improve pedestrian safety. In response to this concern, researchers have encouraged school facility and land use planners to use Smart Growth strategies to build school facilities, plan communities, and create safe streets for both pedestrians and drivers (CEFPI and EPA 2004). Strategies such as providing sidewalks and mounting medians can help reduce traffic-related deaths and injuries for all users (e.g., motorists, pedestrians, and public transit commuters) (CEFPI and EPA 2004).

Conclusion

This study examined the influences of built environments on motorist and pedestrian crashes around schools and found that schools surrounded by more commercial uses, transit stops, and highways had higher motorist and pedestrian crash rates.

A few limitations need to be addressed. First, this study used all pedestrian and motorist crashes around schools as outcome measures. Future studies should consider examining crashes involving children or only school travel-related crashes to further understand school traffic safety. Moreover, because this study primarily focused on the traffic safety, the results and implications would try to maximize this function, which may compromise other functions (e.g., transportation planning) (Mehaffy et al. 2010).

Traffic safety around schools has been and will continue to be an important topic for transportation engineers, urban planners, and land developers. This study provides a starting point, and also demonstrates the need for more detailed studies in this field.

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