Designing for the Safety of Pedestrians, Cyclists, and Motorists in Urban Environments

Eric Dumbaugh[a]; Wenhao Li[a]

[a] Texas A&M University,

PLEASE SCROLL DOWN FOR ARTICLE

Designing for the Safety of Pedestrians, Cyclists, and Motorists in Urban Environments

Eric Dumbaugh and Wenhao Li

Problem: While design solutions aimed at enhancing the safety of pedestrians are viewed as being incompatible with those intended to improve the safety of motorists, there has been little meaningful evaluation of the issue. Instead, this disagreement is based largely on the theoretical assertion that traffic crashes are the result of random driver error, and that the only certain means for addressing safety is to design roadways to be forgiving of these errors when they occur. This perspective overlooks the possibility that crashes may instead be the product of systematic patterns of behavior associated with the characteristics of the built environment.

Purpose: This study sought to discover whether urban crash incidence is the product of random error, or whether it may be influenced by characteristics of the built environment.

Methods: We used negative binomial regression models to examine the relationship between several aspects of the built environment and the incidence of crashes involving motorists, pedestrians, and cyclists. We further subdivided motorist crashes into multiple-vehicle, fixed-object, and parked-car crashes to determine if these crash types had unique characteristics.

Results and conclusions: We used vehicle miles of travel as a proxy for random error and found it to be positively, but weakly, associated with crashes involving motorists and pedestrians. We found stronger associations between crashes and characteristics of the built environment. We found miles of arterial roadways and numbers of four-leg intersections, strip commercial uses,

and big box stores to be major crash risk factors, while pedestrian-scaled retail uses were associated with lower crash incidences. The results suggest that improvements to urban traffic safety require that designers balance the inherent tension between safety and traffic conflicts, rather than simply designing roadways to be forgiving.

Takeaway for practice: Most of the ongoing debate between pedestrian advocates and traffic engineers has focused on the relative desirability of designing urban roadways to be forgiving to random driver error. Such debates have led both groups to ignore the more salient issue of systematic error. This study finds that the factors associated with a vehicle crashing into a pedestrian and cyclist are largely the same as those resulting in a crash with another vehicle. Designs that balance the inherent tension between vehicle speeds and traffic conflicts can be used to enhance the safety of pedestrians, cyclists, and motorists alike.

Keywords: traffic safety, community design, urban design, land use planning

About the authors:
Eric Dumbaugh (edumbaugh@tamu.edu) is an assistant professor at Texas A&M University and the coordinator of its graduate certificate program in transportation planning. His work includes "Safe urban form" (Dumbaugh, & Rae, 2009), which received *JAPA*'s 2009 award for best paper, and "The design of safe urban roadsides" (Dumbaugh, 2006), which received the Transportation Research Board's award for outstanding paper in geometric design in 2007. **Wenhao Li** (liwenhao@neo.tamu.edu) is a master's student at Texas A&M University.

Designs intended to address the safety needs of motorists are viewed as being at odds with those aimed at enhancing the safety of pedestrians and cyclists. This is readily evidenced in the prevailing design guidance on roadway and community design. From the perspective of roadway design, the guiding reference work is the manual entitled *A Policy on the Geometric Design of Highways and Streets* (more popularly known as the "green book'), which specifies that "every effort should be made to use as high a design speed as practical in the interests of safety (American Association of State Highway and Transportation Officials [AASHTO], 2004, p. 67). Because the selection of a roadway's design speed governs the design of its geometric features, the result is a

preference for roadways designed with wider lanes, wider clear zones, longer sight distances, and other high-speed design elements.

While high design speeds are viewed as desirable for motorist safety, they are not safe for pedestrians and bicyclists. Higher vehicle speeds result in an increase in both the frequency and severity of crashes involving pedestrians (Anderson, McLean, Farmer, Lee, & Brooks, 1997; Garder, 2001; 2004; Leaf & Preusser, 1998). Examinations of the spatial distribution of pedestrian crashes show that they cluster along urban arterials, precisely the category of roadways designed with the forgiving roadway features intended to enhance the safety of motorists (Ernst, 2004; Loukaitou-Sideris, Liggett, & Sung, 2007; Miles-Doan & Thompson, 1999). For these reasons, pedestrian and bicycle advocates often call for the adoption of design features intended to reduce vehicle speeds and buffer pedestrians from oncoming traffic, such as narrow travel lanes and the inclusion of trees and other streetscape elements between the sidewalk and the vehicle travelway.

Urban Crash Incidence: A Theoretical Problem

While these two perspectives are certainly in conflict, the question remains: Is motorist safety fundamentally at odds with the safety of pedestrians and cyclists? There is a relatively large disconnect between what is assumed about urban crash incidence and what is actually known. Current traffic safety theory, known alternately as "passive safety" or "forgiving design," emerged in the 1950s and 1960s as safety advocates sought to apply the principles of epidemiology to traffic safety issues (Dumbaugh, 2005a; Weingroff, 2003). While earlier safety efforts had sought to reduce crash incidence by encouraging drivers to modify their behavior, passive safety proponents asserted that such efforts were unreliable, since drivers are inherently fallible and prone to error. From this perspective, the only certain means to address safety is to design roadways to be forgiving of these errors when they occur.

Research examining the safety performance of interstate highways and two-lane rural roadways supports this view. In these environments, which have little or no roadside development and which serve principally longer-distance, mobility-oriented travel, forgiving design features such as wide lanes, wide shoulders, and roadside clear zones, tend to be associated with reduced crash incidence (Zegeer, Deen, & Mayes, 1981; Zegeer, Hummer, Reinfurt, Herf, & Huner, 1988). This evidence was interpreted to mean that using forgiving design

features would enhance safety in other environments as well, regardless of a roadway's traffic function or the characteristics of surrounding development (AASHO, 1974, 2004).

Such an assumption would pose no particular problem if the factors that reduced crash incidence in urban areas were the same as those that reduce crashes on freeways and rural roads, but a growing body of evidence shows that these factors are not the same. While the occasional study finds that widening lanes on urban surface streets is associated with reduced crash incidence (Hadi, Aruldhas, Chow, & Wattleworth, 1995), most recent research reports that wider lanes on urban streets have little or no safety benefit, at least using empirically measured crash incidence (Hauer, 1999; Hauer, Council, & Mohammedshah, 2004; Milton & Mannering, 1998; Potts, Harwood, & Richard, 2007). Likewise, while some studies report safety benefits associated with widening shoulders and roadside clear zones (Noland & Oh, 2004), most find these changes to yield at best minimal improvement (Maze, Sax, & Hawkins, 2008), and some find them to be associated with increases in crash incidence (Dumbaugh, 2006; Hauer, Council, et al., 2004; Ivan, Wang & Bernardo, 2000; Lee & Mannering, 1999). Conversely, one before-and-after study found that the placement of trees and other roadside features in the clear zone produced a significant decrease in crash incidence (Naderi, 2003). Nevertheless, such findings have received little attention from the professional and research communities. As noted in a recent review:

> [S]tudies that find unexpected or unconventional results tend to dismiss these results as aberrations....The results of many of these studies lead us to conclude that the impact of various infrastructure and geometric design elements on safety are inconclusive. (Noland & Oh, 2004, p. 527)

The problem is a theoretical one, and hinges on passive safety's treatment of driver error. Under the passive safety theory, driver error is viewed as a purely random product of human fallibility; the more driving people do, the greater the probability they will engage in an error that produces a crash. This perspective treats driver error as a constant, presuming that it occurs with a fixed frequency regardless of the characteristics of the environment in which it occurs. This is readily evidenced in most of the traffic safety research, which models crash incidence solely as a function of traffic volumes and roadway geometry. The underlying theoretical proposition is that driver errors are purely random in nature, and that any variation in crash incidence that may occur after accounting for traffic

volumes can be understood as a function of whether or not a roadway was designed to be adequately forgiving.

This approach is highly appealing from a design perspective, since it eliminates the need to address the complex series of behavioral or contextual factors that may lead to a crash event. If driver behavior is constant, then forgiving design features should enhance safety, and a roadway designed to be forgiving of errors occurring during high-speed, extreme driving events should also be forgiving of those that occur at lower speeds and during more typical driving events.

Regardless of how appealing this perspective may be, it is incorrect if driver errors are systematic in nature. Unlike freeways and rural highways, which provide the evidence on which forgiving design practice is based, urban surface streets are often required to accommodate access-related traffic associated with adjacent developments, as well as pedestrians and cyclists, users who are not typically found on rural roads and who are legally excluded from using freeways. These differing uses and users may in turn generate unique patterns of behavior that create crash risk in a systematic, non-random manner having little or nothing to do with roadway's geometry.

Examining the Built Environment and Crash Incidence: Methods and Variables

While several earlier works concluded that the anomalous findings in the urban traffic safety literature were likely attributable to systematic driver error (Dumbaugh, 2005a; 2006; Dumbaugh & Rae, 2009), few studies have examined the relationship between the built environment and crash incidence, and none has examined the built environment's effects on different types of crashes. Thus, we examined the environmental factors associated with crash incidence to shed light on anomalies in the existing traffic safety literature, as well as to advance contemporary safety theory, which has remained largely unchanged for more than half a century.

We developed a GIS-based database of crash incidence and urban form for the San Antonio-Bexar County metropolitan region. This database consisted of five years (2003–2007) of crash data from the Texas Department of Transportation (TxDOT), parcel-level land use information from the Bexar County Tax Appraisal District, street network information from the San Antonio-Bexar County Metropolitan Planning Organization, information on traffic volumes from the City of San Antonio and TxDOT, and demographic information from the decennial census.

Collectively, these data allow us to examine the spatial distribution of crashes in conjunction with both traffic volumes and several characteristics of the built environment.

Examining the environmental correlates of crash incidence required several methodological decisions. First, we had to determine an appropriate unit of analysis. Most conventional safety studies analyze crash incidence at the level of the street segment, based on the assumption that roadway traffic volumes and geometric features are sufficient for understanding variations in urban crash incidence. Our study, however, seeks to understand whether the characteristics of the built environment contribute to systematic patterns of crash incidence, requiring us to capture information on urban development in the area where crashes occur. To do this, we opted to analyze small geographic areas rather than individual street segments.

We then had to make decisions about how to delimit the boundaries of these areas, as well as how to deal with information occurring along their edges. Because we wanted to incorporate accurate information about the resident population into our analysis, we decided to rely on census block group definitions. To ensure that we captured information occurring on the boundaries of these block groups, as well as to address any microlevel spatial variation that might exist in the definition of our GIS layers, we included a 200-foot buffer (roughly the width of a fully designed principal arterial) around each census block group.

We sought to focus on crash incidence in urban environments. While we considered a number of ways to define an appropriate study area, ultimately we relied on the region's highway infrastructure as the most straightforward approach. Thus, we chose a study area for this analysis consisting of the 938 block groups contained within the Highway 1604 loop to the north, and I-410 to the south (see Figure 1). The majority of the region's surface transportation network is within our study area, as were 1.2 million of the 1.4 million people living in Bexar County in 2000.

Dependent Variables

Approximately 296,000 crashes occurred in the study area between 2003 and 2007. Of these, roughly 292,000 involved motorists, including 217,000 that involved two moving vehicles, 40,000 that involved a parked car, and 31,000 involved a fixed object, such as a utility pole or a tree. About 3,100 additional crashes involved motorists crashing into pedestrians, and more than 1,000 crashes involved motor vehicles colliding with cyclists (see Table 1). We aggregated each of these crash
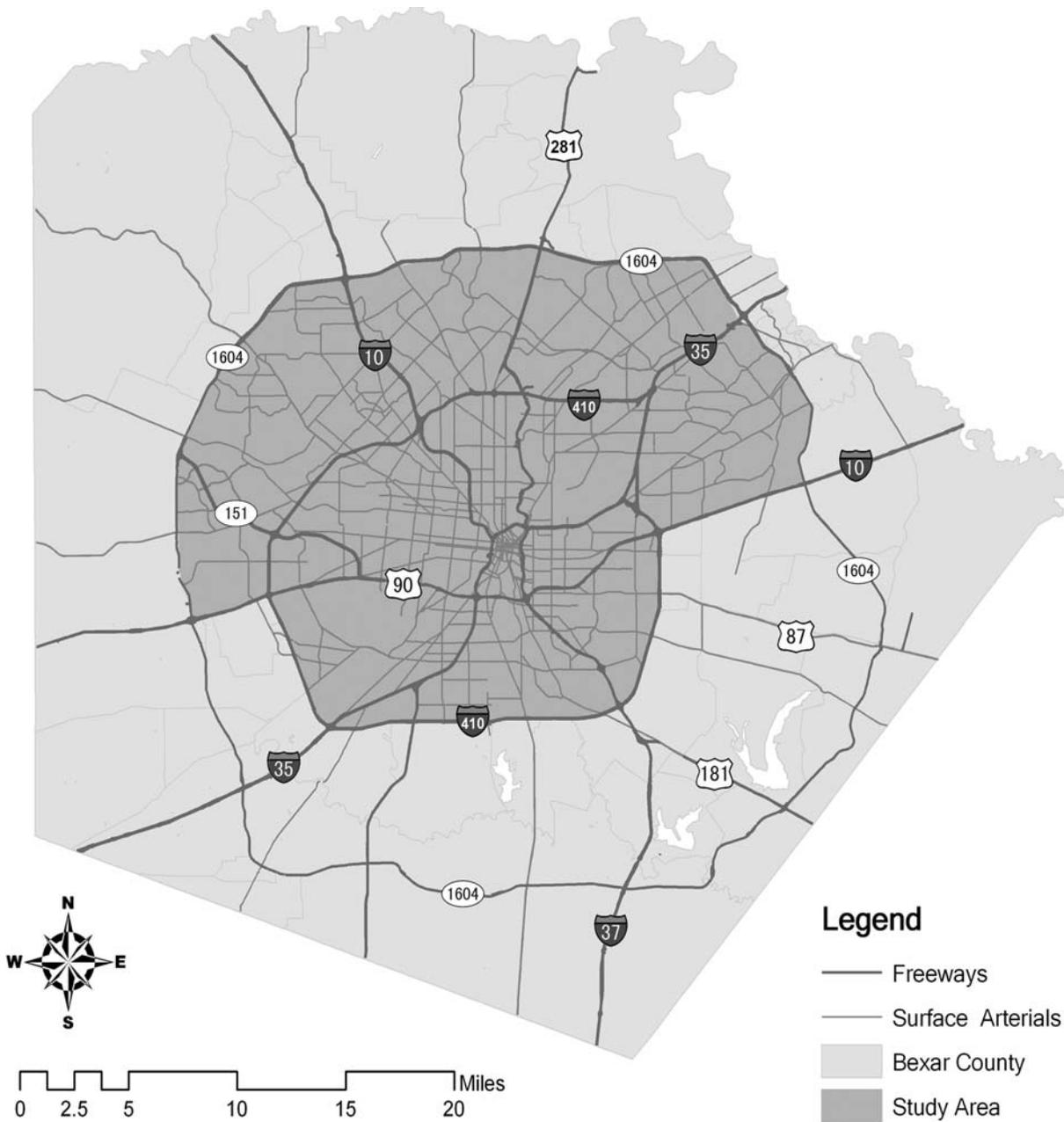
Figure 1. San Antonio-Bexar County study area.

types for each block group and the block group totals for the following crash types make up our dependent variables:

- *Motorist crashes* involve one or more motor vehicles (i.e., no pedestrians or cyclists) and include crashes with other motor vehicles, fixed objects, and parked cars.
- *Multiple-vehicle crashes* involve two or more motor vehicles.
- *Fixed-object crashes* involve a motor vehicle crashing into an object other than a parked car, such as a roadside tree, mailbox, or utility pole.

- *Parked-car crashes* involve a motor vehicle crashing into one or more parked cars.
- *Vehicle-pedestrian crashes* involve a motor vehicle crashing into one or more pedestrians.
- *Vehicle-cyclist crashes* involve a motor vehicle crashing into one or more bicyclists.

Independent and Control Variables

To understand whether attributes of adjacent development or the built environment may be associated with urban crash incidence, we included the following variables in our analysis:

Block Group Acreage. Census block groups vary in size. Those with larger areas are typically located in less

Table 1. Crashes occurring in the San Antonio-Bexar County study area, 2003–2007.

Crash type	Crashes
Motorist	291,509
Multiple-vehicle	217,028
Fixed-object	30,777
Parked-car	40,300
Motorist-other[a]	3,404
Vehicle-pedestrian	3,108
Vehicle-cyclist	1,022
Total	295,639

Note: a. Some motorist crashes did not fall into any of the categories we defined and are included separately here.

densely populated areas at the periphery of the metropolitan area. To control for whatever statistical effects block group definitions may have on our results, we included block group acreage as a control variable.

Vehicle Miles of Travel (VMT). Passive safety theory assumes that driver error is a function of the amount of driving that people do. To account for this, we developed estimates of VMT (denominated in millions) at the block group level. TxDOT provided average daily traffic volumes (ADT) for all state highways (freeways and principal arterials) in the metropolitan area. The City of San Antonio also gave us traffic counts at 804 locations not on the state highway system. Taken together, we had data for all freeways, principal arterials, minor arterials, and collector roadways in the region. Because the state provided ADT for roadway segments and the city provided ADT for single points, we made the two compatible by assuming that point ADT remained the same along a road segment for half the distance to the next data point, where we assumed it changed to the ADT recorded for the next data point.

It was also necessary to subdivide roadway segments so they did not cross block group boundaries. To do so, we again used a 200-foot buffer around each block group in order to include all roadways related to a particular block group. Once the road segments were subdivided, we calculated VMT for each road segment by multiplying that segment's ADT by its length, and then multiplying this value by 365 days and then by five years. We then determined the block-group-level VMT by summing the VMT for all of the individual road segments in the block group and dividing the sum by one million. The resulting value is block-group-level VMT, in millions.

Net Population Density. Several studies have identified higher population densities as a crash risk factor

(Hadayeghi, Shalaby, & Persaud, 2003; Hadayeghi, Shalaby, Persaud, & Cheung, 2006; Ladrón de Guevara, Washington, & Oh, 2004; Lovegrove & Sayed, 2006). To understand the effects that population density might have on crash incidence after accounting for other factors, we calculated the net population density of each block group, measured as the total population of the block group divided by the total acreage of land devoted to residential uses in that block group.

Intersections. Intersections create locations where streams of traffic cross, and are thus locations where conflicts between roadway users may emerge. Because three-way intersections have been found to have different safety effects than other intersection types (Ben-Joseph, 1995; Marks, 1957), we modeled three-leg intersections and four-or-more-leg intersections as separate variables. These variables are simply counts of the numbers of intersections of each type within each block group.

Freeway Mileage. Freeways are high-speed, limited-access facilities that are typically designed to be forgiving to random driver error. Pedestrians and cyclists are legally excluded from using these facilities, and access is strictly controlled through the use of grade-separated interchanges. This variable is the sum of the centerline miles of roadways classified as freeways or interstate highways within each block group.

Surface Arterial Mileage. Arterial thoroughfares are surface streets that incorporate the higher-speed, forgiving design features found on freeways. Unlike freeways, however, arterials include at-grade intersections and must often accommodate lower-speed, access-related uses, as well as pedestrians and cyclists. This variable is the sum of the centerline miles of roadways classified as surface arterials within each block group.

Strip Commercial Uses. Land development codes often encourage commercial and retail uses to locate along arterial thoroughfares. These uses are typically set back from the roadway behind surface parking lots. They often also have direct driveway access to the adjacent arterial thoroughfare, creating locations that may potentially create conflicts between different road users. This variable counts the commercial and retail uses in a block group that are located adjacent to arterials.

Big Box Stores. Big box stores are major trip attractions and can draw traffic from large geographic areas. Given their size, they generate a good deal of off-street traffic as well, as vehicles circulate through these parcels in search of parking and as pedestrians attempt to walk from their cars to the buildings. For this study, a *big-box store* is a retail use with a building area of 50,000 square feet or more and having a floor-area ratio (FAR) of 0.4 or less

(i.e., with more surface parking than building area). This variable counts these uses in a block group.

Pedestrian-Scaled Retail Uses. Pedestrian advocates generally encourage the adoption of more traditional retail configurations, where buildings front directly on the street rather than being set back behind large parking lots (see Figure 2). *A pedestrian-scaled retail use* is defined in this study as a commercial or retail use of 20,000 square feet or less, developed at a FAR of 1.0 or greater (i.e., a building that has little undeveloped surface space on the lot and may front the street). The resulting variable is the count of such uses in a neighborhood, and serves as a rough indicator of a neighborhood's urban nature.

Figure 2. Pedestrian-scaled retail uses in San Antonio.

Model Specification and Reporting

Because our dependent variables are counts of items per block group and are *overdispersed* (they have variances that are greater than their means), we used negative binomial regression models for the following analysis. Each model coefficient reports the percentage change in the dependent variable associated with one unit of change in the independent variable (Hilbe, 2007).

Motorist Crashes

Passive safety asserts that drivers will commit crash-inducing errors as a function of the amount they travel. Table 2 shows that VMT does have a positive and significant relationship with the incidence of all crashes involving motorists. Yet, the magnitude of VMT's effect is slight compared to characteristics of the built environment. Crashes involving motorists increased by only about half of one percent (0.6%) for every million miles of travel. Given that the metropolitan region as a whole generates only about 38 million miles of vehicle travel each year (San Antonio-Bexar County Metropolitan Planning Organization, 2009), even a doubling of the region's VMT would only have a moderate effect on crash incidence. By contrast, each additional strip commercial use is associated with a 2.2% increase in motorist crashes, and each additional big box store is associated with a 7.7% increase in motorist crash incidence. Stated another way, each additional strip commercial use increases motorist crash incidence by about four times as much as adding one million miles of vehicle travel, and each additional big box store increases crash incidence by roughly 14 times as much as adding one million miles of vehicle travel.

Street types matter as well. Each additional mile of freeway was associated with a 4.2% decrease in the number of crashes involving only motorists, a finding expected under conventional traffic safety theory. Yet each additional mile of arterial, typically designed like freeways to be forgiving, was associated with a 9.8% increase in motorist crashes.

Four-or-more-leg intersections were associated with a significant increase in motorist crashes, with each intersection of this type corresponding to a 0.6% increase in motorist crashes, roughly the same effect as adding one million miles of vehicle travel. Each additional pedestrian-scaled retail use was associated with a 3% reduction in motorist crashes, even though these uses are often located in environments that are unforgiving to motorists. Neither density nor three-leg intersections had statistically meaningful relationships with motorist crash incidence, however.

While the model results for VMT confirm that at least some portion of urban crashes may be attributable to random error, motorist crash incidence appears to be more profoundly influenced by the characteristics of the built environment. Yet, the aggregate nature of this model, which lumps all motorist crashes together, might mask the underlying behavioral patterns that explain these findings. In the models below, we examine the specific environmental factors associated with crashes involving multiple vehicles, fixed objects, and parked cars.

Multiple-Vehicle Crashes

Table 3 presents the results of the multiple-vehicle crash model. Given that multiple-vehicle crashes comprise the overwhelming share of crashes involving motorists, it is perhaps unsurprising that the model for multiple-vehicle

Table 2. Negative binomial regression model predicting motorist crashes occurring in the San Antonio-Bexar County study area, 2003–2007.

	Coefficient	z	p	95% Confidence interval	
Constant	5.006	104.97	0.000	4.913	5.100
Block group acreage	−0.000	−3.31	0.001	−0.001	−0.000
VMT (millions)	0.006	13.87	0.000	0.005	0.006
3-leg intersections	0.000	0.09	0.925	−0.003	0.003
4-or-more-leg intersections	0.006	2.46	0.014	0.001	0.011
Net population density	0.000	0.69	0.492	−0.001	0.002
Freeway miles	−0.042	−2.49	0.013	−0.075	−0.009
Arterial miles	0.098	3.58	0.000	0.044	0.152
Strip commercial uses	0.022	8.70	0.000	0.017	0.027
Big box stores	0.077	4.49	0.000	0.043	0.110
Pedestrian-scaled retail uses	−0.031	−4.24	0.000	−0.045	−0.017
Log likelihood	−6,307.184				

Note: $N = 938$.

Table 3. Negative binomial regression model predicting multiple-vehicle crashes occurring in the San Antonio-Bexar County study area, 2003–2007.

	Coefficient	z	p	95% Confidence interval	
Constant	4.985	97.53	0.000	4.885	5.085
Block group acreage	−0.000	−3.30	0.001	−0.001	−0.000
VMT (millions)	0.005	12.62	0.000	0.005	0.006
3-leg intersections	0.000	0.04	0.970	−0.003	0.003
4-or-more-leg intersections	0.006	2.11	0.035	0.000	0.011
Net population density	0.001	0.86	0.392	−0.001	0.002
Freeway miles	−0.053	−2.91	0.004	−0.089	−0.017
Arterial miles	0.114	3.87	0.000	0.056	0.172
Strip commercial uses	0.024	8.62	0.000	0.018	0.029
Big box stores	0.084	4.58	0.000	0.048	0.120
Pedestrian-scaled retail uses	−0.035	−4.48	0.000	−0.051	−0.020
Log likelihood	−6,327.084				

Note: $N = 938$.

crashes is similar to the motorist crash model. VMT again has a positive relationship with crash incidence, with multiple-vehicle crashes increasing by about 0.5% for every million additional miles of VMT. Locations where opposing streams of vehicle traffic intersect were likewise associated with increases in multiple-vehicle crashes. Each four-leg intersection was associated with a 0.6% increase in multiple vehicle crashes, while strip commercial uses and big box stores, which often have direct driveway access to the adjacent street network and thus create informal intersection locations, were associated with 2.4% and 8.4% increases in these crashes, respectively. Each pedestrian-scaled retail use, on the other hand, was associated with a 3.5% reduction in multiple-vehicle crashes.

Freeway and arterial mileages again had differing safety effects. Each freeway mile was associated with a 5.3% reduction in multiple-vehicle crashes, while each mile of arterial was associated with an 11.4% increase. These differences are likely attributable to these facilities' design characteristics. Freeways employ grade-separated interchanges to separate conflicting movements between opposing streams of traffic,

thereby eliminating a major source of multiple-vehicle crash risk. Arterials, on the other hand, must typically accommodate intersections and driveways at grade, with the result being an increased incidence of multiple-vehicle crashes. Finally, we found neither population density nor three-leg intersections to be associated with the incidence of multiple-vehicle crashes. While the findings for three-leg intersections may seem somewhat surprising given the relationship between four-leg intersections and crash incidence, it is consistent with previous research, which finds T-intersections to be safer than four-way intersections both because they have fewer traffic-conflict points and because they terminate street segments, which tends to reduce vehicle speed (Ben-Joseph, 1995; Dumbaugh & Rae, 2009; Marks, 1957). As shown in Figure 3, a three-leg intersection produces only nine conflict points between vehicles, compared to 24 for a four-leg intersection.

Crashes Involving Fixed Objects

Fixed-object crashes are of particular concern because of their severity. While they account for only about 15% of
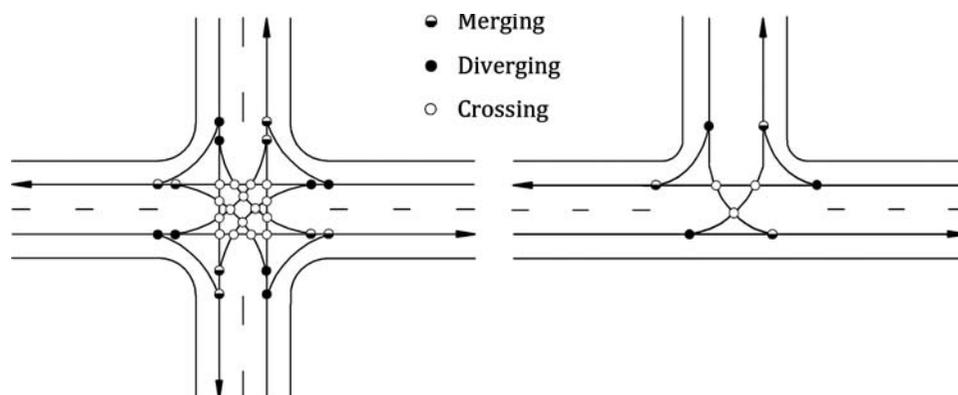

Figure 3. Conflict points at four-leg and three-leg intersections.

the crashes that occur in any given year, fixed objects are associated with nearly one third of the nation's annual traffic fatalities (National Highway Traffic Safety Administration, 2006). A good deal of design guidance exists on how to mitigate these crashes, principally recommending the adoption of wide shoulders and roadside clear zones (American Association of State Highway and Transportation Officials, 2006; Transportation Research Board 2003b; 2003c). Regardless of the conventional wisdom on the subject, research has not found these features to produce a demonstrable safety benefit on urban streets (Dumbaugh, 2005b; 2006; Hauer, Council, et al., 2004; Lee & Mannering, 1999; Maze et al., 2008). The reason is that the type of behavior that they are designed to address (a random midblock encroachment into the roadside) is not the type of behavior responsible for most urban fixed-object crashes.

The primary evidence used to support the use of urban clear zones is a 1990 study by Turner and Mansfield, which reported that 80% of tree-related crashes occurred within 20 feet of the right of way. Yet, this relationship is almost certainly a spurious one. Due to the constrained nature of urban environments, only a small percentage of urban roadways have clear zones of 20 feet or more, a fact which would explain why such roadways experience a small percentage of roadside-related crashes. Figure 4 shows that

the percentage of crashes occurring on roadways with a particular *offset* (clear zone) width corresponds closely to the percentage of roadways with that offset width (Dumbaugh, 2005b). There appears to be a slight safety benefit to clear zones that exceed 15 feet, but even this finding fails to control for traffic volumes or other environmental characteristics that may influence crash incidence.

As revealed in a detailed study of urban fixed-object crash locations, the majority of urban fixed-object crashes were not the result of a purely random encroachment onto the roadside, but instead occurred when drivers attempted to turn onto driveways and intersections at higher-than-appropriate speeds (see Figure 5). In fact, 83% of fixed-object crash locations (and 65% of all crash locations, since the fixed objects could not always be precisely identified) occurred near driveways or intersections (Dumbaugh, 2006). A subsequent examination of urban fixed-object crashes confirmed these findings, reporting that urban fixed-object crashes were twice as likely to occur near intersections than at non-intersection locations, and that there was little safety benefit associated with providing clear offsets greater than 5 feet (Maze et al., 2008).

The model results for fixed-object crashes support these findings. As shown in Table 4, four-leg intersections, which are locations where turning maneuvers occur, were associated with significant increases in the incidence of fixed-object
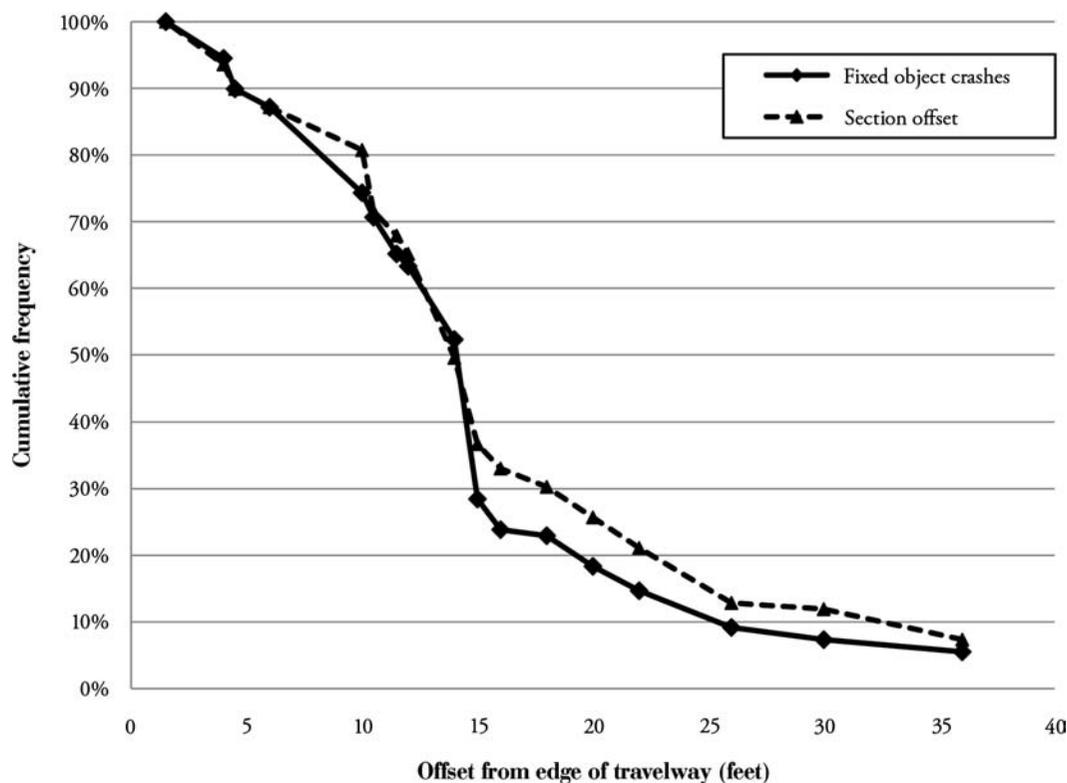

Figure 4. Cumulative frequencies of roadways with different offsets and fixed-object crashes on roadways with those offsets.

Source: Dumbaugh (2005b).

Figure 5. Urban fixed-object crashes are disproportionately associated with turning maneuvers at intersections.

crashes, with each additional four-leg intersection corresponding to a 0.9% increase in fixed-object crashes. Each additional strip commercial use, which would typically have direct driveway access to the arterial system and thus be a location where turning maneuvers occurred, was associated with a 1.4% increase in fixed-object crashes. VMT was also associated with increases in the incidence of fixed-object crashes, yet the association was again inconsequential when compared to the effects of intersections and strip commercial uses, with fixed-object crashes increasing only by 0.5% for every one million additional VMT.

While miles of arterials were positively associated with increases in fixed-object crashes, this variable only entered the model at the 83% confidence level, suggesting that it is the turning maneuvers occurring at driveways and side streets, rather than the arterials themselves, that are the problem. By contrast, each pedestrian-scaled retail use was

associated with a 1.2% reduction in fixed-object crashes. We believe this finding is likely due to the lower operating speeds occurring in the environments where pedestrian-scaled retail uses are located, which would encourage drivers to undertake turning maneuvers at lower speeds, and thereby reduce the likelihood of a turn-related encroachment onto the roadside.

Crashes Involving Parked Cars

Crashes involving parked cars were the second largest crash type in the San Antonio study area, accounting for nearly 15% of the region's approximately 268,000 crashes. To date, most discussion of safety related to parked cars has focused on the potential crash risk posed by on-street parking, as many locations with on-street parking report large numbers of crashes involving parked cars (Box, 2004; Humphries, Box, Sullivan, & Wheeler, 1978). However, a recent review of the subject found no studies that had conducted either matched-pairs comparisons of street segments with and without on-street parking, or comparisons of crash incidences both before and after eliminating on-street parking (Ewing & Dumbaugh, 2009).

Table 5 presents the results of the parked-car crash model. Crashes involving parked cars increased by about 0.1% for every million VMT. Each strip commercial use was associated with a 2.1% increase in crashes involving parked cars, while each big box store was associated with an 11.4% increase in parked-car crashes. This is unsurprising, as these uses include onsite parking lots that create opportunities for motorists to crash into parked cars as they circulate through the site. Similarly, areas with higher population densities, and thus more people attempting to park their cars in a smaller area, were associated with significantly more crashes involving parked cars.

Table 4. Negative binomial regression model predicting fixed-object crashes occurring in the San Antonio-Bexar County study area, 2003–2007.

	Coefficient	z	p	95% Confidence interval	
Constant	3.038	77.58	0.000	2.961	3.114
Block group acreage	−0.000	−1.13	0.259	−0.000	0.000
VMT (millions)	0.005	15.88	0.000	0.005	0.006
3-leg intersections	−0.001	−0.46	0.643	−0.003	0.002
4-or-more-leg intersections	0.009	4.34	0.000	0.005	0.013
Net population density	−0.000	−0.63	0.526	−0.001	0.001
Freeway miles	−0.001	−0.05	0.963	−0.028	0.027
Arterial miles	0.030	1.36	0.173	−0.013	0.073
Strip commercial uses	0.014	6.90	0.000	0.010	0.018
Big box stores	−0.011	−0.78	0.433	−0.037	0.016
Pedestrian-scaled retail uses	−0.010	−1.72	0.086	−0.022	0.001
Log likelihood	−4,233.424				

Note: $N = 938$.

Table 5. Negative binomial regression model predicting parked-car crashes occurring in the San Antonio-Bexar County study area, 2003–2007.

	Coefficient	z	p	95% Confidence interval	
Constant	3.625	82.12	0.000	3.538	3.711
Block group acreage	0.000	0.56	0.572	–0.000	0.000
VMT (millions)	0.001	2.79	0.005	0.000	0.002
3-leg intersections	0.000	0.16	0.875	–0.002	0.003
4-or-more-leg intersections	0.004	1.60	0.111	–0.001	0.008
Net population density	0.001	1.79	0.074	–0.000	0.002
Freeway miles	–0.037	–2.28	0.022	–0.069	–0.005
Arterial miles	0.066	2.65	0.008	0.017	0.116
Strip commercial uses	0.021	8.62	0.000	0.016	0.025
Big box stores	0.114	7.17	0.000	0.083	0.145
Pedestrian-scaled retail uses	–0.012	–1.76	0.078	–0.025	0.001
Log likelihood	–4,650.806				

Note: $N = 938$.

Freeway mileage was associated with a statistically significant reduction in crashes involving parked cars, a finding that likely reflects the fact that parking is prohibited along freeways, thus, reducing exposure. Each additional mile of arterial thoroughfare was associated with a 6.6% increase in parked car crashes. Nonetheless, a limitation of this study is that the data did not allow us to distinguish areas where on-street parking is permitted from those where it is prohibited. It is thus impossible to determine whether the findings for arterial roadways are the result of the hazards associated with permitting on-street parking to occur along arterials, or whether it simply reflects the fact that parking-intensive land uses are often found along arterials. Further research on this subject is needed.

Interestingly, each additional pedestrian-scaled retail use was associated with a 1.2% decrease in crashes involving parked cars. Environments containing pedestrian-

scaled retail uses typically include a combination of both on- and off-street parking (see Figure 2), creating numerous opportunities for parking-related crashes. It is unclear why motorists would find it easier to negotiate around parked cars in these environments than elsewhere, although drivers might be more cautious in areas where such uses are present. This too is an area where more research is needed.

Vehicle-Pedestrian Crashes

The environmental factors associated with the incidence of vehicle-pedestrian crashes are largely identical to those associated with multiple-vehicle crashes (see Table 6). After controlling for VMT, each additional mile of arterial thoroughfare was associated with a 9.3% increase in

Table 6. Negative binomial regression model predicting vehicle-pedestrian crashes occurring in the San Antonio-Bexar County study area, 2003–2007.

	Coefficient	z	p	95% Confidence interval	
Constant	1.120	18.59	0.000	1.002	1.238
Block group acreage	–0.000	–1.69	0.092	–0.001	0.000
VMT (millions)	0.001	1.99	0.047	0.000	0.002
3-leg intersections	–0.004	–2.18	0.029	–0.007	–0.000
4-or-more-leg intersections	0.009	2.97	0.003	0.003	0.015
Net population density	0.003	2.78	0.005	0.001	0.005
Freeway miles	–0.017	–0.81	0.419	–0.057	0.024
Arterial miles	0.093	2.76	0.006	0.027	0.159
Strip commercial uses	0.030	9.38	0.000	0.023	0.036
Big box stores	0.087	4.51	0.000	0.049	0.125
Pedestrian-scaled retail uses	–0.016	–1.76	0.079	–0.034	0.002
Log likelihood	–2,556.308				

Note: $N = 938$.

motorist-pedestrian crashes, each additional strip commercial use was associated with a 3% increase in vehicle-pedestrian crashes, and each big box store was associated with an 8.7% increase in vehicle-pedestrian crashes. Four-leg intersections were associated with a 0.9% increase in this crash type. As was the case with motorist crashes, these findings are likely due to a combination of traffic conflicts and vehicle speeds; vehicle-pedestrian crashes appear to be more likely to occur at driveways and intersections, where pedestrian traffic interacts with opposing streams of vehicle traffic. The model indicated that these hazards were particularly exacerbated along arterials, where vehicles travel at relatively high operating speeds.

We found population density to have a positive and statistically significant relationship to the incidence of crashes involving pedestrians. This is probably because population density serves as a proxy for pedestrian volumes; walking is more common in higher density environments (Ewing & Cervero, 2001). Thus this variable is likely reflecting differences in pedestrian exposure. While pedestrian-scaled retail uses are similarly associated with higher levels of walking, and are thus locations where more vehicle-pedestrian crashes would be expected to occur, they were nonetheless associated with significantly fewer crashes involving pedestrians. As noted previously, this can likely be attributed to lower traffic speeds in these environments.

Vehicle-Cyclist Crashes

While there is a good deal of guidance on the design of bicycle facilities, there has been little empirical research examining the incidence of crashes involving bicyclists. Table 7 presents the model for bicycle crash incidence. As

with the other crash types considered in this study, arterial thoroughfares proved to be a major risk factor, with each additional mile of arterial corresponding to a 6.6% increase in vehicle-cyclist crashes. Four-leg intersections and strip commercial uses, which create locations where vehicles and bicycle traffic may interact, were associated with 1.3% and a 1.7% increases in vehicle-cyclist crashes, respectively. Big box stores were associated with increases in vehicle-cyclist crashes, and pedestrian-scaled retail uses with decreases in these crashes, although both variables fell slightly outside conventional levels of statistical significance. Interestingly, VMT was not significantly associated with vehicle-cyclist crashes, the only crash type for which this was true.

Systematic Error and the Incidence of Crashes Involving Pedestrians, Cyclists, and Motorists

Passive safety theory encourages designers to focus on addressing the safety effects of random error. Yet VMT, a proxy for random error, has a comparatively minor effect on the incidence of urban traffic crashes when compared to the systematic patterns of crash incidence associated with the built environment. To put the hazards posed by random error in perspective, our model indicates that a single strip commercial use would be expected to produce up to 6 times more crashes than one would expect to occur from one million miles of vehicle travel alone, and a single big box store up to 14 times more crashes (see Table 8). Two design-related environmental characteristics appear to explain the systematic patterns of crash incidence in urban areas: traffic conflicts and speed.

Table 7. Negative binomial regression model predicting vehicle-cyclist crashes occurring in the San Antonio-Bexar County study area, 2003–2007.

	Coefficient	z	p	95% Confidence interval	
Constant	0.161	2.43	0.015	0.031	0.291
Block group acreage	−0.000	−2.07	0.039	−0.001	−0.000
VMT (millions)	0.000	0.81	0.417	−0.001	0.001
3-leg intersections	0.002	1.18	0.237	−0.001	0.006
4-or-more-leg intersections	0.013	3.87	0.000	0.006	0.020
Net population density	0.000	0.11	0.913	−0.001	0.001
Freeway miles	−0.014	−0.62	0.536	−0.058	0.030
Arterial miles	0.066	1.90	0.057	−0.002	0.134
Strip commercial uses	0.017	5.29	0.000	0.011	0.024
Big box stores	0.033	1.62	0.104	−0.007	0.072
Pedestrian-scaled retail uses	−0.012	−1.38	0.168	−0.029	0.005
Log likelihood	−1,720.459				

Note: $N = 938$.

Table 8. Negative binomial regression models predicting crashes occurring in the San Antonio-Bexar County study area, 2003–2007.

	Motorist	Multiple-vehicle	Fixed object	Parked car	Vehicle-pedestrian	Vehicle-cyclist
Block group acreage	−0.000 ***	−0.000 ***	−0.000	0.000	−0.000 $^\psi$	−0.000 *
VMT (millions)	0.006 ***	0.005 ***	0.005 ***	0.001 **	0.001 *	0.000
3-leg intersections	0.000	0.000	−0.001	0.000	−0.004 *	0.002
4-or-more-leg intersections	0.006 *	0.006 *	0.009 ***	0.004	0.009 **	0.013 ***
Net population density	0.000	0.001	−0.000	0.001 $^\psi$	0.003 **	0.000
Freeway miles	−0.042 *	−0.053 **	−0.001	−0.037 *	−0.017	−0.014
Arterial miles	0.098 ***	0.114 ***	0.030	0.066 **	0.093 **	0.066 $^\psi$
Strip commercial uses	0.022 ***	0.024 ***	0.014 ***	0.021 ***	0.030 ***	0.017 ***
Big box stores	0.077 ***	0.084 ***	−0.011	0.114 ***	0.087 ***	0.033
Pedestrian-scaled retail uses	−0.031 ***	−0.035 ***	−0.010 $^\psi$	−0.012 $^\psi$	−0.016 $^\psi$	−0.012

$^\psi$ $p < .10$ $^*p < .05$ $^{**}p < .01$ $^{***}p < 0.01$

Traffic Conflicts

Practicing planners and engineers have long recognized that crashes are more likely to occur at intersections and driveways, which are locations where conflicting streams of traffic cross. This recognition has led to the development of countermeasures such as traffic signalization, roundabouts, and traffic circles, either to allocate right-of-way to specific traffic movements, or to reduce the number of conflict points between opposing streams of traffic, both effective means of reducing crash incidence (Ewing, 1999; Federal Highway Administration, 2000; 2004; Zein, Geddes, Hemsing, & Johnson, 1997). While the finding that traffic conflicts pose a crash risk seems obvious, it is important to emphasize that the traffic conflicts occurring at intersections create a common, systematic hazard for all road users, whether they are pedestrians, cyclists, or motorists.

Speed

The second systematic factor is vehicle speed. In urban environments, crash avoidance often requires drivers to be able to brake quickly in response to another roadway user entering the right-of-way. In such conditions, forgiving design elements like wide lanes, wide shoulders, and roadside clear zones may exacerbate crash risk, since all lead to higher vehicle operating speeds (Fitzpatrick, Carlson, Brewer, & Wooldridge, 2001; Gattis, 2000; Gattis & Watts, 1999; Ivan, Garrick, & Hanson, 2009; Naderi, Kweon, & Maghelal, 2008; Smith & Appleyard, 1981; Swift, Painter, & Goldstein, 2006). Higher operating speeds increase stopping sight distances (see Figure 6), making drivers less able to respond to the traffic conflicts created by other road users (American Association of State Highway and Transportation Officials, 2004).

As evidenced in the model results for freeways, roadways designed to accommodate higher operating speeds do not necessarily pose higher crash risks. Each mile of freeway was associated with a 5.3% decrease in crash incidence. Passive safety has historically attributed these crash reductions to the use of forgiving design elements, but we suggest an alternate explanation. Freeways use grade-separated interchanges that eliminate the traffic conflicts associated with driveways and intersections (see Figure 7). We believe that it is the elimination of traffic conflicts, rather than the presence of forgiving features, that is likely responsible for their safety benefits.

Our findings for arterials support this interpretation. While arterials are similarly designed to be forgiving, driveways, intersections, and their related traffic conflicts are located at grade. In this context, the use of forgiving design features simply encourages higher operating speeds. The result is that drivers are less prepared to
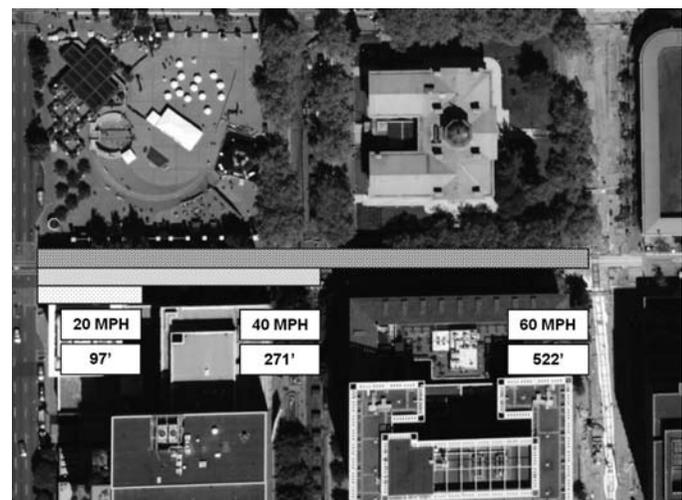

Figure 6. Higher speeds greatly increase stopping sight distance.

Source: Dumbaugh & Rae (2009).

Figure 7. Unlike arterials (top), freeways (bottom) are designed to eliminate the traffic conflicts occurring at driveways and intersections.

respond to the hazard posed by another road user entering the right-of-way, leading to significant increases in crash incidence. To put the relative hazard of these roadways in perspective, a motorist's risk of being involved in a crash on an arterial carrying 40,000 vehicles per day is nearly 438 times greater than would be expected from random error alone.[1]

The presence of pedestrian-scaled retail uses, on the other hand, was associated with significant reductions in multiple-vehicle, parked-car, fixed-object, and pedestrian crashes. We attribute this to reduced vehicle speeds. Street-oriented buildings create a sense of visual enclosure of the street, communicating to the driver that greater caution is warranted, and resulting in reductions in both vehicle speed and crash incidence (Dumbaugh, 2006; Osenbruggen, Pendharkar, & Ivan, 2001; Smith & Appleyard, 1981). These effects appear to be largely independent of a roadway's geometry. A recent study that compared roadway segments with identical geometric elements but different roadside characteristics found that the presence of urban roadside features such as sidewalks and buildings located adjacent to

the street were associated with speed reductions of up to 10 miles per hour (Ivan et al., 2009). In a novel study using a driving simulator, Naderi et al. (2008) found that adding trees along a suburban collector roadway made people perceive it to be safer and also reduced vehicle speeds by 3 miles per hour, on average.

Implications for Practice

These findings suggest that addressing urban crash incidence is more complicated than simply designing a roadway to be forgiving. As detailed above, urban crash incidence can be understood as a function of the latent tension between traffic conflicts and vehicle speeds. While future research is needed to tease out the precise nature of these relationships, the existing evidence on traffic safety makes it nonetheless possible to identify a general range of appropriate solutions (see Figure 8).

High Speed, Low Access: Freeways and Access Management

As demonstrated by the safety performance of freeways, speed is not a crash risk factor if it occurs in an environment designed to eliminate traffic conflicts. While operating speeds on freeways are often 55 miles per hour or greater, freeways report the lowest crash rates of any roadway type because they are designed to eliminate the driveways and intersections that create traffic conflicts.

A related approach, put into practice by safety-minded traffic engineers, is access management. Access management seeks to replicate the safety benefits associated with freeways by not only employing forgiving design features, but by emulating their limited-access characteristics as well. Access management requires consolidating or eliminating
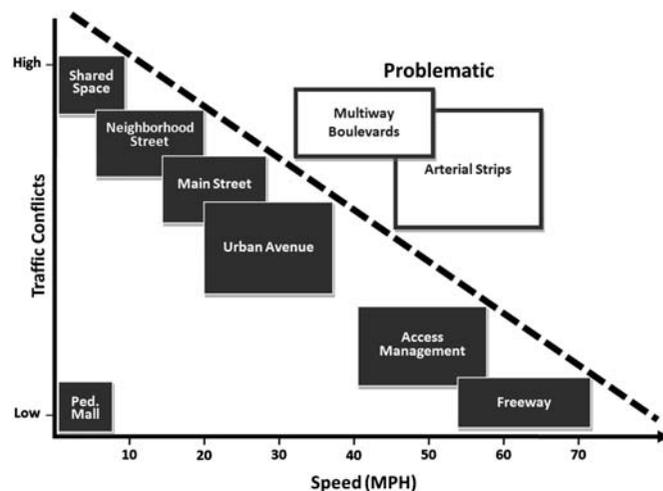

Figure 8. Design solutions for balancing traffic conflicts and speed.

driveways and intersections as well as installing a raised median to eliminate unprotected left-turning maneuvers. The net effect of these features is to reduce both traffic conflicts and crash incidence (Florida Department of Transportation, 2006; Transportation Research Board, 2003a). While access management is typically applied on streets with operating speeds between 40 and 55 miles per hour, it is essential to recognize that its safety benefits hinge on these streets' ability to mirror the limited-access characteristics of freeways (see Figure 9).

High Interaction, Low Speed: Woonerven, Shared Spaces, and Other Livability Strategies

At the opposite extreme are the strategies that seek to address traffic conflicts by forcing vehicles to travel at the speed of pedestrians. While such strategies range from conventional traffic-calming devices to Dutch woonerven ("living streets"), their common characteristic is that they create environments designed to enhance safety by forcing reductions in vehicle speeds (Ewing, 1999; Zein et al.,

Figure 9. Access-managed urban thoroughfares.

1997; see Figure 10). Speeds under 10 miles per hour not only ensure that drivers have time to brake in response to a potential traffic conflict, they also appear to make drivers more accommodating to other roadway users. A study of driver behavior in Maine found that when vehicles were

Figure 10. Shared spaces in and San Diego (top), St. Augustine (middle), and Philadelphia (bottom).

traveling at speeds of 10 miles per hour or less, drivers yielded to crossing pedestrians 100% of the time (Garder, 2001). In the United States, seeking to curb vehicle speeds is typically considered a strategy for enhancing livability rather than a strategy for improving roadway safety, yet such strategies are an established part of European design practice due to their demonstrated ability to reduce crash incidence (Skene, 1999).

Dutch and British designers have sought to extend the woonerf concept to higher-volume urban streets and intersections. This approach, known as "shared spaces," is based on the idea that at very low speeds, drivers will rely on social and behavioral cues from other road users in order to successfully navigate a space. While most of the safety information on shared spaces has been promotional (Shared Space Project Management Team, 2007), a before-and-after analysis of the safety effects of installing shared space features on an intersection initially carrying 1,400 vehicles during the peak hour (the equivalent of 34,000 vehicles per day) found that these features reduced the annual number of crashes from 8.3 to 1 per year while peak hour traffic volumes increased to 1,850 (Noordelijke Hogeschool Leeuwarden, 2007).

While woonerven and shared spaces violate passive safety theory, they are able to enhance safety by addressing systematic error. Traffic conflicts are an inherent part of urban environments, and meaningfully addressing their safety consequences requires vehicles to travel at accommodating speeds. U.S. designers have resisted these strategies because they are not forgiving in the conventional sense. Yet, it is important to recognize that crash severity is principally a function of speed; low speeds result in less severe crashes. A crash involving a pedestrian and a vehicle travelling less than 10 miles per hour would be extremely unlikely (Garder, 2001). Should one occur, it would also be extremely unlikely to lead to serious injury or death (Anderson et al., 1997). Similarly, should a driver randomly err at this speed and crash into a tree, bollard, or other street feature, it would be unlikely to do anything more than minor cosmetic damage to the vehicle. Low speeds are inherently forgiving.

Middle Ground: Residential Streets, Commercial Main Streets, and Urban Avenues

Freeways and woonerven represent the opposite poles of safe design. Most urban streets fall between these two extremes. While there is no shortage of guidance on the design of residential streets, commercial streets, and urban avenues (Duany Plater-Zyberk & Co., 2002; Ewing, 1996; Institute of Traffic Engineers, 2008; Nelessen, 1994; see Figure 11),

Figure 11. Two-lane commercial street (top) and four-lane urban avenue (bottom).

there is comparatively little research on the safety characteristics of different street configurations. Research on residential streets reports that wider rights-of-way lead to higher speeds (Smith & Appleyard, 1981) and increased crash incidence (Swift et al., 2006). Studies report that commercial main streets which have street-oriented buildings and aesthetic streetscape elements are substantially safer than

more conventional, forgiving designs (Ossenbruggen et al., 2001). Previous work by the lead author of this study found that main streets reported, on average, 40% fewer midblock crashes and 67% fewer roadside-related crashes than conventionally-designed arterial roads (Dumbaugh, 2006).

Considered broadly however, safe urban streets appear to share three characteristics. The first is the separation of

vehicle and pedestrian traffic, which on higher-volume streets may entail designating a formal pedestrian-way adjacent to the vehicle travelway, and which often includes features such as sidewalks and streetscaping. The second is the management of traffic conflicts at intersections, either by formally allocating right-of-way using stop signs or traffic signals, or by applying intersection control devices that reduce vehicle speeds and traffic conflicts, such as roundabouts and traffic circles. And the third characteristic is low to moderate vehicle speeds, typically in the range of 15 to 35 miles per hour. While these speeds are too high to allow pedestrians and motorists to actively share the right-of-way, they are nevertheless low enough to enable a driver to brake quickly in response to a motorist or pedestrian entering the right-of-way unexpectedly. It is important to explicitly observe that low speeds do not necessarily equate to low traffic volumes. A four-lane urban avenue for example, can carry more than 40,000 vehicles per day, depending on intersection control (Federal Highway Administration, 2000).

Western Europe's traffic safety performance is far better than that of the United States (Transportation Research Board, 2006; World Health Organization, 2004), suggesting their approach to addressing the tension between speed and traffic conflicts may be instructive. European design guidance limits design speeds to 50 kilometers per hour (31 miles per hour) on all roadways in developed areas or in areas where pedestrians and other sensitive road users are likely to be present (European Transport Safety Council, 1995). While research is needed to determine the specific design thresholds for balancing speed with traffic conflicts, 30–35 miles per hour is a plausible maximum value.

Problematic Streets: Urban Arterials and Multi-Lane Boulevards

Conventional arterial design attempts to accommodate speed and access simultaneously, with serious problems for safety, as the models in this article confirm. Urban designers have increasingly promoted multi-way boulevards as an alternative. Multi-way boulevards combine high-speed travel lanes in the center with lower-speed access lanes along the curb, with the design objective being to create a single roadway that accommodates both speed and access-related functions. The sole evaluation of the safety performance of multi-way boulevards found that they reported the same crash rates as conventionally-designed arterial thoroughfares (Jacobs, MacDonald, & Rofe, 2002). The results of this study suggest that the combination of speeds and traffic conflicts occurring along multi-way boulevards may be problematic, although additional research in this area is needed.

Conclusions

Most of the ongoing safety debate between pedestrian advocates and traffic engineers has focused on the relative desirability of designing urban roadways to be more or less forgiving of random driver error. Such debates have led both groups to ignore the more salient issue of systematic error. Our study finds that the factors associated with a vehicle crashing into a pedestrian or a cyclist are largely the same as those resulting in a crash with another vehicle: traffic conflicts and high vehicle speeds. We further found pedestrian-scaled retail uses to be associated with significant reductions in crashes involving multiple vehicles, parked cars, fixed objects, and pedestrians, a finding we attribute to the lower vehicle speeds common in pedestrian-oriented retail areas.

To date there has been little formal examination of how drivers may adapt their behaviors to the characteristics of the built environment, and none that has sought to correlate these behavioral adaptations to the incidence of crashes. The theory of passive safety has largely discouraged such considerations, treating driver error as a random occurrence that can be adequately addressed through the use of forgiving design features. Yet, as this study has sought to demonstrate, the majority of driver error in urban environments does not appear to be random; the characteristics of the built environment appear to play a profound role in producing error and creating traffic crashes.

We have sought to identify the environmental correlates of urban crash incidence and to infer their likely causes. Yet, correlation is not causation, and inference is not observation. Research is still needed that examines how drivers and other roadway users adapt their behaviors to the characteristics of the built environment, and how these behaviors may increase or reduce their exposure to crash risk. Further, our study only examined total crash incidence; injurious and fatal crashes may have unique characteristics that are distinct from non-injurious crashes. Future research should examine this possibility. Nevertheless, we hope that the results of this study will provide preliminary evidence and a theoretical framework for advancing understanding of urban crash incidence, and developing design that will enhance the safety of pedestrians, cyclists, and motorists alike.

David Sawicki and Amy Helling for their guidance, support, and excellent editorial recommendations on this and earlier works.

Note
1. We calculated this as the ratio of model-predicted crashes on an arterial carrying 40,000 VMT to model-predicted crashes on all roadways per million VMT (40,000 VMT/9.8%) / (1,000,000 VMT/0.56%).

References

American Association of State Highway and Transportation Officials. (1974). *Highway design and operational practices related to highway safety.* Washington, DC: Author.

American Association of State Highway and Transportation Officials. (2004). *A policy on geometric design of highways and streets* (5th ed.). Washington, DC: Author.

American Association of State Highway and Transportation Officials. (2006). *Roadside design guide* (3rd ed.). Washington, DC: Author.

Anderson, R. W. G., McLean, A.J., Farmer, M.J.B., Lee, H., & Brooks, C.G. (1997). Vehicle travel speeds and the incidence of fatal pedestrian crashes. *Accident Analysis and Prevention, 29*(5), 667–674.

Ben-Joseph, E. (1995). *Livability and safety of suburban street patterns: A comparative study.* (Working Paper 642). Berkeley, CA: Institute of Urban and Regional Development, University of California, Berkeley.

Box, P. C. (2004). Curb-parking problems: Overview. *Journal of Transportation Engineering, 130*(1), 1–5.

Duany Plater-Zyberk and Co. (2002). *The lexicon of the new urbanism, Version 3.2.* Miami, FL: Author.

Dumbaugh, E. (2005a). Safe streets, livable streets. *Journal of the American Planning Association, 71*(3), 283–298.

Dumbaugh, E. (2005b). *Safe streets, livable streets: A positive approach to urban roadside design.* Doctoral thesis, Department of Civil and Environmental Engineering, Georgia Institute of Technology, Atlanta, GA.

Dumbaugh, E. (2006). The design of safe urban roadsides. *Transportation Research Record, 1961,* 74–82.

Dumbaugh, E., & Rae, R. (2009). Safe urban form: Revisiting the relationship between community design and traffic safety. *Journal of the American Planning Association, 75*(3), 309–329.

European Transport Safety Council. (1995). *Reducing traffic injuries resulting from excess and inappropriate speed.* Brussels, Belgium: Author.

Ernst, M. (2004). *Mean streets: How far have we come?* Washington, DC: Surface Transportation Policy Project.

Ewing, R. (1996). *Pedestrian and transit friendly design.* Tallahassee, FL: Public Transit Office, Florida Department of Transportation.

Ewing, R. (1999). *Traffic calming state-of-the-practice.* Washington, DC: Institute of Transportation Engineers.

Ewing, R., & Cervero, R. (2001). Travel and the built environment: A synthesis. *Transportation Research Record, 1780,* 87–114.

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

Federal Highway Administration. (2000). *Roundabouts: An informational guide.* Washington, DC: U.S. Department of Transportation.

Federal Highway Administration. (2004). *Signalized intersections: An informational guide.* Washington, DC: U.S. Department of Transportation.

Fitzpatrick, K., Carlson, P., Brewer, M., & Wooldridge, M. (2001). Design factors that affect driver speed on suburban streets. *Transportation Research Record, 1751,* 18–25.

Florida Department of Transportation. (2006). *Median handbook.* Tallahassee, FL: Florida Department of Transportation.

Garder, P. E. (2001). *Pedestrian safety in Maine.* Augusta, ME: Maine Department of Transportation.

Garder, P. E. (2004). The impact of speed and other variables on pedestrian safety in Maine. *Accident Analysis and Prevention, 36*(4), 533–542.

Gattis, J. L. (2000). Urban street cross section and speed issues. *Transportation Research E-Circular #E-C019.* Washington, DC: Transportation Research Board. Retrieved October 21, 2010, from http://onlinepubs.trb.org/onlinepub/circulars/ec019/Ec019_d3.pdf

Gattis, J. L., & Watts, A. (1999). Urban street speed related to width and functional class. *Journal of Transportation Engineering, 125*(3), 193–200.

Hadayeghi, A., Shalaby, A. S., & Persaud, B. N. (2003). Macrolevel accident prediction models for evaluating safety of urban transportation systems. *Transportation Research Record, 1840,* 87–95.

Hadayeghi, A., Shalaby, A. S., Persaud, B. N., & Cheung, C. (2006). Temporal transferability and updating of zonal level accident prediction models. *Accident Analysis and Prevention, 38*(3), 579–589.

Hadi, M. A., Aruldhas, J., Chow, L. F., & Wattleworth, J. A. (1995). Estimating safety effects of cross-section design for various highway types using negative binomial regression. *Transportation Research Record, 1500,* 169–177.

Hauer, E. (1999). *Safety in geometric design standards.* Retrieved January 11, 2005, from http://members.rogers.com/hauer/Pubs/09Safety%20in%20Geometric%20Design.pdf

Hauer, E., Council, F. M., & Mohammedshah, Y. (2004). Safety models for urban four-lane undivided road segments. *Transportation Research Record, 1897,* 96–105.

Hilbe, J. M. (2007). *Negative binomial regression.* Cambridge, UK: Cambridge University Press.

Humphreys, J. R., Box, P. C., Sullivan, T. D., & Wheeler, D. J. (1978). *Safety aspects of curb parking.* (Report No. FHWA-RD-79-76). Washington, DC: Federal Highway Administration.

Institute of Transportation Engineers. (2008). *Designing walkable urban thoroughfares: A context sensitive approach.* Washington, DC: Author.

Ivan, J. N., Garrick, N. W., & Hanson, G. (2009). *Designing roads that guide drivers to choose safer speeds.* Rocky Hill, CT: Connecticut Department of Transportation. Retrieved July 22, 2010, from http://www.ct.gov/dot/LIB/dot/documents/dresearch/JHR_09-321_JH_04-6.pdf

Ivan, J. N., Wang, C., & Bernardo, N. R. (2000). Explaining two-lane highway crash rates using land use and hourly exposure. *Accident Analysis & Prevention, 32*(6), 787–795.

Jacobs, A. B., MacDonald, E., & Rofe, Y. (2003). *The boulevard book: History, evolution, design of multi-way boulevards.* Cambridge, MA: MIT Press.

Ladrón de Guevara, F., Washington, S. P., & Oh, J. (2004). Forecasting travel crashes at the planning levels: Simultaneous negative binomial crash model applied in Tucson, Arizona. *Transportation Research Record, 1897,* 191–199.

Leaf, W. A., & Preusser, D. F. (1998). *Literature review on vehicle travel speeds and pedestrian injuries.* Washington, DC: National Highway Traffic Safety Administration, U.S. Department of Transportation.

Lee, J., & Mannering, F. (1999). *Analysis of roadside accident frequency and severity and roadside safety management.* Olympia, WA: Washington State Department of Transportation.

Loukaitou-Sideris, A., Liggett, R., & Sung, H. G. (2007). Death on the crosswalk: A study of pedestrian-automobile collisions in Los Angeles. *Journal of Planning Education and Research, 26*(3), 338–351.

Lovegrove, G. R., & Sayed, T. (2006). Macro-level collision prediction models for evaluating neighbourhood traffic safety. *Canadian Journal of Civil Engineering, 33*(5), 609–621.

Marks, H. (1957). Subdividing for traffic safety. *Traffic Quarterly, 11*(3), 308–325.

Maze, T. H., Sax, C., & Hawkins, M. (2008). *Clear zone–A synthesis of practice and an evaluation of the benefits of meeting the 10-ft clear zone goal on urban streets.* Ames, IA: Center for Transportation Research and Education.

Miles-Doan, R., & Thompson, G. (1999). The planning profession and pedestrian safety: Lessons from Orlando. *Journal of Planning Education and Research, 18*(3), 211–220.

Milton, J., & Mannering, F. (1998). The relationship among highway geometrics, traffic-related elements and motor-vehicle accident frequencies. *Transportation, 25*(4), 395–413.

Naderi, J. R. (2003). *Landscape design in the clear zone: The effects of landscape variables on pedestrian health and driver safety* (Paper included on the 2003 Transportation Research Board Annual Conference Proceedings CD-ROM). Washington, DC: Transportation Research Board.

Naderi, J. R., Kweon, B. S., & Maghelal, P. (2008). The street tree effect and driver safety. *ITE Journal on the Web, 78*(2), 69–73.

National Highway Traffic Safety Administration (2006). *Traffic safety facts.* Washington, DC: U.S. Department of Transportation.

Nelessen, A. C. (1994). *Visions for a new American dream: Process, principles and an ordinance to plan and design small communities.* Chicago, IL: Planners Press.

Noland, R. B., & Oh, L. (2004). The effect of infrastructure and demographic change on traffic-related fatalities and crashes: A case study of Illinois county-level data. *Accident Analysis and Prevention, 36*(4), 525–532.

Noordelijke Hogeschool Leeuwarden. (2007). *The Laweiplein: Evaluation of the reconstruction into a square with roundabout.* Leeuwarden, The Netherlands: Author.

Ossenbruggen, P. J., Pendharkar, J., & Ivan, J. (2001). Roadway safety in rural and small urbanized areas. *Accident Analysis and Prevention, 33*(4), 485–498.

Potts, I. B., Harwood, D. F., & Richard, K. R. (2007). *Relationship of lane width to safety for urban and suburban arterials.* (Paper included on the Transportation Research Board 2007 Annual Meeting CD-ROM.) Washington, DC: Transportation Research Board.

San Antonio-Bexar County Metropolitan Planning Organization (2009). *Mobility 2035.* San Antonio, TX: Author.

Shared Space Project Management Team. (2007). No accidents after road conversion in Norrkopping. *Shared Space, 6*(3). Retrieved August 9, 2010, from http://www.shared-space.org/files/18445/ nieuwsbriefSS.06.6.pdf

Skene, M. (1999). *Traffic calming on arterial roadways?* (Institute of Transportation Engineers Compendium of Technical Papers.) Washington, DC: Institute of Transportation Engineers.

Smith, D. T., & Appleyard, D. (1981). *Improving the residential street environment.* (Report FHWA/RD-81/031). Washington DC: Federal Highway Administration, U.S. Department of Transportation.

Swift, P., Painter, D., & Goldstein, M. (2006). *Residential street typology and injury accident frequency.* Retrieved July 22, 2010, from http://www.newurbanengineering.com

Transportation Research Board. (2003a). *Access management manual.* Washington, DC: National Research Council.

Transportation Research Board. (2003b). *A guide for addressing collisions with trees in hazardous locations.* Washington, DC: National Research Council.

Transportation Research Board. (2003c). *A guide for addressing run-off-road collisions.* Washington, DC: National Research Council.

Transportation Research Board. (2006). *Critical issues in transportation.* Washington, DC: National Research Council.

Turner, D. S., & Mansfield, E. S. (1990). Urban trees and roadside safety. *Journal of Transportation Engineering, 16*(1), 90–103.

Weingroff, R. F. (2003). *President Dwight D. Eisenhower and the federal role in highway safety.* Retrieved January 11, 2005, from http://www.fhwa.dot.gov/infrastructure/safetypr.htm

World Health Organization. (2004). *World report on road traffic injury prevention.* Geneva, Switzerland: Author.

Zegeer, C. V., Deen, R. C., & Mayes, J. G. (1981). Effects of lane and shoulder widths on accident reduction on rural, two-lane roads. *Transportation Research Record, 806,* 33–42.

Zegeer, C. V., Hummer, J., Reinfurt, D., Herf, L., & Huner, W. (1988). Safety effects of cross-section design for two-lane roads. *Transportation Research Record, 1195,* 20–32.

Zein, S. R., Geddes, E., Hemsing, S., & Johnson, M. (1997). Safety benefits of traffic calming. *Transportation Research Record, 1578,* 3–10.