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Examining the Design and Developmental Factors Associated with Crashes Involving Pedestrians, Cyclists, and Motorists in Urban Environments

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Abstract

Using a parcel-level database of crash incidence and urban form developed for the San Antonio-Bexar County metropolitan region, this study examined how urban form-related variables affect the incidence of crashes involving pedestrians, bicyclists, and motorists. Arterial thoroughfares, strip commercial uses, and big box stores—which involve design features expressly intended to support automobile travel—were found to be associated with significant increases in crashes involving pedestrians, bicyclists, and motorists alike. Population density was found to be associated with increased crash incidence among pedestrians, although this is likely a function of increased crash exposure due to the higher levels of pedestrian activity occurring in higher-density environments. The presence of pedestrian-scaled commercial and retail uses, which is likewise associated with increased pedestrian travel, was nonetheless found to be associated with statistically significant reductions in the incidence of multiple-vehicle, fixed-object, and pedestrian crashes. Given that the developmental risk factors that affect pedestrians, cyclists, and motorists proved to be largely the same, this report outlines potential strategies for addressing urban crash incidence in a comprehensive, multimodal manner.

Executive Summary

While the use of high design speeds is viewed as being desirable from the perspective of motorist safety, the same cannot be said for the safety of pedestrians and bicyclists. Higher vehicle speeds result in an increase in both the frequency and severity of crashes involving pedestrians, and examinations of the spatial distribution of pedestrian crashes find them to cluster along urban arterials, precisely the category of roadways designed with the forgiving roadway features intended to enhance the safety of motorists. 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 the use of narrow travel lanes and the inclusion of trees and other streetscape elements between the sidewalk and the vehicle travelway.

While these two perspectives are certainly in conflict, the following question remains: Is motorist safety fundamentally at odds with the safety of pedestrians and cyclists? Such a view emerged from the prevailing theory of safe design, known alternatively as “passive safety” or “forgiving design.” The guiding design idea is that drivers are prone to error and that safety can be best addressed by ensuring that roadways are designed to be forgiving of these errors when they occur. As such, error can be regarded as a purely random phenomenon attributed to innate driver deficiencies and thus something that can be addressed through the uniform application of forgiving design practices.

Using a parcel-level database of crash incidence and urban form developed for the San Antonio-Bexar County metropolitan region, this study examined how urban form-related variables affect the incidence of crashes involving pedestrians, bicyclists, and motorists. While vehicle miles traveled and its proxy, random error, were associated with an increase in crashes involving motorists and pedestrians, its association was comparatively weak when compared against the effects of the characteristics of the built environment. Arterial roadways, four-leg intersections, strip commercial uses, and big box stores proved to be major risk factors, while pedestrian-scaled retail uses were associated with significant reductions in crash incidence. The results suggest that urban traffic safety is far more complicated than simply designing a roadway to be forgiving; addressing traffic safety requires addressing the underlying behavioral patterns that result in traffic crashes, patterns of behavior that may be potentially exacerbated by the presence of forgiving design elements.

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 to random driver error. Such debates have led both groups to ignore the more salient issue of systematic error. This study found that the environmental 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, namely a combination of traffic conflicts and vehicle speed. Conversely, the presence of pedestrian-scaled retail uses, which encourage lower operating speeds, was found to be associated with significant reductions in crashes involving multiple vehicles, parked cars, fixed objects, and pedestrians.

The results of this study suggest a need to address the systematic factors that influence crash risk, rather than employing a widespread application of forgiving design features. The majority of urban crash incidence can be best understood as a function of systematic error resulting from the tension between vehicle speeds and traffic conflicts. High-speed roadways can be safe if traffic conflicts are eliminated, as is done along interstates and fully access-managed roads. Likewise, traffic conflicts are not a problem if vehicle speeds are kept low, as is done along woonerven and shared-space streets. The problem lies in those roadways that attempt to combine the functions, as is done along most urban and suburban arterials. In such environments, there is a need to balance the tension between speed and access by separating users through design of user-specific rights-of-way, as well as through the allocation of time and space for safe crossing. The street-avenue-boulevard framework, developed as part of a collaborative effort between the Institute of Transportation Engineers and the Congress for the New Urbanism, appears to be an especially fruitful means for creating the necessary balance.

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Introduction

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 and Highway 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, clear zones, sight distance, and other high-speed design elements.

While high design speeds are viewed as being desirable from the perspective of motorist safety, the same cannot be said for the safety of pedestrians and bicyclists. Higher vehicle speeds result in an increase in both the frequency and severity of crashes involving pedestrians (Anderson et al., 1997; Durkin & Pheby, 1992; Garder, 2001, 2004; Leaf & Preusser, 1998), and examinations of the spatial distribution of pedestrian crashes find them to 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 the use of 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 following 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, a problem emerging from the current traffic safety theory. This 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 address traffic safety issues. 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 for addressing 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, the use of forgiving design features, such as wide lanes, shoulders, and roadside clear zones, tend to be associated with reduced crash incidence. This evidence has been interpreted as meaning that the use of forgiving design features enhances safety in other environments as well, regardless of a roadway's traffic function or developmental context (Dumbaugh, 2005; Weingroff, 2003).

Such an assumption would pose no particular problem if the factors that reduce 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 found that widening lanes on urban surface streets was associated with a reduction in crash incidence (Hadi et al., 1995), most recent research reported that wider lanes on urban streets had little or no safety benefit, at least to the extent that safety was measured in terms of empirical observations of crash incidence (Hauer, 1999; Hauer, Council, & Mohammedshah, 2004; Milton & Mannering, 1998; Potts, Harwood, & Richard, 2007). Likewise, while some studies reported safety benefits associated with widening shoulders and clear zones (Noland & Oh, 2004), most found their safety effects to be either minimal at best (Maze, Sax, & Hawkins, 2008), or to be associated with increases in crash incidence (Dumbaugh, 2006; Hauer, Council, & Mohammedshah, 2004; Ivan, Wang, & Bernardo, 2000; Lee & Mannering, 1999). Conversely, a before-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).

Despite the growing prevalence of these findings, they have received little substantive attention from either the professional or the research communities. As noted in a recent review:

> Many studies that find unexpected or unconventional results tend to dismiss these results as aberrations within their dataset and have not examined the issue in further detail. . . . 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 passive safety, 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 is designed to be adequately forgiving.

This approach is highly appealing from a design perspective since it eliminates the need to address or even examine the complex series of behavioral or contextual factors that may lead to a crash event. If driver behavior can be assumed to be constant, then *ceteris paribus*, one would expect forgiving design features to enhance safety; a roadway designed to be forgiving for a high-speed, extreme driving event should also be safe for lesser, more typical driving events.

Yet, regardless of how appealing this perspective may be, it fails to hold 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 that 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 that may have little or nothing to do with a roadway's geometry.

2

Examining the Built Environment and Crash Incidence: Methods and Variables

While several earlier works asserted that the anomalous findings in the urban traffic safety literature are likely attributable to systematic error (Dumbaugh, 2005, 2006; Dumbaugh & Rae, 2009), few studies have examined the relationship between the built environment and crash incidence, and none have conducted a comparative examination of its effects on different crash types. As such, we believed an examination into the environmental factors associated with crash incidence would be helpful for shedding light on the anomalies that have emerged in the existing traffic safety literature, as well as for advancing contemporary safety theory, which has remained largely unchanged for more than half a century.

To do so, we developed a geographic information system (GIS)-based database of crash incidence and urban form for the San Antonio-Bexar County metropolitan region. This database consists of 5 years (2003-2007) of crash data supplied by the Texas Department of Transportation (TxDOT), parcel-level land use information supplied by the Bexar County Tax Appraisal District, street network information acquired from the San Antonio-Bexar County Metropolitan Planning Organization, traffic volume information obtained from the City of San Antonio and TxDOT, and demographic information acquired from the US Census. Collectively, these data allowed us to examine the spatial distribution of crashes in conjunction with both traffic volumes and the characteristics of the built environment.

Examining the environmental correlates of crash incidence requires several methodological decisions. The first entails determining an appropriate unit of analysis. Most conventional safety studies focus on crash incidence at the level of the street segment. This is based on the assumption that roadway traffic volumes and geometric features are sufficient for understanding variations in urban crash incidence. This study, however, sought to understand whether the characteristics of the built environment may result in systematic patterns of crash incidence, requiring us to capture information on the developmental context in which crashes occur. To do so, we opted to analyze small geographic areas rather than individual street segments.

Focusing on small geographic areas for our unit of analysis required operational decisions about how we were to delimit the boundaries of these areas, as well as how we were to deal with information occurring along their edges. Because we wanted to incorporate accurate population-level information 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 and addressed any micro-level spatial variation that may have existed in the definition of our GIS layers, we ran a 200-ft buffer around each block group (roughly the width of a fully designed principal arterial) and aggregated information on crashes and traffic volumes to the buffer area.

We sought to focus on crash incidence in urban environments. While we considered a number of measures for determining what constituted an urban block group, the most straightforward means of doing so proved to be simply following the region's highway infrastructure. Thus, the study area for this analysis ultimately consisted of the 938 block groups contained within Loop 1604 to the north and I-410 to the south (see Figure 1). The majority of the region's surface transportation network was contained within our study area, as were 1.2 million of the 1.4 million people living in Bexar County in 2000.

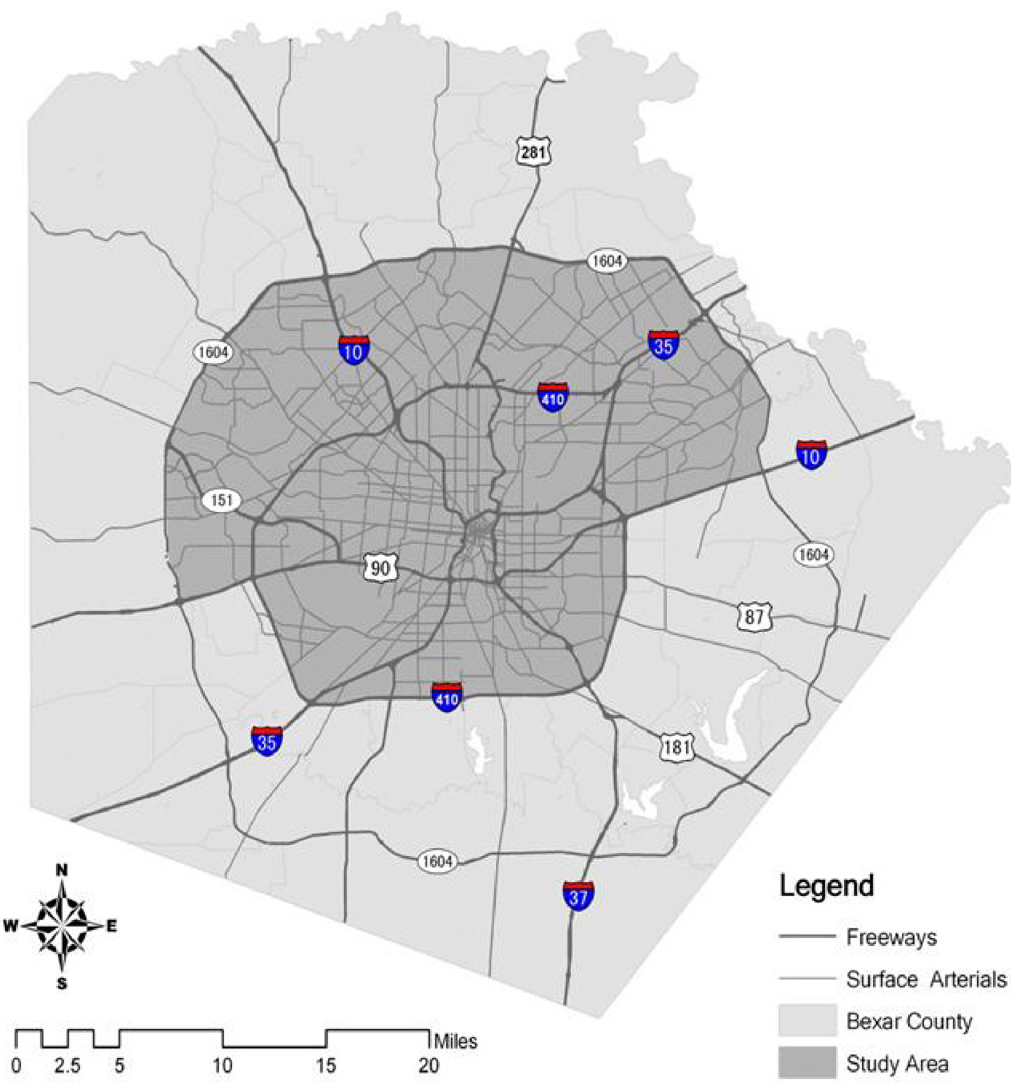

Figure 1: San Antonio-Bexar County Study Area.

Dependent Variables

A total of 268,000 crashes occurred in the study area between 2003 and 2007. Of these, 264,000 involved motorists, including 217,000 that involved two moving vehicles, 40,000 that involved a parked car, and 3,000 that involved a fixed object, such as a utility pole or a tree. An additional 3,100 crashes involved a motorist crashing into a pedestrian, and more than 1,000 crashes involved a vehicle colliding with a cyclist (see Table 1). We aggregated each of these crash types to the block group level. Our dependent variables were defined as follows:

- Motorist crashes—crashes involving only one or more motorists (i.e., no pedestrians or cyclists).
- Multiple-vehicle crashes—crashes involving two motor vehicles in transport.
- Fixed-object crashes—crashes involving a vehicle crashing into a fixed object, such as a roadside tree, mailbox, or utility pole.
- Parked-car crashes—crashes that involved one or more parked cars.
- Vehicle-pedestrian crashes—crashes involving a vehicle crashing into one or more pedestrians.
- Vehicle-cyclist crashes—crashes involving a vehicle crashing into a cyclist.

Table 1: Crashes Occurring within the San Antonio-Bexar County Study Area.

Crash Type	Crashes (2003-2007)
Motorist	**263,809**
Multiple Vehicle	*217,028*
Parked Car	*40,300*
Fixed Object	*3,077*
Motorist—Other	*3,404*
Pedestrian	**3,108**
Cyclist	**1,022**
Total	**267,939**

Independent and Control Variables

To understand whether developmental factors may be associated with urban crash incidence, we included the following variables in our analysis:

- Block group acreage: Census block groups vary in size, with larger block groups typically located in less densely populated areas located at the periphery of a 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 traveled (VMT, in millions): Passive safety asserts that drivers will randomly commit crash-inducing errors as a function of the amount of driving they do. To account for these effects, we developed estimates of VMT at the block group level. The Texas Department of Transportation 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-ft buffer around each block group in order to include all related roadways in the analysis. 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 the value by 365 days and 5 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 1 million. The resulting value was block group level VMT, in millions.

- Net population density: Several studies have identified higher population densities as being a crash risk factor (Hadayeghi, Shalaby, & Persaud, 2003; Hadayeghi et al., 2006; Lovegrove & Sayed, 2006; Ladrón de Guevara, Washington, & Oh, 2004). 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. Net population density was measured as the total population of the block group divided by the total acreage of land dedicated to residential use.
- Intersection counts: 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 (Marks, 1957; Ben-Joseph, 1995), we modeled three-leg intersections and four-or-more-leg intersections as separate variables. These variables were simply the count of the number of intersections of each type within the block group.
- Freeway mileage: Freeways are high-speed, limited-access facilities that are 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 was 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 was the sum of the centerline miles of roadways classified as a surface arterial located 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 by 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 was the sum of commercial and retail uses located in a block group that were located adjacent to an arterial.

- Big box stores: Big box stores are major trip attractions that can draw traffic from a large geographic area. Given their size, they also generate a good deal of off-street traffic, as vehicles circulate through the parcel in search of parking and as pedestrians attempt to walk from their cars to the building. For this study, a big box store was identified as a retail use comprised of 50,000 sq ft or more, and having a floor-area ratio (FAR) of 0.4 or less (i.e., more surface parking than building area). This variable was the sum of these uses within a block group's boundaries.
- Pedestrian-scaled retail uses: Pedestrian advocates generally encourage the adoption of more traditional retail configurations, where buildings are aligned to the street rather than set back by a large parking lot (see Figure 2). Pedestrian-scaled retail uses were defined in this study as a commercial or retail use of 20,000 sq ft or less, but developed at FARs of 1 or greater (i.e., buildings that fronted the street or otherwise had little undeveloped surface space on the lot). The resulting variable was the count of such uses in a neighborhood and served as a rough indicator of a neighborhood's urbanism.

Model Specification and Reporting

Because the dependent variables were count data that were overdispersed (i.e., the variance was greater than the mean), negative binomial regression models were used for the following analysis. The model coefficients reported the percentage change of the dependent variable that occurred with each 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 of travel they do, and as shown in Table 2, VMT had a positive and significant relationship with motorist crash incidence. Yet, the magnitude of the effect of VMT was slight when compared against the characteristics of the built environment. Crashes involving motorists increased by only about 0.56% for every million miles of travel. Given that the region as a whole generates only about 38 million miles of vehicle travel each year (San Antonio-Bexar County Metropolitan Planning Organization, 2009), doubling the region's VMT would not be expected to have much of an effect on crash incidence. By contrast, each strip commercial use was associated with a 2.2% increase in motorist crashes, and each big box store was associated with a 7.7% crash incidence. Stated another way, each strip commercial use had about four times the effect on crash incidence as a million miles of vehicle travel, and each big box store had roughly 14 times the effect.

Figure 2: Pedestrian-Scaled Retail Uses in San Antonio.

Table 2: Motorist Crash Model.

Motorist	Coef.	*z*	*p*	95% Conf. Interval	
Block group acreage	-0.00037	-3.31	0.001	-0.0006	-0.00015
VMT (millions)	0.00561	13.87	0.000	0.004813	0.006397
# of three-leg intersections	0.000129	0.09	0.925	-0.00254	0.002796
# of four-or-more-leg intersections	0.006123	2.46	0.014	0.001245	0.011001
Net population density	0.000415	0.69	0.492	-0.00077	0.001598
Freeway miles	-0.04192	-2.49	0.013	-0.0749	-0.00895
Arterial miles	0.09795	3.58	0.000	0.044283	0.151617
# of strip commercial uses	0.022054	8.70	0.000	0.017088	0.027021
# of big box stores	0.076872	4.49	0.000	0.04328	0.110464
# of pedestrian-scaled retail uses	-0.03073	-4.24	0.000	-0.04496	-0.01651
Constant	5.006456	104.97	0.000	4.912972	5.099939
Log likelihood = -6307.1844					
N = 938					

Street types mattered as well. Freeways, which employ forgiving design features, were associated with a 4.2% decrease in the number of crashes involving motorists, a finding expected under conventional traffic safety theory. Yet, arterials, which are similarly designed to be forgiving, were associated with a 9.8% *increase* in motorist crashes.

Four-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 1 million miles of vehicle travel. Pedestrian-scaled retail uses, which are often unforgiving to motorists, were associated with a 3% *reduction* in crashes involving motorists. Neither density nor three-leg intersections had a statistically meaningful relationship with crash incidence, however.

While the model results for VMT confirmed that at least some portion of urban crashes may be attributable to random error, 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, may mask the underlying behavioral patterns that explain these findings. In the models discussed below, we examined 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 crashes is largely similar to the motorist crash model. VMT again had a positive relationship with crash incidence, with multiple-vehicle crashes increasing by about 0.55% for every million 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 0.56% 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 a 2.4% and 8.4% increase in these crashes, respectively. Each pedestrian-scaled retail use, on the other hand, was associated with a 3.5% reduction in multiple-vehicle crashes.

Table 3: Multiple-Vehicle Crash Model.

Multiple Vehicle	Coef.	*z*	*p*	95% Conf. Interval	
Block group acreage	-0.0004	-3.3	0.001	-0.00064	-0.00016
VMT (millions)	0.005482	12.62	0.000	0.00463	0.006333
# of three-leg intersections	0.000054	0.04	0.970	-0.00279	0.002896
# of four-or-more-leg intersections	0.005641	2.11	0.035	0.000404	0.010877
Net population density	0.000569	0.86	0.392	-0.00074	0.001874
Freeway miles	-0.05287	-2.91	0.004	-0.0885	-0.01724
Arterial miles	0.113844	3.87	0.000	0.056155	0.171533
# of strip commercial uses	0.023552	8.62	0.000	0.018196	0.028908
# of big box stores	0.084139	4.58	0.000	0.048157	0.12012
# of pedestrian-scaled retail uses	-0.03518	-4.48	0.000	-0.05057	-0.01979
Constant	4.985296	97.53	0.000	4.88511	5.085482
Log likelihood = -6327.0837					
N = 938					

Freeways and arterials 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 their design characteristics. Freeways employ grade-separated interchanges to separate conflicting movements between opposing streams of traffic, thereby eliminating a major source of crash risk between multiple vehicles. 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, neither population density nor three-leg intersections were found 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 found T-intersections to be safer than four-way intersections in that they produce fewer intersection conflict points and terminate street segments, which in turn encourages reductions in vehicle speed (Ben-Joseph, 1995; Dumbaugh & Rae, 2009; Marks, 1957). As shown in Figure 3, three-leg intersections produce only nine conflict points between vehicles, compared to 24 for a four-leg intersection.

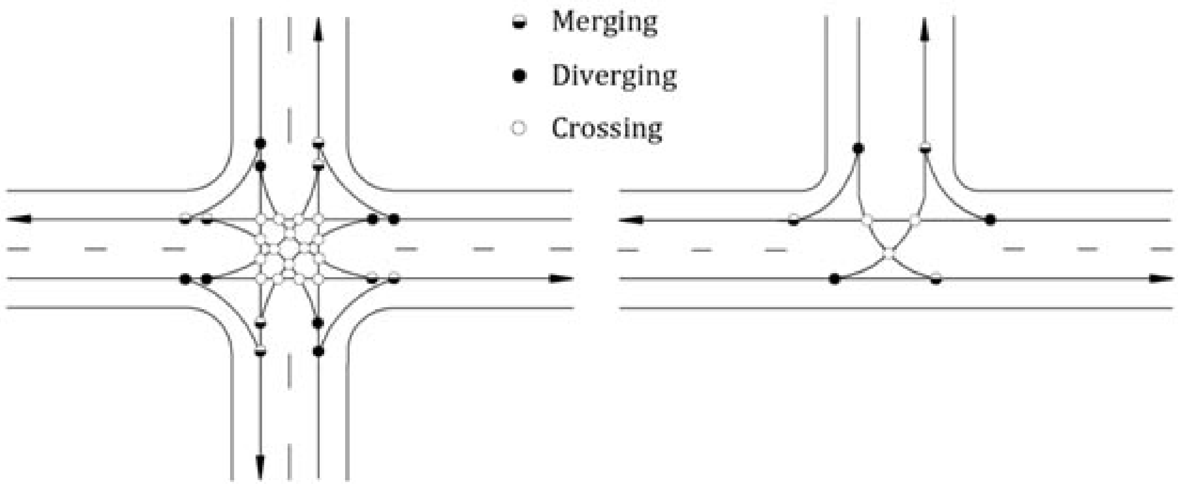

Figure 3: Conflict Points at Four-Leg and Three-Leg Intersections.

Crashes Involving Fixed Objects

Fixed-object crashes are of particular concern because of their severity. While they account for only about 15% of the crashes that occur in any given year, fixed objects are associated with nearly a third of the nation's annual traffic fatalities (National Highway Traffic Safety Administration [NHTSA], 2006). A good deal of design guidance exists on how to mitigate these crashes, principally by recommending the adoption of wide shoulders and clear zones (AASHTO, 2006; Transportation Research Board [TRB], 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 (Hauer, Council, & Mohammedshah, 2004; Lee & Mannering, 1999; Dumbaugh, 2005, 2006; Maze, Sax, & Hawkins, 2008).[1] 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.

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 4). Eighty-three percent of the identified fixed-object crash locations (65% of the total, since the objects involved in some locations could not be precisely identified) occurred behind a driveway or intersection (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 an intersection than at a non-intersection location, and that there was little safety benefit associated with widening fixed-object offsets beyond 5 ft (Maze, Sax, & Hawkins, 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 a significant increase in the incidence of fixed-object crashes, with each additional four-leg intersection corresponding to a 0.88% increase in fixed-object crashes. The presence of strip commercial uses, which typically have direct driveway access to the arterial system and are thus locations where turning maneuvers occur, were 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 result was again inconsequential when compared to the effects of intersections and strip commercial uses, with fixed-object crashes increasing by only 0.5% for every million vehicle miles of travel.

Figure 4: Urban Fixed-Object Crashes Are Disproportionately Associated with Turning Maneuvers at Intersections
(Source: Dumbaugh, 2006).

While arterials were positively associated with increases in fixed-object crashes, this variable only entered at the 83% confidence level, suggesting that the turning maneuvers occurring at driveways and side streets, rather than the arterials themselves, are the problem. By contrast, pedestrian-scaled retail uses were associated with significant *reductions* in the incidence of fixed-object crashes. Each pedestrian-scaled retail use was associated with a 1.2% reduction in fixed-object crashes, a finding likely attributable to the lower operating speeds found in these environments, which would appear to encourage drivers to undertake turning maneuvers at lower speeds, thereby reducing the likelihood of a turn-related encroachment onto the roadside.

Table 4: Fixed-Object Crash Model.

Fixed Object	Coef.	z	p	95% Conf. Interval	
Block group acreage	-0.00011	-1.13	0.259	-0.00029	0.000078
VMT (millions)	0.00526	15.88	0.000	0.004611	0.005909
# of three-leg intersections	-0.00053	-0.46	0.643	-0.00278	0.001715
# of four-or-more-leg intersections	0.008835	4.34	0.000	0.004846	0.012824
Net population density	-0.00026	-0.63	0.526	-0.00106	0.00054
Freeway miles	-0.00065	-0.05	0.963	-0.02806	0.02676
Arterial miles	0.029805	1.36	0.173	-0.01308	0.07269
# of strip commercial uses	0.013975	6.9	0.000	0.010007	0.017943
# of big box stores	-0.01063	-0.78	0.433	-0.03719	0.015926
# of pedestrian-scaled retail uses	-0.01007	-1.72	0.086	-0.02156	0.00142
Constant	3.037651	77.58	0.000	2.960903	3.114398
Log likelihood = -4233.4239					
N = 938					

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 268,000 crashes. To date, most of the safety discussion surrounding parked cars has focused on the potential crash risk hazard posed by the presence of on-street parking, a hazard evidenced in descriptive statistics reporting that locations with on-street parking often report a large number of crashes involving parked cars (Box, 2004; Humphreys et al., 1978). Nonetheless, a recent review of the subject was unable to find a single study that conducted a matched-pair comparison of street segments with and without on-street parking, nor a before-after study examining changes in crash incidence occurring as a result of eliminating on-street parking (Ewing & Dumbaugh, 2009).

Table 5 presents the results of the parked-car crash model. Crashes involving a parked car increased by about 0.1% for every million miles of vehicle travel. 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. These findings are unsurprising, as these uses include on-site 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 5: Parked-Car Crash Model.

Parked Car	Coef.	z	p	95% Conf. Interval	
Block group acreage	0.0000698	0.56	0.572	-0.00017	0.000312
VMT (millions)	0.001004	2.79	0.005	0.000298	0.001711
# of three-leg intersections	0.000204	0.16	0.875	-0.00235	0.002757
# of four-or-more-leg intersections	0.003807	1.6	0.111	-0.00087	0.008484
Net population density	0.001156	1.79	0.074	-0.00011	0.002423
Freeway miles	-0.03738	-2.28	0.022	-0.06947	-0.0053
Arterial miles	0.066383	2.65	0.008	0.017198	0.115568
# of strip commercial uses	0.020568	8.62	0.000	0.015894	0.025243
# of big box stores	0.114275	7.17	0.000	0.083057	0.145493
# of pedestrian-scaled retail uses	-0.01183	-1.76	0.078	-0.02499	0.001329
Constant	3.624701	82.12	0.000	3.538192	3.71121
Log likelihood = -4650.806					
N = 938					

Freeways were associated with a statistically significant reduction in crashes involving parked cars, a finding that is likely reflective of 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 was permitted from those where it was prohibited. It was thus impossible to determine whether the findings for arterial roadways were the result of the hazards associated with permitting on-street parking to occur along arterials, or whether they simply reflected the fact that parking-intensive land uses tend to congregate along arterials. Future research on this subject is needed.

Interestingly, the presence of pedestrian-scaled retail uses was associated with a 1.2% decrease in crashes involving a parked car. 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 should have less difficulty negotiating around parked cars in this environment than others, although a possible explanation is that drivers may 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 were 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 vehicle-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 are more likely to occur at driveways and intersections, which are locations where pedestrian traffic is likely to interact with opposing streams of vehicle traffic. These hazards are particularly exacerbated along arterials, where vehicles are traveling at higher operating speeds.

Table 6: Vehicle-Pedestrian Crash Model.

Pedestrian	Coef.	z	p	95% Conf. Interval	
Block group acreage	-0.00026	-1.69	0.092	-0.00057	0.000043
VMT (millions)	0.000908	1.99	0.047	0.00001	0.001804
# of three-leg intersections	-0.00367	-2.18	0.029	-0.00697	-0.00038
# of four-or-more-leg intersections	0.009113	2.97	0.003	0.003094	0.015132
Net population density	0.002826	2.78	0.005	0.000836	0.004815
Freeway miles	-0.0167	-0.81	0.419	-0.05719	0.023781
Arterial miles	0.092968	2.76	0.006	0.026961	0.158975
# of strip commercial uses	0.029624	9.38	0.000	0.023432	0.035817
# of big box stores	0.086999	4.51	0.000	0.049185	0.124813
# of pedestrian-scaled retail uses	-0.01604	-1.76	0.079	-0.03392	0.001835
Constant	1.119725	18.59	0.000	1.001689	1.237761
Log likelihood = -2556.3081					
N = 938					

Population density was found to have a positive and statistically significant relationship to the incidence of crashes involving pedestrians. This is likely due to the fact that population density serves as a proxy for pedestrian volumes; walking is more common in higher-density environments (Ewing & Cervero, 2001). As such, 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 a significant *reduction* in crashes involving pedestrians. This too is likely attributable to the speed found 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 thoroughfare corresponding to a 6.6% increase in vehicle-cyclist crashes. Four-leg intersections and strip commercial uses, which create locations where vehicle and cyclist traffic may interact, were associated with a 1.3% and a 1.7% increase in vehicle-cyclist crashes, respectively. Big box stores were associated with increases in vehicle-cyclist crashes, and pedestrian-scaled retail uses were associated with decreases in these crashes, although both variables fell slightly outside conventional levels of statistical significance. Interestingly, VMT did not prove to be associated with vehicle-cyclist crashes, the only crash type for which this was true.

Table 7: Vehicle-Cyclist Crash Model.

Cyclist	Coef.	z	p	95% Conf. Interval	
Block group acreage	-0.00037	-2.07	0.039	-0.00072	-0.00002
VMT (millions)	0.000399	0.81	0.417	-0.00057	0.001363
# of three-leg intersections	0.002266	1.18	0.237	-0.00149	0.00602
# of four-or-more-leg intersections	0.013088	3.87	0.000	0.006463	0.019712
Net population density	0.0000694	0.11	0.913	-0.00118	0.00132
Freeway miles	-0.01384	-0.62	0.536	-0.05766	0.029975
Arterial miles	0.066113	1.9	0.057	-0.00209	0.134312
# of strip commercial uses	0.017179	5.29	0.000	0.010811	0.023546
# of big box stores	0.032759	1.62	0.104	-0.00677	0.072288
# of pedestrian-scaled retail uses	-0.01216	-1.38	0.168	-0.02945	0.005127
Constant	0.16105	2.43	0.015	0.031359	0.290742
Log likelihood = -1720.4591					
N = 938					

3

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

Passive safety encourages designers to focus on addressing the safety effects of random error. Yet, VMT and its proxy, random error, have 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, a single strip commercial use would be expected to produce between three to six times more crashes than would randomly occur from a million miles of vehicle travel, and a single big box store would be expected to produce 14 times as many 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 8: Urban Form and Crash Incidence.

	Motorist	Multiple Vehicle	Parked Car	Fixed Object	Pedestrian	Cyclist
Block group acreage	-0.00037***	-0.00040***	0.00007	-0.00011	-0.00026$^{\Psi}$	-0.00037*
VMT (millions)	0.00561***	0.00548***	0.00100**	0.00526***	0.00091*	0.00040
# of three-leg intersections	0.00012	0.00005	0.00020	-0.00053	-0.00367*	0.00227
# of four-or-more-leg intersections	0.00612*	0.00564*	0.00381	0.00884***	0.00911**	0.01309***
Net population density	0.00041	0.00057	0.00116$^{\Psi}$	-0.00026	0.00283**	0.00007
Freeway miles	-0.04192*	-0.05287**	-0.03738*	-0.00065	-0.01670	-0.01384
Arterial miles	0.09795***	0.11384***	0.06638**	0.02981	0.09297**	0.06611$^{\Psi}$
# of strip commercial uses	0.02205***	0.02355***	0.02057***	0.01398***	0.02962***	0.01718***
# of big box stores	0.07687***	0.08414***	0.11428***	-0.01063	0.08700***	0.03276
# of pedestrian-scaled retail uses	-0.03073***	-0.03518***	-0.01183$^{\Psi}$	-0.01007$^{\Psi}$	-0.01604$^{\Psi}$	-0.01216

$^{\Psi}$ p < .10, * p < .05, ** p < .01, *** p < .001

Traffic Conflicts

As shown in Table 8, crashes involving pedestrians, cyclists, and motorists are more likely to occur in the presence of intersections and driveways, which are locations where conflicting streams of traffic cross. Practicing planners and engineers have long recognized that crashes are more likely to occur at these locations, a recognition that has led to the emergence of countermeasures such as traffic signalization, roundabouts, and traffic circles, among others. These devices are intended to either allocate right-of-way to specific traffic movements or reduce the number of conflict points between opposing streams of traffic, both of which are effective at reducing crash incidence (Ewing, 1999; Federal Highway Administration [FHWA], 2000, 2004; Zein, Geddes, Hemsing, & Johnson, 1997). While the finding that traffic conflicts pose a crash risk seems patently obvious on its surface, it is important to observe that these locations create a common, systematic hazard for all road users, whether they are a pedestrian, a cyclist, or a motorist.

Speed

This suggests the second systematic factor, which is the moderating role of vehicle speed. The presence of forgiving design features would be expected to do little or nothing to address the hazards resulting from traffic conflicts, since crash avoidance is dependent almost entirely upon a motorist's ability to brake quickly in response to the hazard posed by another road user entering the right-of-way. Indeed, forgiving design elements would be expected to exacerbate the crash risk at these locations, since wider lanes, shoulders, and clear zones all lead to higher vehicle operating speeds (Fitzpatrick et al., 2001; Gattis, 2000;Gattis & Watts, 1999; Ivan, Garrick, & Hanson, 2009; Naderi, Kweon, & Maghelal, 2008; Smith & Appleyard, 1981; SwiftPainter, & Goldstein, 2006), and higher operating speeds increase stopping sight distances (see Figure 5), making drivers less prepared to brake in response to another roadway user entering the right-of-way (AASHTO, 2004).

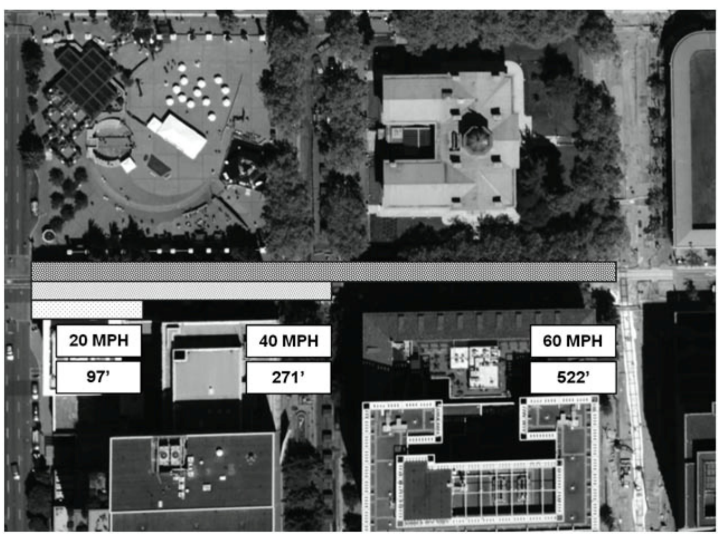

Figure 5: Higher Speeds Greatly Increase Stopping Sight Distance
(Source: Dumbaugh and Rae, 2009).

As evidenced in the model results for freeways, roadways designed to accommodate higher operating speeds need not necessarily pose a crash risk hazard. Each mile of freeway was associated with a 5.3% *decrease* in crash incidence. Passive safety theory has historically attributed these crash reductions to the use of forgiving design elements, yet a consideration of the design characteristics of freeways suggests an alternate explanation. Beyond their use of forgiving design elements, freeways use grade-separated interchanges that eliminate the traffic conflicts associated with driveways and intersections (see Figure 6). It is the elimination of traffic conflicts, rather than the presence of forgiving features, that is likely responsible for their safety benefits.

While arterials are similarly designed to be forgiving, driveways and intersections are located at grade. In this context, the use of forgiving design features simply encourages higher operating speeds, while leaving the embedded traffic conflicts intact. The result is that drivers are less prepared to respond to the hazard posed by another road user entering the right-of-way, leading to significant increases in crashes 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 (see Figure 6).[2]

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. This is almost certainly attributable to their effects on vehicle speeds. Street-oriented buildings create a sense of visual enclosure to the street, communicating to the driver that greater caution is warranted and resulting in reductions in both vehicle speeds and crash incidence (Dumbaugh, 2006; Ossenbruggen, 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 buildings located adjacent to the street and sidewalks, were associated with speed reductions of up to 10 MPH (Ivan, Garrick, & Hanson, 2009). In a novel study using a driving simulator, Naderi, Kweon, and Maghelal (2008) found that the simple addition of trees along the roadside of a suburban collector roadway not only made people perceive a roadway as being safer but also reduced vehicle speeds by 3 MPH, on average.

Figure 6: Unlike Arterials (top), Freeways (bottom) Are Designed to Eliminate the Traffic Conflicts Occurring at Driveways and Intersections.

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 7).

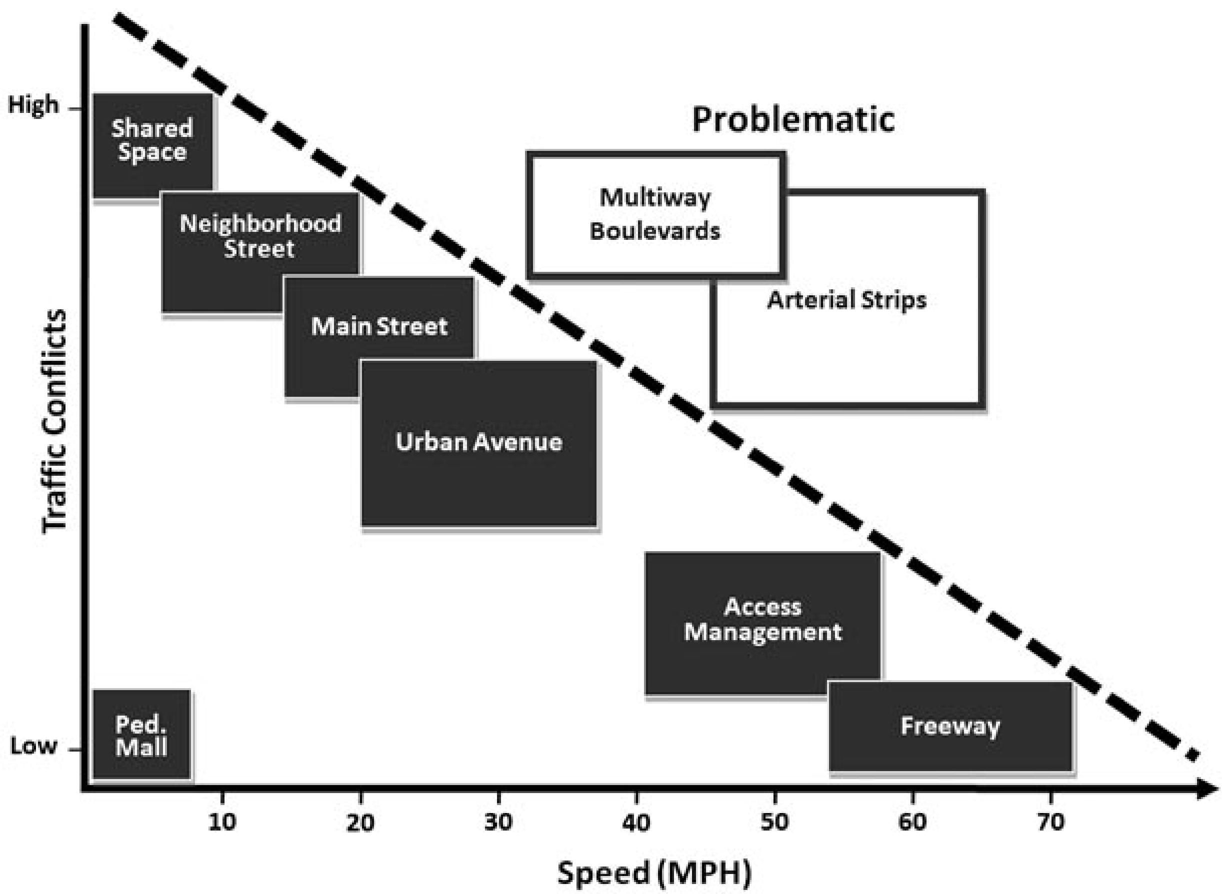

Figure 7: Design Solutions for Balancing Traffic Conflicts and Speed.

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 the traffic conflicts created by the presence of other roadway users. While operating speeds on freeways are often 55 MPH or greater, freeways report the lowest crash rates of any roadway type because there 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 the use of forgiving design features but also emulating their limited-access characteristics. Access management entails the consolidation or elimination of driveways and intersections, as well as the installation of a raised median, which eliminates the traffic conflicts associated with unprotected left-turning maneuvers. The net effect of these features is a reduction in the number of traffic conflicts along higher-speed thoroughfares and a corresponding reduction in crash incidence (Florida Department of Transportation, 2006; TRB, 200a). While access management is typically applied on streets with operating speeds between 40 and 55 MPH, it is essential to recognize that their safety benefits hinge on their ability to mirror the limited-access characteristics of freeways (see Figure 8).

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

At the opposite extreme are strategies that seek to address traffic conflicts by forcing vehicles to travel at the speed of pedestrians. While speed-reduction strategies come in a variety of flavors, ranging from conventional traffic calming devices to Dutch woonerven (living street), their common characteristic is that they create environments that are designed to enhance safety by forcing reductions in vehicle speeds (Ewing, 1999; Zein et al., 1997; see Figure 9). Speeds between 5-10 MPH not only ensure that drivers are able to quickly brake in response to a potential traffic conflict but also appear to make drivers more accommodating to other roadway users. A study of driver behavior in Maine found that when vehicles were traveling at speeds of 10 MPH or less, drivers yielded to crossing pedestrians 100% of the time (Garder, 2001). In the United States, strategies that seek to curb vehicle speeds are typically lumped into the category of "livability" features, yet they are an established part of European design practice due to their demonstrated ability to reduce crash incidence (Skene, 1999).

Figure 8: Access-Managed Urban Thoroughfares.

Figure 9: Shared Spaces in San Diego (top), St. Augustine (middle), and Philadelphia (bottom).

Based on the European experience with the woonerf, Dutch and British designers have sought to apply the 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 in nature (Shared Spaces, 2007), a before-after analysis examining the safety effects of the installation of shared-space features on an intersection carrying 1,400 vehicles in 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. During the same time period, traffic volumes actually increased to 1,850 during the peak hour (Noordelijke Hogeschool, 2007).

While woonerven and shared spaces violate the design logic embedded in passive safety theory, their safety benefits come from their ability to address systematic error. Traffic conflicts are an inherent part of urban environments, and meaningfully addressing their safety consequences requires vehicles to travel at accommodating speeds. US 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. At speeds of 5-10 MPH, any potential crash event involving a vehicle and a pedestrian is unlikely to lead to an injury or death (Anderson et al., 1997), although crashes at these speeds are extremely unlikely (Garder, 2001). Similarly, should a driver randomly err and crash into a tree, bollard, or other street feature, the crash is 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 will 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 Transportation Engineers, 2008; Nelessen, 1994; see Figure 10), there is comparatively little research on the safety characteristics of different street configurations. Research on residential streets has reported that wider rights-of-way lead to higher speeds (Smith & Appleyard, 1981) and increased crash incidence (Swift, Painter, & Goldstein 2006). Studies of commercial streets have reported that streets designed using main street-type configurations are substantially safer than more conventional, forgiving designs (Ossenbruggen, Pendharkar, & Ivan, 2001), with one study finding that main streets reported, on average, 40% fewer midblock crashes and 67% fewer roadside-related crashes than conventionally designed arterial roads (Dumbaugh, 2006).

Figure 10: Two-Lane Commercial Street (top) and Four-Lane Urban Avenue (bottom).

Considered broadly, however, safe urban streets likely share three characteristics. The first is the separation of vehicle and pedestrian traffic, which on higher-volume streets may entail the designation of 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 through the formal allocation of right-of-way using stops signs or traffic signals or through the application of intersection control devices that reduce vehicle speeds and traffic conflicts, such as roundabouts and traffic circles. The third characteristic is low to moderate vehicle speeds, typically in the range of 15-35 MPH. 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 (FHWA, 2000).

Given that Western Europe's safety performance greatly exceeds that of the United States (World Health Organization, 2004; TRB, 2006), their approach to addressing the tension between speed and traffic conflicts may be instructive. European design guidance limits design speeds to 50 km/h (31 MPH) for 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 MPH is a plausible maximum value.

Problematic Streets: Urban Arterials and Multi-Lane Boulevards

The safety problem associated with conventional arterial design is that it attempts to accommodate speed and access simultaneously. Urban designers have increasingly promoted multi-way boulevards as an alternative. Multi-way boulevards combine high-speed travel lanes in their center with lower-speed access lanes located against 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), a finding that is cause for concern.

Conclusion

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. This study found that the environmental 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, namely a combination of traffic conflicts and vehicle speed. Conversely, the presence of pedestrian-scaled retail uses, which encourage lower operating speeds, was found to be associated with significant reductions in crashes involving multiple vehicles, parked cars, fixed objects, and pedestrians.

To date, there has been little formal examination of how drivers may adapt their behaviors to the characteristics of the built environment, and no studies have sought to correlate these behavioral adaptations to the incidence of crashes. 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 sought to demonstrate, the majority of driver errors in urban environments do not appear to be random; the characteristics of the built environment play a profound role in the production of error and creation of traffic crashes.

In this report, 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. There is a need for research 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 decrease—their exposure to crash risk. Further, this study only examined total crash incidence; injurious and fatal crashes may have unique characteristics that are distinct from non-injurious crashes. Future research is needed to examine this possibility. Nevertheless, it is our hope that the results of this study will provide the preliminary evidence and theoretical framework needed to advance the current understanding of urban crash incidence, as well to identify and develop design solutions that may be used to enhance the safety of pedestrians, cyclists, and motorists alike.

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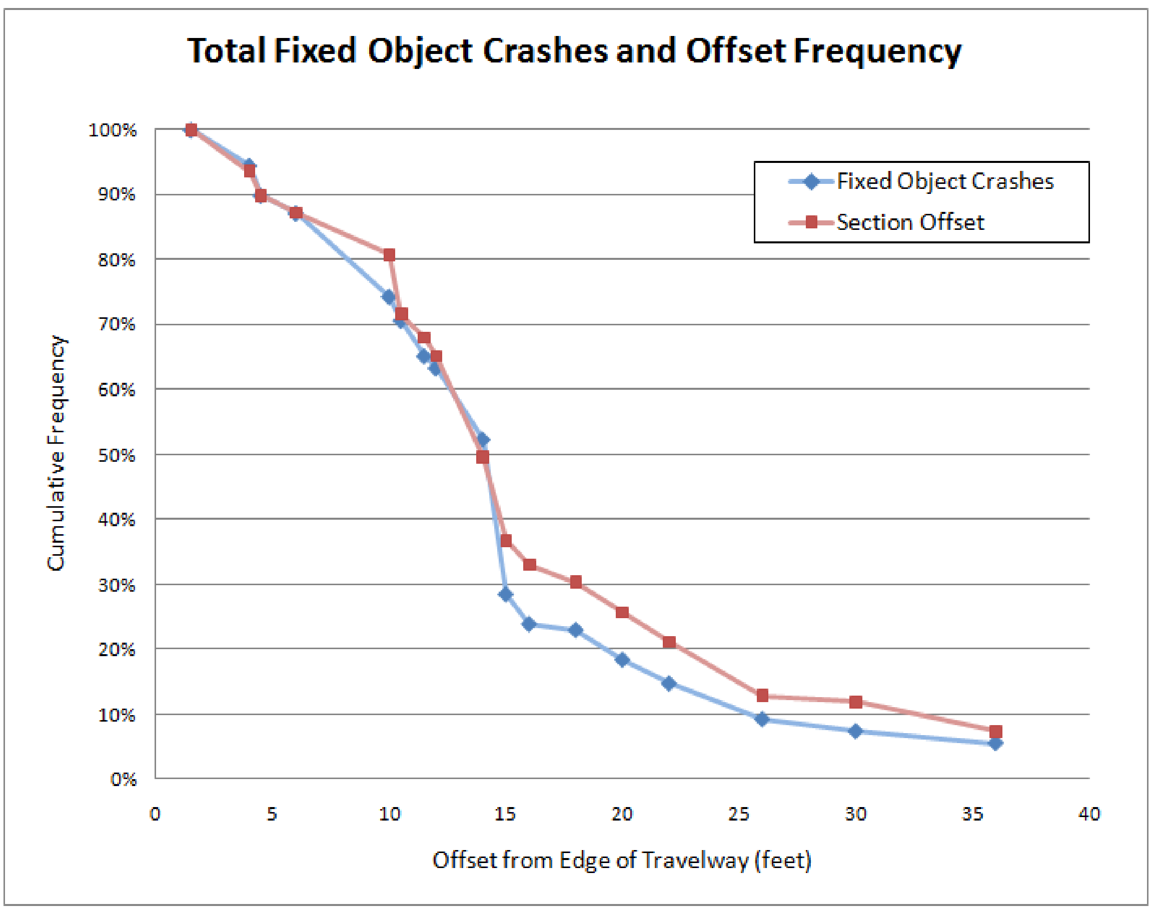
Notes

Endnotes

[1] The primary evidence used to support the application of urban clear zones is a 1990 study by Turner and Mansfield, which reported that 80% of tree-related crashes occurred within 20 ft of the right-of-way. The relationship was presumed to be causal and has been used to assert that eliminating all roadside objects within 20 ft of the right-of-way will therefore eliminate 80% of roadside-related crashes. Yet, this relationship is almost certainly a spurious one. Due to the constrained nature of urban environments, only a small portion of urban roadways have clear zones of 20 ft or greater. It should thus be unsurprising that a comparatively small percentage of roadside-related crashes occur in this environment. As shown in the figure below, which also reports that 80% of urban fixed-object crashes occur within 20 ft of the right-of-way, the percentage of crashes occurring on roadways with different offset widths is largely a function of the percentage of roadways with different offset widths (Dumbaugh, 2006). There appears to be a slight safety benefit as clear zones exceed 15 ft, but even this finding is questionable, as it fails to control for traffic volumes or the number of driveways and intersections. In short, Turner and Mansfield's findings, while interesting, ultimately explain little about the nature of urban roadside crashes.



[2] This was calculated by determining the ratio of arterial crashes versus the expected rate of crashes associated with VMT (40,000 VMT/9.8%) / (1,000,000 VMT/0.56%).