Design of Safe Urban Roadsides

An Empirical Analysis

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To date, there has been little examination of the area of roadside safety on nonfreeway urban roads. To understand better the design of safe roadsides in urban environments, this study used negative binomial regression models to examine the safety effects of three roadside design strategies: widening paved shoulders, widening fixed-object offsets, and providing livable-street treatments. The model results indicated that of the three strategies, only the livable-streets variable was consistently and negatively associated with reductions in roadside and midblock crashes. Wider shoulders were found to increase roadside and midblock crashes, while unpaved fixed-object offsets had a mixed safety effect by decreasing roadside crashes but having a slightly positive effect on midblock crashes. To understand better the reasons for these findings, this study then examined roadside crash site locations for tree and utility pole crashes. It found that the majority (between 65% and 83%) did not involve random midblock encroachments, as currently assumed, but instead involved objects located behind both driveways and side streets along higher-speed urban arterials. Collectively, these findings suggest that most urban roadside crashes are not the result of random error but are instead systematically encoded into the design of the roadway. The study concluded by distinguishing between random and systematic driver errors and by discussing strategies for eliminating systematic error while minimizing the consequences of random error.

The provision of forgiving roadsides is a central strategy in the design of safe roadways. As enumerated in design guidance such as the AASHTO *Roadside Design Guide* (*1*) and *A Policy on Geometric Design of Highways and Streets* (*2*), roadway designers can enhance the safety of a roadway by ensuring that the roadside environment is free of fixed-object hazards or, at a minimum, by designing the roadside to minimize the consequences of a vehicle's leaving the travel way. In general, this is to be achieved by eliminating fixed-object hazards, making them traversable by errant vehicles, or by shielding those hazards to minimize the severity of a crash.

While the provision of a forgiving roadside environment is well-established in design practice and guidance, there has been little focused examination into the design of safe roadsides in urban environments generally and along nonfreeway urban roadways in particular. As the *Roadside Design Guide* states, "generally, the principles and guidelines for roadside design presented in . . . this *Guide* discuss roadside safety considerations for rural highways, Interstates and freeways" (*1*, p. 10-1). To advance the professional understanding of urban roadside safety better, this study examines the design of safe roadsides on nonfreeway urban roads.

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Transportation Research Record: Journal of the Transportation Research Board, No. 1961, Transportation Research Board of the National Academies, Washington, D.C., 2006, pp. 74–82.

LITERATURE REVIEW

The early research on roadside safety, which serves as the basis for many of the recommendations contained in roadside design guidelines, presents only basic descriptive information on the locations of roadside crashes, without examining whether certain roadside configurations are associated with increases or decreases in roadside crash frequency or severity (*3–6*). While it is useful to know that 80% of tree-related crashes occur within 20 ft of the travel way (*5, 6*), such statistics do not allow one to arrive at meaningful conclusions about the safety benefits associated with widening shoulders or clear zones. Such conclusions can emerge only by comparing a roadway's crash performance before and after a specific roadside improvement is adopted or else by examining how variations in roadside design influence a roadway's actual crash performance.

Recognizing the limitations of these early roadside safety studies, recent research has sought to evaluate the safety effects associated with the provision of forgiving roadsides through the use of more appropriate analytical methods. Milton and Mannering (*7*) modeled the crash performance of principal arterials in Washington State through use of a Poisson regression. The authors included a dummy variable in their model to identify roadways with narrow shoulders, defined as roadways with shoulder widths less than 5 ft. The variable entered the model with a positive coefficient at statistically significant levels, indicating that total crash frequencies increased as shoulder widths dropped below 5 ft. Yet Milton and Mannering's results, which seemed to confirm the recommendations of the *Roadside Design Guide,* appeared to be the exception rather than the rule. Ivan et al. (*8*), also using a Poisson regression, found that wider shoulders were associated with a decrease in single-vehicle crashes but resulted in statistically significant increases in multiple-vehicle crashes, thereby negating safety improvements associated with reductions in single-vehicle crashes. In a subsequent follow-up study, Ivan et al. found that widening shoulders increased both single- and multiple-vehicle crashes (*9*).

Other studies reported similar findings. Noland and Oh (*10*) used a negative binomial model to estimate the safety effects of a variety of geometric elements on state roadways in Illinois. The authors found that increases in shoulder widths were associated with decreases in total crashes but increases in fatal ones at the 92% level of confidence. Benekohal and Lee (*11*) conducted a series of before-and-after studies of 17 resurfacing, restoration, and rehabilitation projects that included, among other improvements, widening lane and shoulder widths and increasing fixed-object offsets. Of these projects, seven reported reductions in fixed-object crashes in the after period, four reported no change, and six reported increases in fixed-object crashes, suggesting that road and roadside improvements had a mixed safety effect.

Lee and Mannering (*12*) used a negative binomial model to examine the safety effects of geometric design features in both rural and urban environments. While their rural model performed as expected—with wider lanes, shoulders, and fixed-object offsets all reducing the frequency of fixed-object crashes—they found the opposite to be true for urban environments. Lanes greater than 12 ft were found to be significantly related to an increase in fixed-object crash frequency, while the placement of urban streetscape features, such as trees and signposts along the roadside, were found to be associated with statistically significant decreases in the likelihood that a roadside crash would occur. Conversely, tree groups (a characteristic of rural environments) and bridges were both associated with increases in roadside-related crashes and injuries in urban areas.

In addition to these more conventional roadside safety studies, several additional studies have sought to examine the safety effects associated with the placement of aesthetic streetscape treatments along the roadsides of urban environments. These studies are interesting from a roadside-safety perspective in that the aesthetic streetscape treatments examined in these studies are generally by design unforgiving to errant motorists. In the earliest of these studies, Ossenbruggen et al. (*13*) examined sites with urban, suburban, and residential characteristics in New Hampshire, hypothesizing that the urban village areas, which have pedestrian-oriented roadside treatments, would have higher numbers of crashes and injuries. Instead, they found the opposite: the village areas reported 250% fewer crashes than either the suburban or rural roadways. Naderi (*14*) examined the safety effects of aesthetic streetscape improvements along five arterial roadways in downtown Toronto, Canada, and found that the placement of trees and concrete planters along the edge of the travel way resulted in statistically significant decreases in midblock crashes along all five roadways. Finally, Dumbaugh (*15*) compared the safety performance of livable-streetscape treatments to more conventionally designed segments along the same roads, and found that the sections incorporating livable-street treatments reported fewer roadside and midblock crashes than the conventionally designed sections.

When the recent safety literature as a whole is considered, the safety benefits associated with the provision of wide shoulders and clear offsets appears to be uncertain, at best. Yet several issues permeate the literature. First, the majority of research focuses either exclusively or predominantly on rural roadways, making it difficult to translate these findings to urban environments, which serve different trip purposes and often have different operating characteristics than do rural roads. Second and perhaps equally important, precise measurements of a roadway's design characteristics are difficult to acquire from secondary data sources, a situation that results in the use of models that rely heavily on dummy variables or approximations of a roadway's geometric design characteristics. Paved shoulder widths are typically used as a proxy for a roadway's clear zone width, although it is unclear whether safety conclusions drawn from observations of paved shoulder widths can be meaningfully used to estimate the safety benefits associated with the provision of an unpaved clear roadside. Third, despite an emerging trend in the safety literature suggesting that forgiving roadside design may have a negative effect on safety, there has been little examination into the reasons for, or implications of, these unexpected research findings.

EXAMINING URBAN ROADSIDE SAFETY

Given the anomalous safety findings contained in the recent roadside design literature, as well as the absence of focused research into the area of urban roadside safety, there is a clear need for more focused research into this area. To begin to address this need, this study examined the crash performance of urban arterial roadways located in Florida Department of Transportation (FDOT) District 5. To overcome the data limitations associated with many earlier studies, this study focused specifically on urban arterial roadways traveling through small metropolitan areas so as to permit the manual collection of precise measurements of a roadway's lane, median, shoulder, and unpaved fixed-object offset widths.

Two specific criteria were used to identify the roadways evaluated in this analysis. First, because of the recent interest in the safety performance of pedestrian-friendly roadside treatments, roadways that incorporated such treatments at some point along their length were specifically sought for examination. To prevent variations in a roadway's operating characteristics from producing biased results, researchers selected a roadway only if there were no major changes in its operating characteristics along its urbanized length. For example, many two-way roadways will convert to one-way pairs in central business districts and thus result in a substantial change in the roadway's operating characteristics. To eliminate the effects that one-way travel might have on safety performance, researchers included in this analysis only roadways with two directions of travel along their entire length.

After preliminary field investigations of 17 candidate roadways were conducted, 3 met the selection criteria for this study: SR-15 in DeLand (Woodland Boulevard); SR-44, also in Deland (New York Avenue); and SR-40 in Ocala (Silver Springs Boulevard). In total, the urbanized portions of these roadways were 27 mi long and had a high degree of design variation that would permit the development of meaningful statistical models. Crash data for the 1999 to 2003 period were supplied by FDOT generously, and manual field measurements of the lane, median, shoulder, and fixed-object widths were collected for these roadways as supplements to the data provided by FDOT.

Model Development

While a variety of modeling techniques are available for analyzing crash data, the consensus in the literature is that negative binomial regression models are most appropriate for examining trends in crash frequency and severity. A negative binomial regression model is similar to a Poisson, but, through the inclusion of a gamma-based error term in the model specification, it relaxes the assumption that the mean and the variance are equal. The use and appropriateness of negative binomial models have been well detailed in recent safety literature (*16, 17*).

To model crash performance, it was necessary to break the roadway into segments that could be specifically modeled. The three roadways examined in this study were segmented into ¼-mi sections, with crash data and geometric design data aggregated to the segment level. While this approach results in the problem that a roadway's geometric design characteristics may vary within a given segment, the consensus in the literature is that fixed-length segments are preferable to the use of homogeneous sections of unequal length (*16, 18*). A second issue is how geometric design data are to be appropriately aggregated to the segment level. For this study, the dominant characteristics of the road section were used for each segment. Fortunately, because of the use of standard cross sections along these roadways, there were relatively few instances where there were notable internal differences in a segment's geometry within a section or between the two sides of the road.

Dependent Variables

For this study, roadside crashes for each segment were calculated as the sum of crashes involving trees, poles, signs, ditches, and other objects along the roadside. Because some sections of these roadways permitted on-street parking, and thus could result in parked cars functioning as fixed-object hazards, crashes involving parked cars were included in the roadside crash totals.

While this study was principally interested in roadside safety, the review of the literature suggested the need to consider how roadside design affects not only roadside crashes but midblock crashes as well, because increases in nonroadside crashes were often found to negate safety gains made from reductions in fixed-object crashes. Thus, in addition to roadside crashes, midblock crash performance was also considered. Midblock crashes, rather than total crashes, were used here because cross-street traffic volumes and the type of intersection control device used at an intersection can have a profound effect on crash performance that is independent of a roadway's specific design characteristics. To prevent such factors from producing misleading safety estimates, only midblock crashes were considered. In total, there were 109 roadside-related crashes and 411 midblock, nonintersection crashes during the 5-year analysis period.

Independent Variables

There were three roadside variables of interest to this study. The first was a measure of the paved shoulder width of each road segment. Nevertheless, a major advancement of this research over earlier studies was that it modeled paved shoulders and unpaved fixed-object offsets separately to gauge their independent safety effects. Correspondingly, a segment's unpaved fixed-object offset was a second independent variable of interest, with a roadway's fixed-object offset defined as the distance from the edge of the paved portion of the roadway to the nearest adjacent roadside fixed object.

Recent research has further suggested that pedestrian-oriented livable-streetscape treatments, which buffer the pedestrian portion of the right-of-way from the vehicle travel way through the use of trees, street lighting, or other roadside features may also have an affect on a roadway's crash performance. To account for the influence that such roadside treatments might have on safety, a dummy variable was included in the model to indicate the presence of a livable-street treatment along a section. While livable-street treatments may include a host of elements—including traffic calming applications, narrow travel lanes, aesthetic pavement, or other design features—for the purpose of this study, a livable street was defined simply as a street with pedestrian-oriented streetscape features that buffer the sidewalk from the vehicle travel way (Figure 1). In total, 2 of the 27 mi analyzed in this study included livable-street treatments.

Finally, because roadside design is only one of a variety of features that can influence a roadway's safety performance, average daily traffic (ADT) volumes, posted speed limits, number of travel lanes, lane widths, and median widths were included as control variables to account for the safety effects each may have on a roadway's crash performance.

Reporting

Before the model results are presented, it is important to first clarify the statistics of interest. While many studies using regression analysis report only coefficients and test statistics for statistically significant variables, this approach has received a good deal of criticism recently because it implies that variables having a specific effect on safety, but not at statistically significant levels, have no effect on safety. As Hauer (*19*) writes, "in this manner, good data are drained of real content, the direction of empirical conclusions reversed, and ordinary human and scientific reasoning is turned on its head." To ensure that the best possible information is provided by these models, this study reports the coefficients and test statistics for all modeled variables, as well as the 95% percentile confidence interval, which should be regarded as the best possible estimate of the safety effects of a specific design application.

Model Results

Total Roadside Crashes

Table 1 presents the results for the model of total roadside crashes. All of the control variables entered with plausible signs, with roadside crashes increasing with ADT and the number of lanes, and crashes decreasing with increases in lane and median widths. Of the roadside variables, shoulder widths entered positively at the 80% confidence level, a finding that contradicts conventional roadside design guidance but is consistent with earlier research. The width of a roadway's unpaved fixed-object offset entered negatively with a z-statistic of –1.51, indicating that roadways with wider unpaved clear offsets generally report fewer roadside crashes. While such a finding is supported by conventional design guidance, the livable-street variable

(a) (b) (c)

FIGURE 1 Livable-street sections.

TABLE 1 Negative Binomial Model of Total Roadside Crashes

	Coefficient	z-Statistic	95% Confidence Interval	
ADT	0.0000267	1.05	–0.000023	0.0000764
Speed limit	–0.019414	–0.62	–0.0811245	0.0422957
No. of lanes	0.0281937	0.13	–0.4062023	0.4625897
Lane width	–0.099938	–0.62	–0.4157851	0.2159087
Median width	–0.027056	–1.79	–0.0567412	0.0026294
Paved shoulder width	0.0546558	0.85	–0.0716248	0.1809365
Object offset	–0.038137	–1.51	–0.0874755	0.0112013
Livable street	–1.532556	–2.33	–2.823685	–0.2414263

$N = 109$; log likelihood = –144.

also entered negatively at the .009 level of confidence, which indicates that one can be 99% confident that the presence of a livable-street treatment is also associated with reductions in roadside crashes.

Total Midblock Crashes

As discussed earlier, a safe roadside design is one that reduces fixed-object crashes without having these safety gains offset by increases in midblock crashes. Thus, one would expect an effective strategy to be associated with declines in both roadside and midblock crashes. Table 2 presents the results of the negative binomial model for midblock crashes. In this model, the control variables again entered with plausible signs, with ADT, speed limit, and the number of lanes all associated with increases in midblock crashes, while wider lanes and medians were associated with decreases in midblock crashes. Nevertheless, the roadside variables again entered with signs that are inconsistent with design guidance. Paved shoulders and fixed-object offsets both entered with positive coefficients, although at weak and statistically insignificant levels (4% and 10% levels of confidence, respectively). By contrast, the livable-streets variable again entered negatively and at the conventional 95% level of confidence.

Summarizing the Model Results

Collectively, these findings indicate that wider shoulders increase both roadside and midblock crashes, while wider fixed-object offsets have a mixed safety effect. Roadways with wider clear offsets have fewer roadside object-related crashes, but these reductions appear to be offset by an increase in total midblock crashes. Of the three roadside variables, only the livable-streets variable was consistently associated with reductions in roadside and midblock crashes, and in both cases, at statistically significant levels. Considered holistically, there is a seeming paradox here: roadside safety (if not midblock safety) appears to be enhanced by both widening unpaved clear offsets and the use of unforgiving livable-street treatments. Perhaps more surprisingly, the livable-streets variable was the only roadside design variable that was associated with statistically significant reductions in both roadside and midblock crashes. Collectively, this suggests that there is more involved in the design of safe urban roadsides than simply ensuring that they are forgiving of a run-off-roadway event.

RECONSIDERING ROADSIDE CRASHES: A FIELD INVESTIGATION

Despite the consistency of these findings with previous research, almost no research has sought to understand their meaning or implications. Part of the problem rests in the nature of the analysis method; regression analysis is useful for identifying broad trends in larger data sets, but is unable to provide information into unquantified factors that may influence the model results. Given the potential importance of these findings on the design of safe roadsides, it is clear that more focused analysis is warranted.

TABLE 2 Negative Binomial of Total Model of Midblock Crashes

	Coefficient	z-Statistic	95% Confidence Interval	
ADT	0.0000603	4.46	0.0000338	0.0000868
Speed limit	0.0052272	0.29	–0.0305573	0.0410116
No. of lanes	0.1758359	1.33	–0.0827752	0.434447
Lane width	–0.4355661	–3.39	–0.687361	–0.1837712
Median width	–0.0226616	–2.68	–0.039212	–0.0061113
Paved shoulder width	0.0034967	0.09	–0.0695613	0.0765546
Object offset	0.0033041	0.24	–0.0239571	0.0305653
Livable street	–0.649918	–1.66	–1.416271	0.1164354

$N = 109$; log likelihood = –240.

Field Analysis

To understand better the factors that may produce such unexpected findings, detailed field analyses were conducted for all locations where tree and utility pole crashes occurred along these three roadways. Trees and utility poles were selected for specific analysis both because they were the most prevalent roadside crash types along these three roadways and for the more practical reason that they could, in most cases, be readily identified. Typically, only one tree or utility pole was located in the vicinity of the milepost number listed in the crash data, which allowed the specific object involved in the crash to be readily identified. Signs and ditches, the other two objects most frequently involved in roadside crashes, were much harder to identify, ditches because it is impossible to determine exactly where such crashes occurred (ditches typically extend linearly along the length of the travel way) and signs because they often occurred near intersections where multiple signs were present, which made it difficult to isolate the specific sign involved in the crash.

Of the 109 roadside crashes included in the negative binomial model, 51 involved either a tree or a utility pole. Of these, 40 (78%) were precisely identified on the basis of information contained in the crash reports. The remaining 11 crash locations could not be identified for one of two reasons. First, in some locations, individual trees could not be identified because of the density of the tree cover adjacent to the roadside. In others, the object could not be identified because no tree or pole could be found at the location listed in the crash data. Whether this inconsistency was a product of data coding errors or the subsequent elimination of the object involved in the crash is unknown.

Results

Previous studies that have examined roadside crash locations typically present cumulative distributions of the percentage of fixed-objects crashes set back at varying distances from the vehicle travel way. Both Ziegler (*6*) and Turner and Mansfield (*5*), for example, found that 80% of tree-related crashes involved objects located within 20 ft of the travel way. Yet unlike these earlier studies, which have been interpreted as meaning that the majority of roadside crashes can be eliminated by widening clear offsets beyond 20 ft, this study also sought to determine whether the lower percentage of roadside crashes was a function of reduced crash rates occurring at areas with higher fixed-object offsets, or simply a function of the fact that most road sections have clear offsets of less than 20 ft. If such statistics are to be interpreted as suggesting that 80% of crashes can be eliminated by widening offset distances beyond 20 ft, as was done when the early roadside design guidance was developed, then one would expect crashes to agglomerate on the lower end of the distribution (i.e., substantially more roadside crashes should be located on sections with offsets of less than 20 ft than on those with offsets greater than 20 ft). Figure 2 plots the cumulative distribution of tree and pole crashes against the cumulative distribution for the clear offsets for each road segment. As with previous studies, roughly 80% of roadside crashes occurred in areas with offsets of 20 ft or less. Nevertheless, the probability of a tree- or pole-related crash holds relatively constant for all sections until clear offsets exceed 15 ft, at which there appears to be a slight (5% to 10%) reduction in crashes. In short, such statistics do little to explain the incidence of roadside-related crashes.

A focused examination of the individual crash site locations, combined with an analysis of the precrash behavior of the driver, proved much more informative. Conventional roadside design practice is based on the assumption that drivers are fallible and prone to error and that the best means of addressing safety is to ensure that the roadside is forgiving of those errors when they occur. Such an approach is appealing from a design perspective because it eliminates the need to account for the behavioral factors that produce run-off-roadway events. As the *Roadside Design Guide* states, "Regardless of the reason for a vehicle leaving the roadway, a roadside environment free of fixed-objects . . . enhances the opportunity for reducing crash severity" (*1*, p. 1–2). As a result, conventional roadside design practice is based on the assumption that run-off-roadway crashes are the result of random midblock encroachments, an assumption evidenced by the use of a 25° impact angle for roadside crash-testing applications (*20*). Such an angle is reasonably

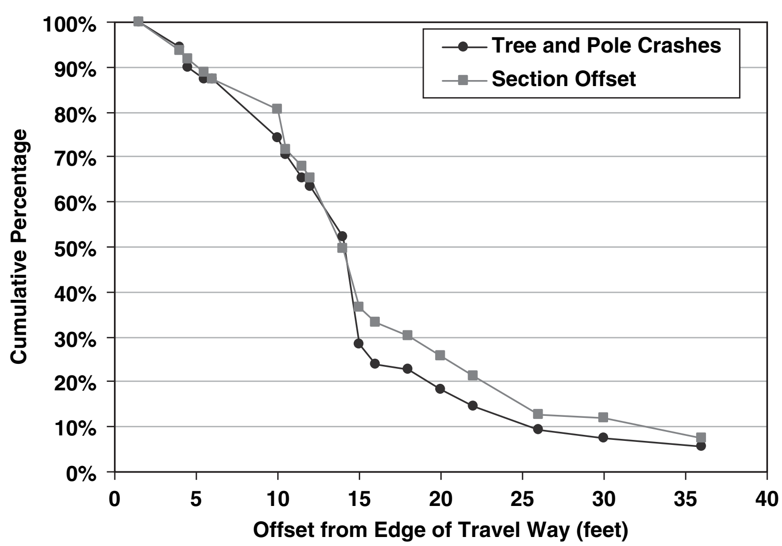

FIGURE 2 Tree and pole crashes and lateral clearance from travel way.

reflective of a vehicle's trajectory in relation to roadside objects should a vehicle randomly encroach upon the roadside at a midblock location.

Yet the field analysis results indicated that this hypothetical roadside crash scenario was not representative of most urban tree- and pole-related crashes. As shown in Table 3, 83% of identified tree and utility-pole crashes and 65% of the total—whether identified or not—were not random midblock encroachments but were instead located behind driveways and intersections. These results, combined with precrash information contained in the crash data, indicate that the majority of urban tree- and pole-related roadside crashes occur when a driver attempts to negotiate a turn from the arterial roadway onto an intersecting driveway or side street.

Figure 3 shows a representative urban fixed-object crash location. In this case, the object involved in the crash is a utility pole located behind a side street. The apparent cause of the crash is not, as often assumed, a random midblock encroachment, but is instead associated with a vehicle attempting to negotiate a right-turn maneuver from the arterial to the side street. In this case (and indeed, the majority of the cases investigated as part of this study), the roadside crash appears to be attributable to a combination of two factors: an arterial roadway designed to accommodate high operating speeds and the presence of driveways and side streets intersecting the arterial. When these elements are combined, the result is the creation of a condition that will enable (and possibly encourage) drivers to attempt to negotiate turns at higher-than-appropriate speeds. Thus, while the crash may be attributable to driver error, the nature of the error is not random, but is instead systematic: all that is required to translate this design configuration into a fixed-object crash is a driver who is attempting to accomplish a turning maneuver at the prevailing speed of the arterial roadway.

FIGURE 3 Representative urban fixed-object crash.

DISCUSSION: RETHINKING URBAN ROADSIDE CRASHES

The seeming anomalies that have emerged in the recent safety literature cease to be anomalous when one distinguishes between random error, which is error that naturally occurs as a result of human fallibility, and systematic error, which occurs when a roadway's design is inadequately matched to its actual use (*21*). Currently, design guidance and practice gives little consideration to how specific designs can encourage or discourage unsafe operating behavior. Instead, roadways are classified solely in terms of their mobility or access characteristics, and guided by the assumption that higher-speed, more forgiving designs enhance safety. Green Book specifications for urban arterials, for example, encourage design speeds that begin at 30 mph, although "every effort should be made to use as high a design speed as practical to attain a desired degree of safety" (*2*, p. 67).

The problem with such guidance is that the use of high design speeds encourages high operating speeds, which is evidenced by the fact that 75% or more of drivers in urban environments exceed posted speed limits (*22–26*). If reducing roadside crashes is to be a serious design consideration, then designs must strive to eliminate the systematic error that produces these crashes. Because a majority of roadside crashes appear to be the result of the combination of high operating speeds and turning maneuvers, two design approaches are available to eliminate systematic error: the first is to eliminate turning maneuvers (the Interstate approach) and the second is to reduce operating speeds (the livable-streets approach). Both strategies are addressed in turn.

TABLE 3 Locations of Pole and Tree Crashes

Location	Pole	Tree	Total	% Identified	% Total
Intersection	22	5	27	67.5	52.9
Driveway	4	2	6	15.0	11.8
Midblock/not at intersection	3	4	7	17.5	13.7
Not located	4	7	11		21.6
Total	33	18	51		100.0

Eliminate Turning Maneuvers: The Interstate Approach

The current approach to geometric design in the United States (although not in other developed countries) often attempts to address safety through the use of higher design speeds and thus higher design values for features such as lane widths, paved shoulders, and fixed-object offsets. This approach emerged in the 1960s out of the observation that Interstates had lower rates of crashes and injuries than other roadway types. The reason for the safety performance of the Interstate system was attributed to its use of high design values, a condition that resulted in the assertion that higher design values are more forgiving to error and equate to improved safety performance (*15*, *27*).

Yet when one examines safety from the perspective of systematic error, the Interstate system's roadside crash performance is perhaps better explained by the fact that it eliminates the design conditions that produce many roadside crashes, namely, turning maneuvers attempted at higher operating speeds. Access to the Interstate system is strictly controlled through the use of on- and off-ramps that permit gradual vehicle acceleration and deceleration—and thus eliminate sharp, high-speed turns. Many design professionals have implicitly recognized this fact, which has led to the adoption and application of access management principles along many arterial roadways. The access management approach attempts to eliminate crashes and injuries associated with turning maneuvers by eliminating the turns and providing deceleration lanes—and thus eliminating the design conditions that result in systematic error.

Reduce Operating Speeds: Livable-Streets Approach

While the Interstate system is reasonably effective in terms of roadside safety, the operating characteristics of the Interstate system are rarely met on many urban roadways. The central purpose of cities—and thus the streets that serve them—is to agglomerate compatible developments together and encourage a great deal of access between them. Designing urban arterial roadways to function like freeways fails to account for the simple and obvious fact that most surface streets in urban environments, regardless of their specific functional classification, must accommodate a high degree of roadside access. In these conditions, designing for high-speed operations can encourage systematic error because they encourage drivers to attempt turning maneuvers at higher-than-appropriate speeds.

Rather than attempting to function as freeways, the livable streets examined in this study instead address safety by discouraging the high-speed operating behavior that produces systematic error. Specifically, because land use access is an embedded feature of the roadway's environment, these streets instead encourage drivers to reduce their operating speeds to levels that will allow them to safely accomplish turning maneuvers. Further, as European designers have long recognized (*28–30*), lower-speed crashes are by definition more forgiving. Simple physics indicates that a crash occurring at a lower speed will be less severe than those that occur at higher speeds. By reducing operating speeds to safe levels, livable-street designs address not only systematic error but random error as well.

When one considers the safety performance of livable streets, it is clear that they are much safer than their more conventional urban counterparts. Table 4 compares the livable-street treatments with the urbanized portions of their respective roadways in terms of crashes per 100 million vehicle miles traveled (MVMT). When compared with the urbanized portions of these roadways as a whole, the livable streets showed 67% fewer roadside crashes than one would expect and a complete elimination of roadside-related injuries. These streets were also much safer in terms of overall midblock crashes, with 40% fewer midblock crashes and 28% fewer injuries being reported. Further, there was not a single fatality on any of the livable-street sections during this period, whether a roadside object, a multiple-vehicle crash, or a vehicle–pedestrian crash was involved.

The key issue surrounding the design and use of livable streets, and the one that is currently the source of much disagreement, is the means by which they are able to achieve these safety gains. These roadways are not forgiving to roadside encroachments in the conventional sense; fixed objects line these roadways, and any deviation from the travel way can have serious consequences. Yet it is important to recognize that roadside hazards along these roadways are clearly visible and expected and inform the driver that higher-speed operating behavior is undesirable. As a result, drivers appear to behave as reasonable people would be expected to: they slow down to minimize their exposure to harm and injury.

Figure 4 shows an example of such an unforgiving design: this ½-mi section of roadway is lined by a double row of mature street trees, with trees set back 4 ft. from the travel way. Despite the presence of such seeming hazards, not a single roadside crash—whether injurious or not—occurred along this stretch of roadway during the 5-year analysis period, and there were only four injurious midblock crashes. Insofar as one measures safety in terms of crashes and injuries, there can be little doubt that this is a safe roadway.

To test the speed-reduction hypothesis, the author conducted an ad hoc floating car study on this roadway by following lead vehicles on the approach to the section and monitoring their speed as they traveled through it. While the measurements were not exact (the speed of the lead vehicle was determined by monitoring a speedometer rather than using an appropriately instrumented vehicle), the speed of the lead vehicle was in all cases between 25 and 30 mph. What appeared to be occurring was that, on the approach to the section, drivers visually noted the change in the roadside environment and decelerated to speeds they viewed as appropriate in this context. What was particularly interesting was that the chosen operating speed was at or even below the roadway's posted speed of 30 mph.

These findings should not be interpreted as meaning that livable-street treatments will enhance safety wherever they are applied. Like the use of Interstate designs, there are contexts in which the use of livable-street treatments may enhance safety, may have no effect on safety, or may even be detrimental to safety. But in conditions where

TABLE 4 Crash Performance of Livable Streets vs. Urban Roadways, per 100 Million Vehicle Miles Traveled (MVMT)

		Fixed-Object Crashes per 100 MVMT			Midblock Crashes per 100 MVMT		
Location	Crash	Urban (all)	Livable Only	Difference	Urban (all)	Livable Only	Difference
SR 15	Total	7.1	3.2	–55.0%	31.9	28.6	–10.5%
	Injurious	4.0	0.0	–100.0%	22.7	22.2	–2.2%
SR 44	Total	11.4	6.1	–46.3%	37.1	18.3	–50.7%
	Injurious	5.8	0.0	–100.0%	27.7	18.3	–33.9%
SR 40	Total	15.0	15.7	4.0%	42.0	15.7	–62.8%
	Injurious	9.2	0.0	–100.0%	25.7	7.8	–69.5%
Averages	Total	10.1	3.3	–67.3%	38.3	23.1	–39.7%
	Injurious	5.7	0.0	100.0%	25.1	18.1	–27.7%

FIGURE 4 "Safe" urban roadside treatment.

land use access and turning maneuvers are expected, it is clear that they may improve safety performance by encouraging reductions in operating speeds—and thereby eliminate the systematic error that produces crashes and injuries.

CONCLUSION

This study employed negative binomial regression models to examine the safety effects of three roadside design strategies in urban areas: widening paved shoulders, widening fixed-object offsets, and providing livable-street treatments. The model results indicated that, of the three strategies, only the livable-streets variable was consistently associated with reductions in both roadside and midblock crashes. Wider shoulders were found to increase roadside and midblock crashes, while unpaved fixed-object offsets had a mixed safety effect, decreasing roadside crashes but having a slightly positive effect on net midblock crashes.

To understand better the reasons for these findings, this study further examined the locations of tree- and pole-related crashes. The majority of these crashes (between 65% and 83%) occurred not at midblock locations, but behind driveways and side streets, with the principal cause of the crash attributable not to random midblock encroachments, but instead to drivers attempting to accomplish turning maneuvers from higher-speed arterials onto driveways and side streets. This suggests that the majority of roadside crashes are not the result of random driver error, as currently assumed, but instead the result of error that is systematically encoded into the design of the roadway.

When one considers the systematic nature of many urban roadside crashes, two strategies are available for eliminating these crashes. The first is that currently used on Interstates and freeways, which is to restrict roadside access and to permit gradual vehicle acceleration and deceleration through the use of special lanes or freeway ramps. The second is to permit turning maneuvers but to restrict operating speeds to levels that encourage drivers to attempt them at safe speeds. The safety performance of the livable streets considered in this study appears to be principally the result of their ability to reduce operating speeds to levels that allow vehicles to safely access adjacent land uses.

When one considers this study in conjunction with previous studies on the relationship between geometric design and safety, it becomes clear that there is a need to move roadside design practice beyond the simple assumption of random driver error and to begin to account more meaningfully for the systematic factors that produce an overwhelming majority of fixed-object crashes. This will require both a better understanding of actual driver behavior and a moving beyond conventional arterial definitions of mobility to account better for the actual purpose and use of arterial roadways in urban environments.

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The Geometric Design Committee sponsored publication of this paper.