Appendix D: What the Traffic Safety Literature Tells Us[6]

In 2007, a front page story in *USA Today* proclaimed: "16 states see road deaths slashed" (January 30, 2007). State officials attributed the drop to traffic enforcement, education, and unspecified improvements in highway design. However, the article ended on a less congratulatory note. One expert called it "unfair" to give too much credit to these factors, without looking at "*vehicle miles traveled*, the cost of gas, whether people were driving as much" (emphasis added). And the final paragraph noted: "In states where fatalities rose substantially, agencies cited increases in *pedestrian deaths*, aggressive driving, drunken driving, and *speeding* as factors" (emphasis added). Readers who turned to page 3 learned that 10 states saw very significant increases in traffic fatalities.

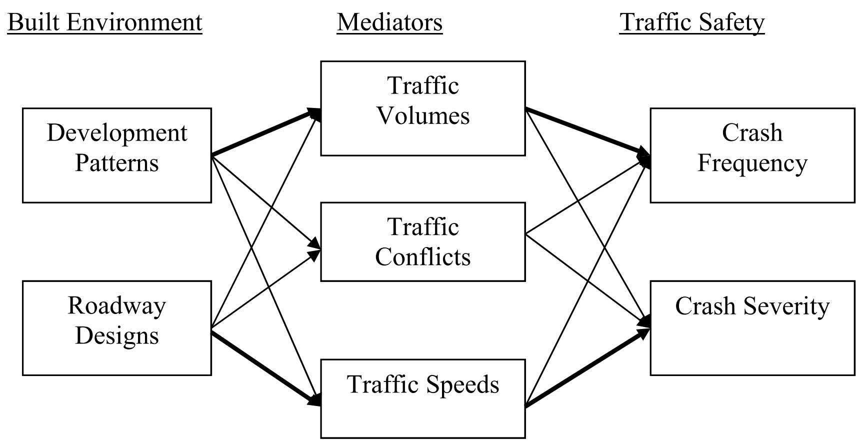
Before we declare victory in the war against highway deaths and injuries, we should take a closer look at the factors highlighted in the previous paragraph. This chapter summarizes the literature on the relationship between the built environment and traffic safety. We begin by examining broad impacts on traffic safety at the macro levels of the region and community, and then examine impacts at the micro levels of the street and site.

Conceptual Framework

A conceptual framework for this literature review is presented in Figure D-1. The published literature is generally supportive of this framework. In this framework, the built environment affects crash frequency and severity through the mediators of traffic volume and traffic speed. Development patterns impact safety primarily through the traffic volumes they generate, and secondarily through the speeds they encourage. Roadway designs impact safety primarily through the traffic speeds they allow, and secondarily through the traffic volumes they generate. Traffic volumes in turn are the primary determinants of crash frequency, while traffic speeds are the primary determinants of crash severity.

Figure D-1. Conceptual Framework Linking the Built Environment to Traffic Safety

6 This appendix is taken from Ewing, R. and Dumbaugh, E. (2009). The Built Environment and Traffic Safety: A Review of Empirical Evidence, *Journal of Planning Literature*, 23(4), 347-367.



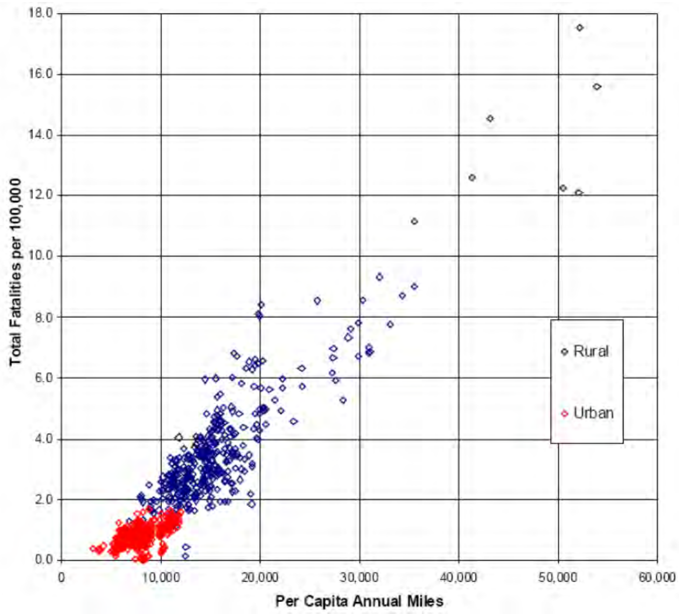
Mediating Factors

Traffic Volume

A key tenet in traffic safety is that humans are prone to error. Failure to notice a potential hazard, delayed response to a perceived hazard, or unexpected behaviors by other road users can all produce traffic crashes. Thus, each and every trip—whether as a motorist, pedestrian, or bicyclist—involves an element of risk.

Ceteris paribus, the more vehicular travel, the more risk of crashes. Litman and Fitzroy (2005) examined the relationship between per capita traffic fatalities and vehicle miles traveled (VMT) for urban and rural areas in the United States. As shown in Figure D-2, the relationship is roughly linear: as VMT increases, so do traffic fatalities. For urban areas, each 1% increase in travel is associated with a 1% increase in traffic fatalities. For rural areas, each 1% increase in VMT is associated with a 1.5% increase in traffic fatalities (Litman and Fitzroy 2005).

Figure D-2: Traffic Fatalities and VMT for Urban and Rural Areas



Source: Litman and Fitzroy (2005)

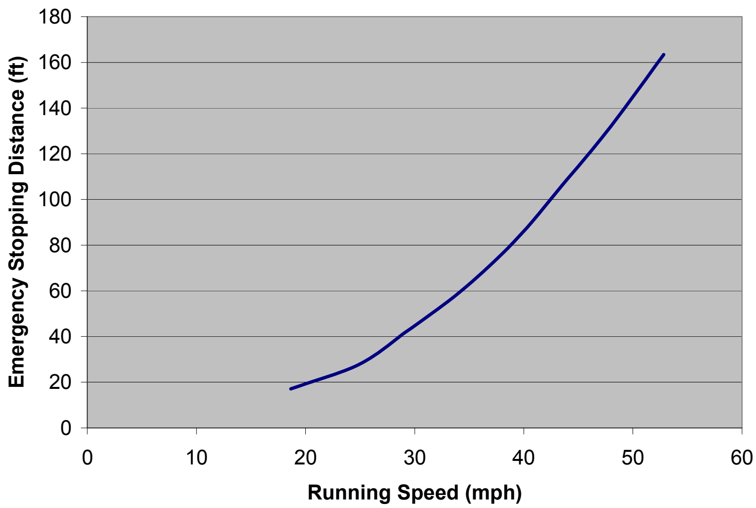
Balkin and Ord (2001) found that fatalities along individual highway facilities vary seasonally, with crashes increasing during periods that experience seasonal increases in VMT. A study of young drivers found that "the consistently significant factor influencing risk of motor vehicle crash involvement was *quantity* of kilometres driven" (Bath 1993). Similarly, the lower crash rate observed for female drivers is approximately equal to their lower average driving mileage (Butler 1996).

Other studies finding significant relationships between average daily traffic or VMT and crash frequency include Levine et al. (1995a, 1995b), Roberts et al. (1995), Hadayeghi et al. (2003), Lovegrove et al. (2006), and Hess et al. (2004).

Traffic Speed

The other main mediating factor is traffic speed. Simple physics tells us that higher operating speeds give drivers less time to react to unforeseen hazards and result in increased force of impact when crashes occur. At a running speed of 40 mph, a typical driver needs more than 80 feet to stop on wet pavement; at 30 mph, emergency stopping distance drops to just over 40 feet and at 20 mph, it is about 20 feet (see Figure D-3).

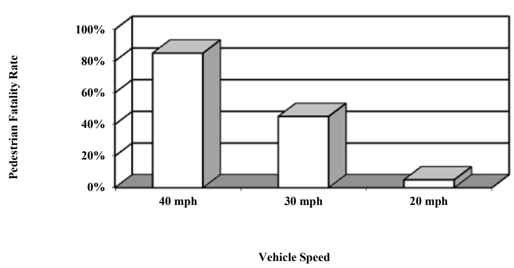
Figure D-3. Typical Emergency Stopping Distance on Wet Pavement for Various Running Speeds ()



Source: Transportation Research Institute (1997).

Beyond the generalized safety benefits associated with lower vehicle operating speeds, lower speeds have a profound effect on pedestrian safety. Struck by a vehicle traveling 40 mph, a pedestrian has an 85 percent chance of being killed. The fatality rate drops to 45 percent at 30 mph and to 5 percent at 20 mph or less (U.K. Department for Transport 1997; Zegeer et al. 2002a). This relationship is non-linear as well, with crash severity increasing exponentially with vehicle speed (see Figure D-4).

Figure D-4. Pedestrian Fatality Rates for Collisions at Different Speeds.



Source: Zegeer et al. (2002a, p. 13)

Yet perhaps more importantly, the very likelihood that a pedestrian-related crash will occur appears to increase with vehicle operating speeds. In general, low speed, "main street" type designs experience the lowest rates of vehicle-pedestrian crashes, while downtown areas with wide travel lanes and higher operating speeds experience the highest rates (Garder 2004).

It is for these reasons that European roadway engineers design for lower vehicle operating speeds, at least in developed areas (Federal Highway Administration 2001; Lamm et al. 1999; Organisation for Economic Co-Operation and Development [OECD] 1998; U.K. Department for Transport 2007).

Traffic Conflicts

It is not traffic speed alone that causes crashes. Rather it is speed differentials among vehicles in the traffic stream. Likewise, it is not traffic volume alone that causes crashes, but rather conflicting movements when traffic volumes are high. The independent role of conflicts comes up in discussions of on-street parking, access management, traffic calming, intersection control, and pedestrian countermeasures. To make this point explicit, an extra box, representing the mediating effect of traffic conflicts, has been added to Figure D-1.

Development Patterns and Traffic Safety

Accepted Theory

The literature is replete with studies showing that areas with more residents, more employment, and more arterial lane miles experience more crashes (Levine et al. 1995a, 1995b; Hadayeghi et al. 2003; Kmet, Brasher and Macarthur 2003; Ladron de Guevara et al. 2004; Hadayeghi et al. 2006; and Lovegrove et al. 2006). Such studies may be useful for crash prediction. However, they do not explain the relative risk of crashes or the rate of crashes per capita, only overall crash frequency. Where there are more people and jobs, there tends to be more of everything, from traffic to crime to coffee shops. Most of these crash prediction studies do not control for the confounding influence of VMT.

Some small-area studies have reported more crashes at higher population densities. Any attempt to infer a causal relationship is fraught with difficulty (Hadayeghi et al. 2003). Areas with high population densities tend to be located in or near employment centers, thus experiencing not only local traffic but also regional traffic entering from other areas. Also, high density areas are more likely to be traversed by multi-lane arterials, roadways with high crash rates. These too are confounding influences.

Alternative Theory

Given the direct relationship between VMT and crash exposure, development patterns with lower VMT should also have lower traffic crash rates.

Starting in about 1990, researchers began to rigorously study the relationships between the built environment and travel, with the term "3Ds" being coined to describe the factors most likely to influence travel behavior—density, diversity, and design (see Chapter 3). Other Ds were added subsequently. The D's are consistently found to have a significant effect on the distance people travel and the mode they choose. Trip lengths are generally shorter at locations that are more accessible, have higher densities, or feature mixed uses. This holds true for both the home end (i.e., residential neighborhoods) and non-home end (i.e., activity centers) of trips. Walk and transit modes claim a larger share to all trips at higher densities and in mixed-use areas, meaning that the number of vehicle trips (VT) drops as well.

Urban Sprawl

If the relationship between VMT and traffic fatalities is near-linear, then "sprawling" environments, which are known to generate higher per capita VMT, should also report higher rates of traffic crashes and fatalities (Ewing et al. 2002). The *Mean Streets* series, put out by the Surface Transportation Policy Project, shows pedestrian fatality rates, adjusted for exposure, to be higher in metropolitan areas generally viewed as more sprawling (2000, 2002, 2004). STPP created a pedestrian danger index by adjusting annual pedestrian fatality rates for a measure of exposure, the share of commuters walking to work from the U.S. Census. The 10 most dangerous places in terms of this index are all sprawling sunbelt metros (see Table D-1).

Limiting the value of these studies is the fact that they (1) do not measure sprawl explicitly, (2) do not control for potentially confounding variables such as income and age distribution, (3) use an imprecise measure of pedestrian exposure, and (4) fail to test for statistical significance. As with all studies at this level of geographic aggregation, the possibility of aggregation bias may preclude extension of results to smaller areas.

Table D-1. Most Dangerous Metropolitan Areas for Pedestrians*

	Metro Area	Pedestrian Danger Index
1	Orlando, FL	243.6
2	Tampa-St Petersburg-Clearwater, FL	215.3
3	West Palm Beach-Boca Raton, FL	209.9
4	Miami-Fort Lauderdale, FL	166.3
5	Memphis, TN-AR-MS	159.1
6	Atlanta, GA	144.4
7	Greensboro--Winston-Salem--High Point, NC	122.5
8	Houston-Galveston-Brazoria, TX	121.9
9	Jacksonville, FL	120.7
10	Phoenix-Mesa, AZ	117.2

* The Pedestrian Danger Index is calculated by dividing the average annual fatality rate per 100,000 population for a metropolitan area by the percentage of commuters walking to work in that metropolitan area, using "journey to work" data from the decennial Census.

Source: Surface Transportation Policy Project (2004)

A study for the U.S. Environmental Protection Agency (EPA) matched metropolitan areas in terms of size and density, but consciously chose metros with contrasting transportation systems (EPA 2004). Differences were evident in block size, street network density, intersection density, percent of four-way intersections, and transit service density. Metros with smaller blocks, dense streets and intersections, more four-way intersections, and more transit service were said to epitomize "smart growth." The others were more representative of sprawl. The matched comparison showed that metros with smart growth transportation systems (the first one in each set in Table D-2) sometimes had lower annual traffic fatality rates per million population. This was the case for Philadelphia, New Orleans, and Omaha. Other times the reverse was true. Results were also mixed for annual fatalities per billion VMT traveled.

Applicability of these results is, once more, limited by the geographic scale of the places compared, by lack of control variables, and lack of statistical testing. Compared to the results of studies using more complete measures of the built environment, they suggest that transportation system characteristics by themselves (absent more compact land use patterns) do not guarantee a safer traffic environment.

Table D-2. Traffic Safety Measures for 13 Study Regions

	Fatalities per million population per year	Fatalities per billion VMT per year
Philadelphia	66	9.6
Atlanta	119	9.8
Houston	137	14.2
Pittsburgh	99	10.9
Tampa/St. Petersburg	179	20.2
St. Louis	89	8.1
New Orleans	112	19.2
Charlotte	145	11.8
Nashville	175	15.5
Omaha	81	10.1
Little Rock	190	16.3
Erie	135	22.9
Binghamton	107	8.9

Source: EPA (2004)

In an attempt to overcome such limitations, Ewing et al. (2002, 2003a) developed metropolitan sprawl indices and related them to various transportation outcomes. Sprawl was defined by: (1) a population widely dispersed in low density residential development; (2) a rigid separation of homes, shops, and workplaces; (3) a lack of distinct, thriving activity centers, such as strong downtowns or suburban town centers; and (4) a network of roads marked by very large block size and poor access from one place to another. Principal component analysis was used to reduce 22 land use and street network variables to four factors representing these four dimensions of sprawl, each factor being a linear combination of the underlying operational variables. The four were combined into an overall metropolitan sprawl index. All indices were standardized on a scale with a mean value of 100, and a standard deviation of 25. The way the indices were constructed, the higher the value of the index, the more compact the metropolitan area. The lower the value, the more sprawling the metropolitan area.

Controlling for sociodemographic differences across metropolitan areas, three of the factors—density, mix, and centering—were significantly related to annual traffic fatalities per 100,000 residents (see Table D-3). The higher the density, the finer the mix, and the more centered the development pattern, the fewer highway fatalities occur on a per capita basis. This is in part due to the mediating influence of VMT per capita, which is lower in compact metropolitan areas. But it may also be due to another mediating influence, lower average speeds. The traffic fatality rate actually declines at a faster rate than VMT as density, mix, and centering increase.

Table D-3. Best-fit regression equation for annual traffic fatalities per 100,000 residents (t-statistics in parentheses).

constant	20.16
metropolitan density factor	-0.105 (-2.5)*
metropolitan mix factor	-0.041 (-2.5)*
metropolitan centeredness factor	-0.037 (-2.3)*
metropolitan streets factor	0.0149 (0.8)
metropolitan population	-9.4E-08 (-0.3)
average household size	0.667 (0.3)
percentage working age population	0.226 (1.1)
per capita income	-0.00032 (-2.6)*
adjusted R^2	0.44

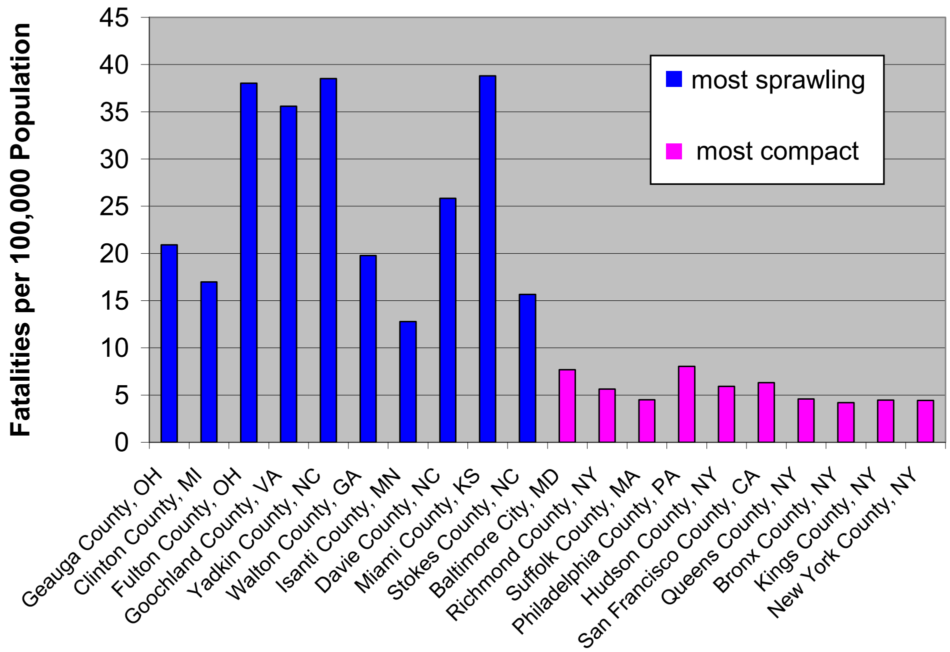
* .05 probability level
** .01 probability level
*** .001 probability level

Source: Ewing (2002)

Ewing et al. (2003b) also developed a simpler county sprawl index to measure the built environment at a finer geographic scale, the individual county. It is a linear combination of six variables from the larger set, these six being available for counties, whereas many of the larger set are available only for metropolitan areas. Four of the variables relate to residential density and two relate to street accessibility from one place to another. Principal component analysis was used to extract the single factor that best represents the degree of sprawl. The factor was then transformed into a scale with a mean of 100 and standard deviation of 25.

County-level sprawl proved significantly related to each of three accident-related variables, the overall county-level traffic fatality rate per 100,000 residents and two county-level traffic fatality rates specific to pedestrians. Controlling for socioeconomic differences across counties, the more sprawling the area, the higher the all-mode traffic fatality rate and the higher the rate of pedestrian fatalities, adjusted for exposure (see Figure D-5). The relationship between county-level sprawl and miles driven has recently been confirmed for teenage drivers as well (Trowbridge and McDonald 2008).

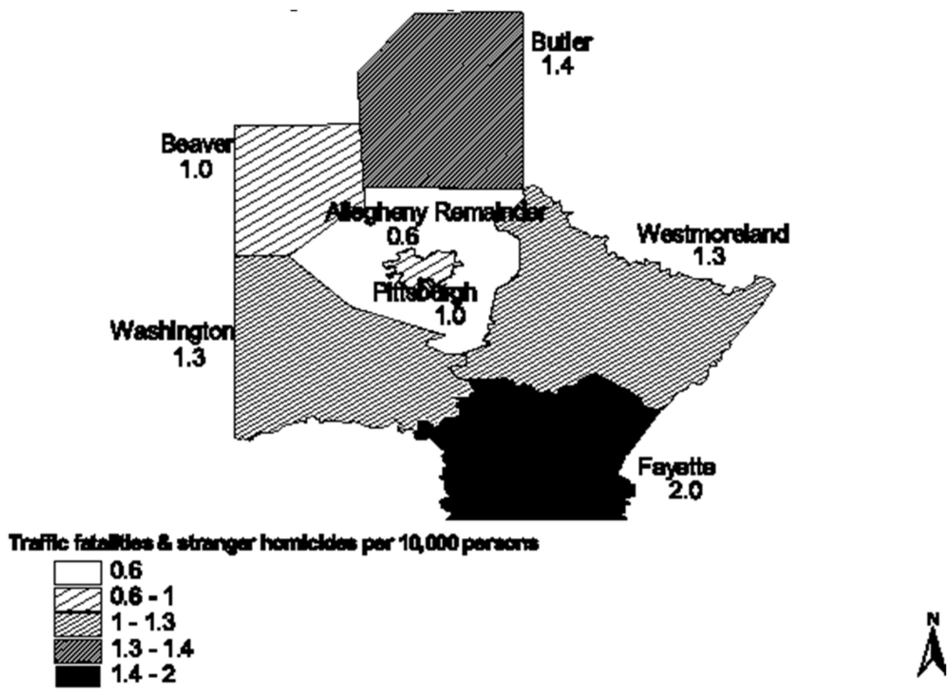
Figure D-5. All-Mode Traffic Fatality Rate for Most Sprawling and Most Compact Counties



Source: Ewing et al. (2003b)

Finally, a novel study by Lucy and colleagues (Lucy and Rabalais 2002; Lucy 2003; Lucy and Phillips 2006) compared the relative risk of living in cities and suburbs, taking into account both traffic fatalities and homicides. Leaving home proved more dangerous for residents of outer suburban areas than for many central city residents and for nearly all inner suburban residents. They reached this conclusion by analyzing the locations and rates of traffic fatalities and homicides by strangers. The metropolitan areas examined were Baltimore, Chicago, Dallas, Houston, Milwaukee, Minneapolis-St. Paul, Philadelphia, and Pittsburgh for the years 1997 through 2000. Homicides committed by family and friends, usually in the home, were excluded as irrelevant to the study of safety and the built environment. The overall fatality rate by county for one metropolitan area is plotted in Figure D-6. Note the greater danger associated with outlying areas.

Figure D-6. Average Rate of Traffic Fatalities + Stranger Homicides for the Pittsburgh Metropolitan Area



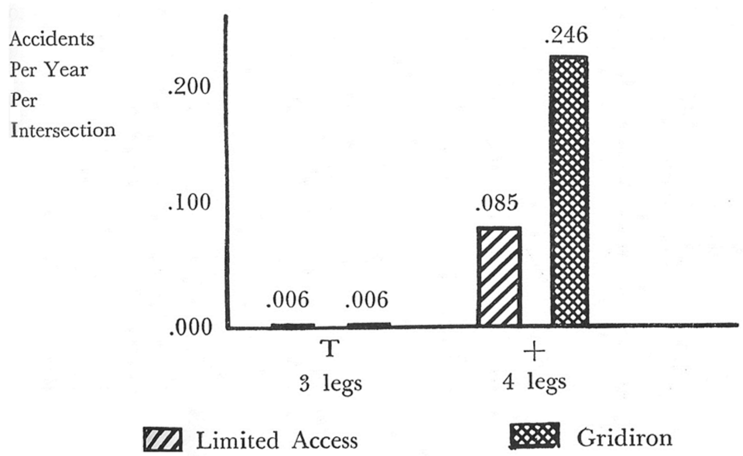
Source: Lucy and Rabalais (2002)

Street Network Design

The traditional urban grid has short blocks, straight streets, and a crosshatched pattern. The typical contemporary suburban street network has large blocks, curving streets, and a branching pattern. The two prototypical networks differ in three respects: (1) block size, (2) degree of curvature, and (3) degree of interconnectivity.

One early study compared crash rates in subdivisions with the two types of networks, referred to as gridiron and limited-access (Marks 1957). These roughly correspond to the traditional and contemporary networks described above. The distribution of crashes was fairly uniform across the gridirons; crashes were concentrated wherever two continuous streets met at a four-way intersection. Where there were interruptions in the grid, creating three-way intersections, crashes were infrequent. The limited-access networks also had crashes concentrated at four-way intersections, but there were relatively few of these intersections in the network. The large number of T-intersections in the limited-access network had practically no crash history. Overall, the crash frequency for the five-year period studied was 77.7 crashes per year for the gridiron subdivisions and 10.2 crashes per year for the limited access subdivisions. The difference was in the proportion of four-way vs. three-way intersections for the two types of networks. Crash frequencies were dramatically higher for four-way than three-way intersections, regardless of the network type (see Figure D-7). As discussed in the traffic calming section below, roundabouts and other techniques can mitigate dangers at four-way intersections, thus addressing the safety concerns of a gridiron network.

Figure D-7. Crash History of 3-Way and 4-Way Intersections



Source: Marks (1957)

The Marks study has been criticized for failing to consider the severity of crashes in the two networks, and the rate of crashes for the networks as a whole (not just the portion within subdivisions). Still, the main conclusions are supported by more recent studies.

Lovegrove et al. (2006) found that areas with more 4-way intersections had higher crash rates than those with 3-way intersections. They also found that areas with more lane miles of arterials had significantly higher crash rates relative to those with more local street mileage. Ladron de Guevara et al. (2004) similarly found a positive relationship between percentage of roadways classified as arterials or collectors and rates of total and injurious crashes, if not fatal ones. Higher intersection densities were associated with fewer total, injurious, and fatal crashes, a result attributed to lower speeds.

Generalizing, it appears that the shorter the uninterrupted length of roadway, the slower the traffic will travel and the less severe any crashes will be. Short stretches ending in T-intersections are particularly effective in reducing speed, crash frequency, and crash severity.

Roadway Design and Traffic Safety

Accepted Theory

The conventional theory of roadway design is that wider, straighter, flatter, and more open is better from the standpoint of traffic safety. High speed designs are presumed to be more forgiving of driver error, and thus to lead to reduced incidence of crashes and injuries. As stated in the AASHTO *Green Book*: "every effort should be made to use as high a design speed as practical to attain a desired degree of safety" (AASHTO 2004a, p. 67).

Two facts and two concurrent trends support this view. One fact is that high speed design features such as wide shoulders and gentle curves improve highway safety in rural areas, particularly on two-lane rural roads (Zegeer and Council 1995). The other fact is that the Interstate highway system, which is designed for high speeds, generally experiences lower crash rates than other roadway classes.

The concurrent trends are (1) the sharp decline in crash rates over the past 40 years at the same time (2) lanes and shoulders have been widened, curves straightened, and design speeds generally raised. Concurrent timing has led to the assumption of causality, specifically, that the use of higher design speeds enhances roadway safety (Dumbaugh 2005a).

The conventional engineering wisdom fails to account for an array of confounding factors that influence the safety performance of highways. Land use context and vehicle operating conditions are entirely different in urban than rural areas. The much greater degree of conflict among road users in urban areas renders findings from rural safety studies of limited value in urban areas. The lower crash rates on the Interstate highway system are at least in part attributable to controlled access, which eliminates the turning maneuvers and speed differentials that produce the majority of urban crashes (Dumbaugh 2005a; 2006b). In addition, pedestrians and bicyclists, vulnerable road users, are banned from the Interstate highway system.

As for the concurrent trends, after accounting for changes in the demographic mix of the driver population, increased seat belt use, and improvements in emergency services, one national study of crash performance found that:

> Changes in highway infrastructure that have occurred between 1984 and 1997 have not reduced traffic fatalities and injuries, and have even had the effect of increasing total fatalities and injuries… other factors, primarily changes in the demographic age mix of the population, increased seat belt usage and improvements in medical technology are responsible for the downward trend in fatal accidents (Noland 2001).

This study was replicated using more focused data for the state of Illinois, and again it was found that "changes in infrastructure have actually led to increased accidents and fatalities" (Noland and Oh 2004).

Alternative Theory

Beginning with Jane Jacobs' *The Life and Death of Great American Cities* (Jacobs 1961) and extending to the New Urbanism (Duany and Talen 2002), walkable communities (Bicycle Federation of America 1998), and smart growth (Smart Growth Network) movements, urban planners have argued for narrower, shorter, more enclosed, and more interconnected streets. The viewpoint of planners is almost 180 degrees counter to conventional engineering practice.

Planner/engineer Peter Swift studied approximately 20,000 police accident reports in Longmont, Colorado to determine which of 13 physical characteristics at each accident location (e.g., width, curvature, sidewalk type, etc.) accounts for the crash. The results are not entirely surprising: the highest correlation was between collisions and the width of the street. A typical 36-foot wide residential street has 1.21 collisions/mile/year as opposed to 0.32 for a 24 foot wide street. The safest streets were narrow, slow, 24-foot wide streets (Swift 2006).

Who is right? How to reconcile these different points of view? Based on a review of urban safety studies, this section concludes that what is good for rural roads and urban freeways is not necessarily best for urban roadways generally. Due to their different operating conditions and different contexts, urban roadways appear to follow a different set of safety rules more in line with the views of the urbanists. Still, when it comes to on-street parking, access management, and pedestrian countermeasures, the engineers may have gotten it right.

Road Width

There is constant pressure to add lanes and widen roads in order to relieve congestion. Whatever the operational benefits, research has shown the road widenings occur at the expense of safety, even after controlling for traffic volumes (Dumbaugh 2005b; Harwood 1986; Milton and Mannering 1998; Noland and Oh 2004; Sawalha and Sayed 2001; Vitaliano and Held 1991; Hummer and Lewis 2000--see Table D-4). Conversely, eliminating lanes appears to improve traffic safety. Studies of "road diet" projects, which are projects that convert four-lane roadways into roadways with two-through lanes and a center turn lane, find that traffic crashes decrease as lanes are eliminated (Huang et al. 2002; Knaap and Giese 2001).

Table D-4. Collision Rates by Cross Section, Development Type, and Development Density

	Collisions per 100 Million Vehicle Miles			
Development Density:	Medium		High	
Development Type: Cross Section	Residential	Commercial	Residential	Commercial
Two-lane	110	270	230	[a.]
Three-lane	180	210	190	230[b.]

Undivided four-lane	230	260	370	1500[b.]

[a.] No data

[b.] Very small sample sizes

Source: Hummer and Lewis (2000)

Wide lanes may also adversely affect traffic safety, at least in urban areas. Noland and Oh (2004) found that wider lanes were associated with statistically-significant increases in total and fatal crashes in the state of Illinois. Lee and Mannering (1999) discovered that while wide lanes reduced the probability of run-off-roadway crashes in rural settings, they were associated with *increases* in the same crash types in urban areas. Hauer (1999) re-examined the historical literature on lane widths and traffic safety, and found that research from 1940 forward has consistently shown crashes increasing as lanes exceed 11 feet in width.

The root cause may be speed. Vehicle operating speeds decline somewhat as individual lanes and street sections are narrowed (Harwood 1990; Farouki and Nixon, 1976; Heimbach et al. 1983; Clark 1985; Gattis and Watts 1999; Gattis 2000; Fitzpatrick et al. 2001). Drivers seem to behave less aggressively on narrow streets, running fewer traffic signals, for example (Untermann 1990). Also, drivers may feel less safe and drive more cautiously on narrow streets (Mahalel and Szternfeld 1986). On two-lane roads, prudent drivers set the pace and others must follow. On multi-lane roads, where passing is possible, high-speed drivers set the prevailing speed (Burden and Lagerwey 1999).

Yet, one should be careful not to give too much credit to narrow cross sections alone. Dumbaugh (2005b) concluded that it is not narrow lanes by themselves that reduce speeds, but narrow lanes combined with other design elements, such as roadside streetscape elements, that re-enforce the message to slow down.

On-Street Parking

Good shopping streets nearly always have on-street parking. So do most residential streets. Parked cars act as a buffer between traffic and pedestrians (Schmitz & Scully 2009; Livingston 2005). They are a convenience to shoppers and residents.

However, these benefits may be realized at the expense of traffic safety. The limited literature on the subject suggests that on-street parking accounts for a significant proportion of urban crashes (Seburn 1967; Humphreys et al. 1978; Texas Transportation Institute 1982; McCoy et al. 1990; McCoy et al. 1991; Box 2000; ITE 2001; Box 2002; Box 2004). This is especially true for children, as a large number of child injuries and fatalities from motor vehicle crashes occur when children dart out from between parked cars. If parking is permitted, conflicts with parked cars produce about 40 percent of total crashes on two-way major streets, 70 percent on local streets, and a higher percentage on one-way streets (Box 2000). The number of crashes increases with the parking turnover rate, meaning that land uses which generate high turnover will also generate more traffic crashes (Humphreys et al. 1978). Crash rates are particularly high with angle parking, as compared to parallel parking (McCoy et al. 2001; ITE 2001; Box 2002).

Interestingly, we could find no study of crash rates on comparable roadway sections with and without curbside parking, the ultimate test of on-street parking's safety impact. One study that did measure residential street typology and the rate of crashes with pedestrians found that the existence of parking had no affect on crash rates (Swift 2006). It is possible that where parking is provided, parked cars account for a large proportion of crashes, and yet overall crash rates are about the same as on sections without parking.

Another consideration with on-street parking is its effect on bicycle safety. One of the main causes of vehicle-bicycle incidents is “dooring” – a vehicle occupant suddenly opening a door into the path of a cyclist. Designers go to great lengths to create facilities that place cyclists out of the door zone. Norwegian research suggests that prohibiting on-street parking leads to a 20-25 percent reduction in vehicle-bicycle collisions. So while parking acts as a buffer for pedestrians and provides “friction” which slows vehicles, it presents challenges for cyclists and can “hide” children from drivers

Traffic Calming Measures

Speed humps, traffic circles, and other traffic calming measures are perceived by some traffic engineers, residents, and members of the media as obstacles in the roadway. Were they truly obstacles, such measures might increase crash rates. They do just the opposite by slowing traffic.

The Insurance Corporation of British Columbia summarized 43 international traffic calming case studies (Geddes 1996). Collision frequencies declined by anywhere from eight to 100 percent with traffic calming. Ewing (2001) compared collision frequencies before and after traffic calming measures were installed. For the sample as a whole, collisions declined to a very significant degree after traffic calming (the difference being statistically significant at the .001 probability level). Adjusting for changes in traffic volumes, and dropping cases for which volume data were not available, collisions still declined significantly at the conventional 0.05 probability level. As for individual traffic calming measures, all reduced the average number of collisions on treated streets, and 22-foot tables and traffic circles produced differences that were statistically significant (see Table D-5).

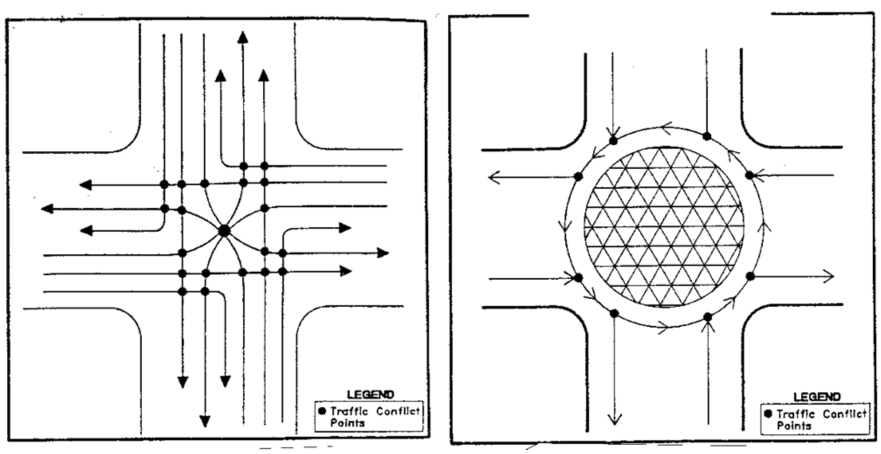
The mitigating role of traffic conflicts is implicit in these statistics. Speed tables are believed to have a better safety record than speed humps because their higher design speeds require less deceleration on the approach, and less acceleration on the exit (Ewing 1999). This reduces the likelihood of rear-end collisions. Seattle traffic circles particularly improve safety by reducing the number of conflicting movements at uncontrolled four-way intersections. Seattle circles thus overcome the primary disadvantage of the traditional urban grid (see Figure D-8 and “Street Network Design”).

Table D-5. Safety Impacts of Traffic Calming Measures

	Number of Observations	Average Number of Collisions Before/After Treatment	% Change in Collisions Before->After Treatment	t-statistic (significance level—two-tailed test)
Humps	54	2.8/2.4	-14%	-1.2 (.22)
22' Tables	51	1.5/.8	-47%	-3.0 (.005)
Circles				
without Seattle	17	5.9/4.2	-29%	-2.2 (.05)
with Seattle	130	2.2/.6	-73%	-10.8 (.001)
All Measures				
without adjustments	235	2.2/1.1	-50%	-8.6 (.001)
with adjustments	47	1.8/1.2	-33%	-2.5 (.05)

Source: Ewing (2001)

Figure D-8. Conflict Points for Uncontrolled Intersection without and with a Traffic Circle



It is curious that safety impacts of traffic calming in the U.S., while favorable, would be less pronounced than outside the U.S. One possible explanation is that European and British traffic calming treatments are more intensive and more integrated with their surroundings than U.S. treatments. Reported speeds drop on average by almost 11 mph or 30 percent in a British sample (County Surveyors Society 1994) compared to under 7 mph or 20 percent for U.S. treatments (Ewing 2001).

All of the traffic calming literature referenced thus far relates to traffic collisions generally. One recent study showed that the presence of speed humps on a street was associated with lower odds of child pedestrians being injured within their neighborhoods or being struck in front of their homes (Tester et al. 2004).

Access Management

Speed is not the only culprit in urban traffic crashes. The presence of driveways and side streets along arterials create conflicts between through-moving vehicles and those attempting to turn into and out of adjacent driveways. Rear-end crashes are common as drivers decelerate to negotiate turns or enter the traffic stream from driveways or side streets at lower-than-prevailing speeds. Angle crashes are commonplace as drivers attempt to turn left into driveways or side streets, but have insufficient time to clear opposing traffic lanes.

Two strategies exist for moderating access-related crashes. The first is to reduce the speeds of through-moving vehicles, thereby minimizing speed differentials with turning vehicles (Dumbaugh 2006a). The second is to control turning movements, while maintaining higher speeds for through-moving vehicles, through access management. Access management is the control of the location, spacing, and operation of driveways, median openings, and street connections to a main roadway.

The traffic safety benefits associated with access management techniques are summarized by S&K Transportation Consultants (2000). They range from a 20 percent reduction in crashes associated with the addition of right turn bays, to a 67 percent reduction associated with the addition of left-turn dividers. Crash rates appear to vary with the square root of access density, up to about 40 access points per mile (Committee on Access Management 2003). Crash rates are higher on roads with unlimited left turns (Gluck et al. 1999). The dual effects of two variables—access point density and non-traversable medians—are reflected in Table D-6.

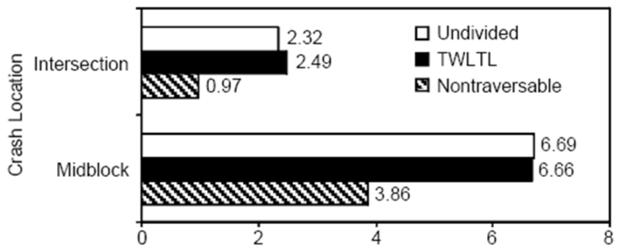
Table D-6. Crash Rates on Urban and Suburban Roads with Different Levels of Access Control (per million vehicle miles)

	Median Type		
Access Points per Mile	Undivided	Two-Way Left-Turn Lane	Non-Traversable Median
≤ 20	3.8	3.4	2.9
20-40	7.3	5.9	5.1
40-60	9.4	7.9	6.8
>60	10.6	9.2	8.2

Source: Committee on Access Management (2003)

Raised medians, embraced by highway agencies for operational reasons, are favored by pedestrian advocates as well. They provide refuge areas for pedestrians, who can cross in stages. A study of pedestrian-vehicle crash experience on arterial roadways in Atlanta, Phoenix, and Los Angeles found that crash rates were about half as high on arterials with raised medians compared to undivided roadways or roadways with center two-way left-turn lanes (see Figure D-9).

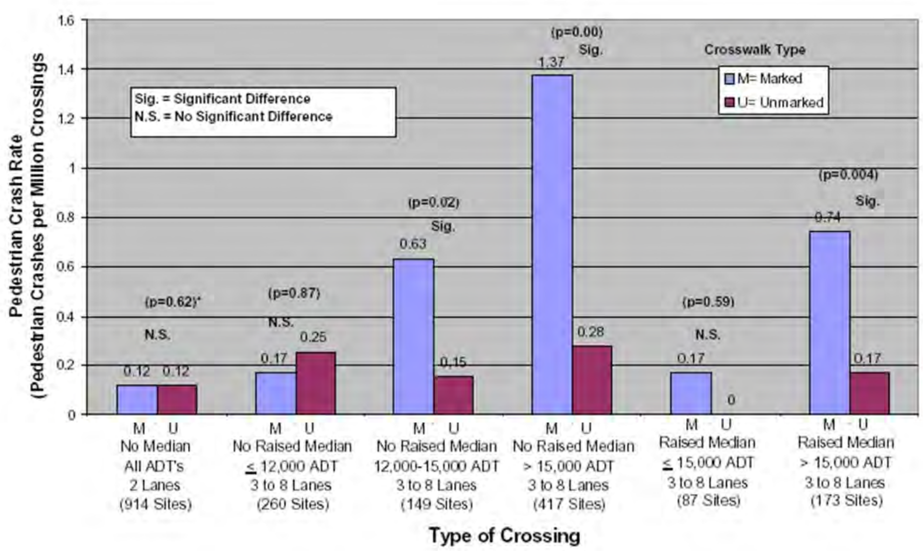
Figure D-9. Pedestrian Crash Rates for Suburban Arterials with Different Access Control



Source: Bowman and Vecellio (1994)

Safety benefits of medians appear to vary by type and width. In one study, pedestrian collisions fell by 23 percent when a 6-foot painted median was replaced with a wide raised median (Claessen and Jones 1994). In another study, the narrowest medians (four feet) had four times the pedestrian crash rate of the widest medians (10 feet) (Scriven 1986). Very narrow medians may reduce vehicle-to-vehicle crashes but have no effect on pedestrian crashes (Johnston 1962; Leong 1970). Raised medians and raised crossing islands may reduce vehicle-pedestrian crashes on multi-lane roads, while painted medians and two-way left turn lanes do not (see Figure D-10).

Figure D-10. Pedestrian Crash Rates by Type of Crossing



Source: Zegeer et al. (2002b, p. 8)

Access management can also benefit cyclists for the same reason it affects overall traffic flow. Without the distraction of constant driveways and cross-traffic, cycling is safer and more comfortable.

Before one declares access management a win-win for motorists and pedestrians, two caveats should be noted. First, while medians may enhance pedestrian safety, it is not clear that access management strategies, considered as a whole, also do so. Central to the concept of access management is wide spacing of signalized intersections, preferably with distances of one-quarter mile or greater (Florida Department of Transportation 2006; Minnesota Department of Transportation 2002; Nevada Department of Transportation 1999). Such spacing limits the number of opportunities for pedestrians to cross with signals, thus encouraging hazardous midblock crossings. Also, access management may involve the provision of service roads adjacent to the main line or parallel reliever roads for local traffic. A portion of the reported safety benefits currently attributed to access management may be lost when access-related crashes are transferred from a main arterial to parallel roads.

Intersection Control

Crashes are concentrated at intersections because vehicle-vehicle and vehicle-pedestrian conflicts are concentrated there. Some forms of intersection control are more effective at reducing conflicts than others.

All-way stops have never been a favorite with U.S. traffic engineers. Yet, all-way stops produce lower vehicle speeds near intersections than do traffic signals or two-way stops. From a safety standpoint, they appear to outperform signals at moderate traffic volumes, say, up to 10,000 vehicles per day on the major street (Bissell and Neudorff 1980; Ebbecke and Schuster 1977; and Syrek 1955). One study found that pedestrian collisions declined by 25 percent when traffic signals at low-volume urban intersections were converted to all-way stops (Persaud et al. 1997).

Historically, U.S. traffic engineers have not favored roundabouts either, as modern roundabouts were mistaken for old-fashioned traffic circles. With modern roundabouts, yield to circulating vehicles, deflection at entry, and the curvature of the travel path through the intersection, all reduce travel speeds. Counter-clockwise circulation around the center island reduces the number of conflict points, largely eliminating certain types of collisions such as right angle and left turn head-on crashes.

Several studies have shown that roundabouts outperform other intersection control devices with respect to safety (Persaud et al. 2002; Jacquemart 1998; Maycock and Hall 1984; Robinson 2000; Schoon and Minnen 1993; Schoon and Minnen 1994). Even where crash frequencies are comparable to other intersections, crash severity is lessened (Brown 1995). Persaud et al. (2002) evaluated the change in crash rates following the conversion of 24 intersections to modern roundabouts in the United States. There was a significant overall reduction of 39 percent in crash rates. For crashes involving injuries, the reduction was 76 percent. Crashes involving deaths or incapacitating injuries fell by about 90 percent.

Small and medium capacity roundabouts are safer than large or multilane roundabouts (Maycock and Hall 1984; Alphand et al. 1991). Single-lane roundabouts, in particular, have been reported to produce substantially lower pedestrian crash rates than comparable intersections with traffic signals (Brude and Larsson 2000). Crash reductions are most pronounced for motor vehicles, less pronounced for pedestrians, and uncertain for bicyclists, depending on the study and bicycle design treatments (Robinson 2000; Schoon and Minnen 1993; Schoon and Minnen 1994; Brown 1995). Comparative crash statistics from one study are presented in Table D-7.

Table D-7. British Crash Rates for Pedestrians at Roundabouts and Signalized Intersections

Intersection Type	Pedestrian Crashes per Million Trips
Mini-roundabout	0.31
Conventional roundabout	0.45
Flared roundabout	0.33
Signals	0.67

Source: Robinson (2000).

While the European experience with roundabouts suggests that they are relatively safe for pedestrians and bicyclists, there remains in the United States a preference for traffic signals at locations with high pedestrian and bicycle traffic. Signals provide a periodic gap in traffic for crossing pedestrians, while the continuous flow of roundabouts does not. Signals require no deflection of motor vehicles crossing an intersection, while roundabouts may cause motorists to cross paths with bicyclists. There are particularly serious issues of access for pedestrians with disabilities. Some of this may be attributed to low levels of cycling and walking in the United States as compared to Europe, which creates a more hostile relationship between drivers and other roadway users.

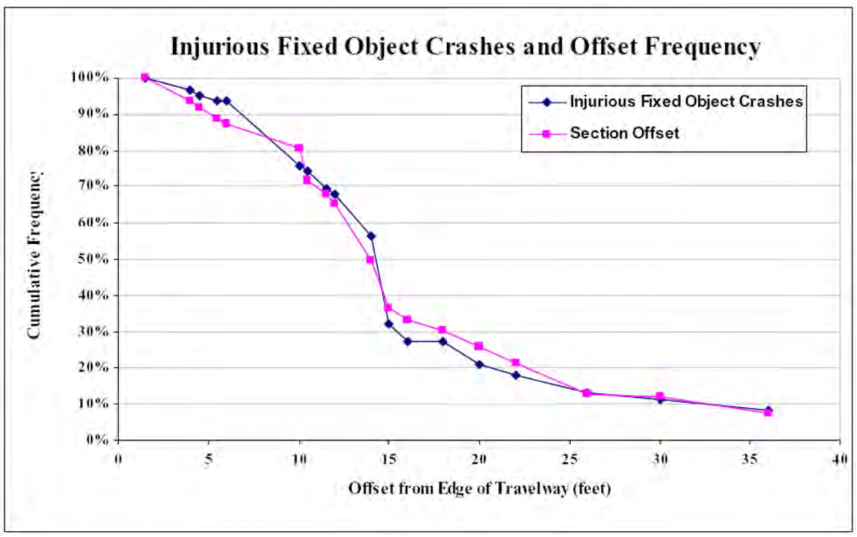
Roadside Design

The roadside is the location for most pedestrian amenities, including sidewalks, street trees and street lighting. Conventional engineering design practice encourages placement of such features as far away from the roadway as possible, to create a wide "clear zone" in case motorists lose control and leave the roadway. "…the wider the clear zone, the safer it will be" (Transportation Research Board 2003, p. V-43).

This recommendation is based on the physical locations of roadside crashes. Hall et al. (1976) observed that most utility pole crashes occur along curves and within 11.5 feet of the travelway, Zeigler (1986) that 85 percent of tree-related crashes occurred within 30 ft of the travelway, and Turner and Mansfield (1990) that 60 percent of trees involved in crashes were located along horizontal curves, and that 80 percent were within 20 feet of the travelway.

Such descriptive statistics only tell us where roadside crashes occur, not whether roadside crashes are more likely or more severe when fixed objects are near the roadway. Also, any conclusions related to clear zones on high-speed rural roads will not necessarily apply to low-speed urban streets. Lee and Mannering (1999) found that urban roadways with trees located in the nominal "clear zone" actually have fewer roadside crashes than locations where trees were not present. Naderi (2003) examined the safety effects of urban streetscape improvements along five arterial roadways in downtown Toronto, and concluded that the addition of roadside features such as trees and concrete planters reduced crashes by 5 to 20 percent. Plotting the frequency of injurious roadside crashes against the actual percentage of road segments that had clear zones of each offset width, Dumbaugh (2005b) found that the probability of a roadside-object related crash was largely independent of the roadway's fixed-object offset (see Figure D-11).

Figure D-11. Injurious Roadside Crashes and Roadside Offset



Source: Dumbaugh (2005b)

Pedestrian Countermeasures

Pedestrian countermeasures are engineering actions taken to improve the safety of roadways for pedestrians. One study classified countermeasures into three broad categories: separation of pedestrians from vehicles by time and space; measures that increase the visibility and conspicuity of pedestrians; and reductions in vehicle speed (the last of these already covered under the heading of traffic calming) (Retting et al. 2003). The *Pedestrian Facilities Users Guide* lists 47 such measures (Zegeer et al. 2002a).

Most of the studies of pedestrian countermeasures have used proxies for traffic safety to document impacts. Travel speeds have been measured in some cases, conflict counts and yielding behavior in others. Actual crash rates are seldom measured in such studies.

This may not constitute as big a shortcoming as would at first appear, however, since conflict counts have been shown to provide an accurate estimate of multi-year crash rates (Hauer and Garder 1986).

Sidewalks are an absolute necessity along all through-streets serving developed areas. Vehicle-pedestrian collisions are more likely on street sections without sidewalks than those with them, two and one-half times more likely according to one study (Knoblauch et al. 1988). Sidewalk clearances, vertical curbs, street trees between street and sidewalk, and parked cars all add to the sense of security.

At signal- and stopped-controlled intersections, traffic is forced to stop for pedestrians with or without marked crosswalks. The issue is whether to mark crosswalks at uncontrolled intersections and midblock locations. In one study of uncontrolled locations, drivers were found to approach pedestrians in a crosswalk somewhat slower, and crosswalk usage was found to increase, after markings were installed (Knoblauch et al. 2001). However, this study found no changes in driver yielding behavior or pedestrian assertiveness. Overall, the study concluded that marking pedestrian crosswalks at relatively low-speed, low volume, unsignalized intersections is a desirable practice.

Another study evaluated driver speeds before and after installation of crosswalk markings at uncontrolled intersections (Knoblauch and Raymond 2000). Speed data were collected under three conditions: no pedestrian present, pedestrian looking, and pedestrian not looking. Overall, there was a significant reduction in speed under both the no pedestrian and the pedestrian not looking conditions. It appeared that crosswalk markings made drivers on relatively low-speed arterials more cautious and more aware of pedestrians.

The most ambitious study of crosswalks at uncontrolled locations involved a comparison of five years of pedestrian crashes at 1,000 marked crosswalks and 1,000 matched unmarked comparison sites. All sites in this study lacked traffic signals or stop signs on the approaches (Zegeer et al. 2002b). The study results revealed that on two-lane roads, the presence of a marked crosswalk alone at an uncontrolled location was associated with no difference in pedestrian crash rate, compared to an unmarked crossing. Further, on multi-lane roads with traffic volumes above about 12,000 vehicles per day, having a marked crosswalk alone (without other substantial improvements) was associated with higher pedestrian crash rates (after controlling for other site factors). Hazards were mitigated by raised medians.

A comparative evaluation of different engineering treatments found that the particular crossing treatment employed has a dramatic effect on motorists' propensity to yield to crossing pedestrians. Treatments that show a red signal indication to motorists have a statistically significant advantage over devices that do not show a red indication. Specifically, midblock signals, half signals, and high-intensity activated crosswalk (HAWK) signal beacons have compliance rates greater than 95 percent even on busy, high-speed arterial streets. Pedestrian crossing flags and in-street crossing signs also were effective in prompting motorist yielding, achieving 65 and 87 percent compliance, respectively. However, most of these crossing treatments were installed on lower-speed and lower-volume, two-lane roadways. High visibility signs and markings, and overhead flashing beacons, had much lower compliance rates. On this basis, the study recommended changes in the *Manual on Uniform Traffic Control Devices* (MUTCD) pedestrian traffic signal warrant.

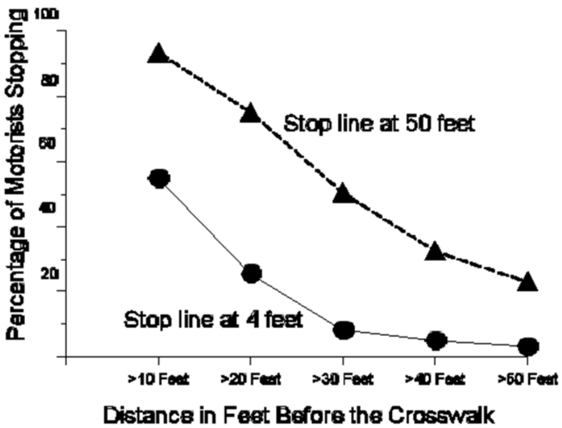
Studies from other countries speak to the safety benefits of pedestrian activated signals at uncontrolled crossing points. Installing so-called Pelican signals was highly effective in reducing crashes in Australia, the quarterly crash rate falling by 90 percent (Geoplan 1994). The Pelican signal is similar to a standard mid-block pedestrian signal, except that during the pedestrian clearance phase, the display facing motorists changes to a flashing yellow, indicating that vehicles may proceed cautiously through the crossing but are required to yield to pedestrians. In this way these signals produce less delay for motorists than standard pedestrian-activated signals. Installing standard pedestrian activated signals at midblock locations also gave rise to statistically significant reductions in crashes. In this case the adjusted reduction was 49 percent.

Canadian research in the area of pedestrian safety has focused on six countermeasures:

- Interventions to prompt pedestrians to look for turning vehicles when crossing at signalized crosswalks, including modification of the pedestrian signal head.
- Modification of pedestrian signals to increase the clarity of the indication for the clearance interval.
- The use of pedestrian activated flashing beacons at midblock crosswalks and at crosswalks on major roads at intersections not controlled by traffic signals.
- The use of advance stop lines to get motorists to stop upstream of crosswalks.
- Interventions to increase the conspicuity of crosswalks.
- The use of multifaceted programs that focus on engineering, enforcement, and education (the three E's) to increase yielding to pedestrians in crosswalks.

Studies of these countermeasures have demonstrated changes in behavior of motorists and/or pedestrians (Van Houten and Malenfant 1999). For example, advance stop lines, placed 50 feet upstream of a crosswalk rather than the standard four feet, cause a higher percentage of drivers to stop well in advance of the crosswalk rather than encroaching on it (Figure D-12). At signalized intersections, exclusive pedestrian intervals—which stop all vehicle traffic for all or part of the pedestrian crossing signal—have been shown to significantly reduce conflicts between pedestrians and motor vehicles (Van Houten et al. 2000). Two studies of in-pavement flashing warning lights automatically activated by the presence of pedestrians have shown reductions in both vehicle speeds and conflicts at uncontrolled crossings (Hakkert et al. 2001; Prevedourous 2001).

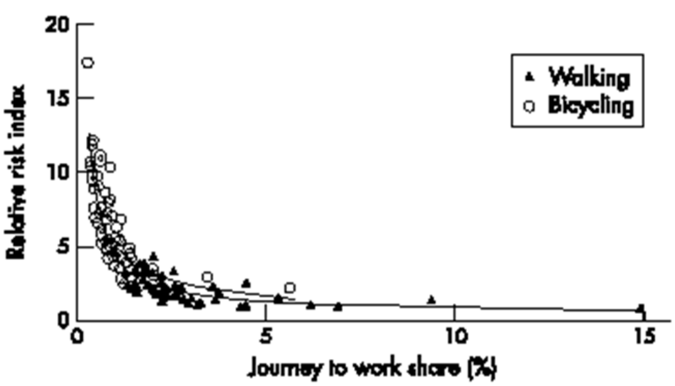
Figure D-12. Percentage of vehicles stopping more than 10 ft, 20 ft, 30 ft, 40 ft, and 50 ft from the crosswalk for each placement of the stop line



Source: Van Houten and Malenfant (1992)

Finally, the most compelling countermeasure for pedestrian and bicyclist safety is simply more people out walking and bicycling, which can be viewed as another positive effect of compact development patterns. There appears to be safety in numbers. Jacobsen (2003) demonstrated a direct relationship between number of cyclists and pedestrians and their safety (see Figure D-13). For a 100 percent increase in walking, the attendant increase in injuries is only 32 percent. So while there might be more injuries, there are fewer per capita. Australian research has confirmed these findings. "If cycling doubles, the risk per kilometre falls by about 34 percent; conversely, if cycling halves, the risk per kilometre will be about 52 percent higher" (Robinson 2005).

Figure D-13. Relative risk of pedestrian and bicyclist crashes as a function of journey to work mode shares in 68 California cities



Source: Jacobsen (2003).

Context-Sensitive Design

In urban areas, the literature generally shows enhanced safety with lower-speed, less "forgiving" design treatments—such as narrow lanes, traffic calming measures, and street trees close to the roadway. The reason for this apparent anomaly may be that less forgiving designs provide drivers with clear information on safe and appropriate operating speeds, thereby preparing drivers to respond to the many vehicle and pedestrian "conflicts" present in highly-urbanized areas. As detailed by Dumbaugh (2005b), the basis is both biological and psychological. There is a well-documented communicative process that exists between the road environment and the roadway user. Where a roadway consistently informs the driver that caution is warranted, the result is that drivers are more vigilant in their search for oncoming hazards, as well as better prepared to respond to these hazards when they occur.

European designers have long recognized that the use of high design speeds leads to higher operating speeds, and have sought to remedy this problem by designing roadways for their intended operating speeds (Study Tour Team 2001). Unlike in the United States, where roadways are classified mainly in terms of their access and mobility functions, European design practice begins by examining the developmental context of a roadway, identifying the hazards that are expected to exist in these environments, and then specifying a target design speed to ensure that the driver travels at speeds that are appropriate given these hazards (Lamm et al. 1999). The result is that a roadway's operating speed is consistent with its target speed, contributing to per capita traffic fatalities that are 50 to 75 percent lower than those in the United States (World Health Organization 2004).

Many individual engineers have recognized the need for lower-speed designs in urban contexts, a recognition that has led to the emergence of "context-sensitive design" as a new paradigm. The context-sensitive redesign of Bridgeport Way, the main street of University Place, Washington, led to a 69 percent crash reduction. Several local, state, and national organizations now encourage engineers to practice context-sensitive design on a project-by-project basis, and many exemplary projects have been built in recent years (Committee on Geometric Design 2004; Congress for the New Urbanism 2002; AASHTO 2004b). Yet, national and state highway design manuals continue to point engineers in the wrong direction, toward less safe designs, in urban settings (Ewing 2002). This may be changing, thanks to efforts such as the Institute of Transportation Engineers' proposed recommended practice for major urban thoroughfares, prepared through an unprecedented collaboration with the Congress for the New Urbanism (Daisa et al. 2006).

Discussion

Contemporary transportation engineering practice is oriented towards mobility, with safety identified as a complementary goal. This is readily evidenced in the goal statements of metropolitan planning organizations and state departments of transportation, where the provision of a “safe and efficient” transportation system is listed as a single agency goal. Because safety and efficiency are treated as mutually-supportive goals, most conventional transportation planning applications begin by identifying levels of congestion for a given horizon year, and then proposing mobility-oriented solutions, such a road widenings. Once a mobility need is identified, safety is addressed by designing these improvements for higher design speeds under the presumption that higher design speeds equate to enhanced safety performance. To the extent that the built environment is considered at all, it is solely for forecasting future levels of traffic demand to identify needed mobility improvements.

Yet, the empirical evidence on traffic safety strongly suggests that safety and mobility may be conflicting goals, at least in urban areas. Contrary to accepted theory, the stop-and-go, high-volume traffic environments of dense urban areas appear to be safer than the lower-volume environments of the suburbs. The reason is that many fewer miles are driven on a per capita basis, and the driving that is done is at lower speeds that are less likely to produce fatal crashes. Also contrary to accepted theory, at least in dense urban areas, less “forgiving” design treatments—such as narrow lanes, traffic calming measures, and street trees close to the roadway—appear to enhance a roadway’s safety performance when compared to more conventional roadway designs. The reason for this apparent anomaly may be that less forgiving designs provide drivers with clear information on safe and appropriate operating speeds.

Considered broadly, the fundamental shortcoming of conventional traffic safety theory is that it fails to account for the moderating role of human behavior on crash incidence. Decisions to reduce development densities and segregate land uses, or to widen specific roadways to make them more forgiving, are based on the assumption that in so doing, human behavior will remain unchanged. And it is precisely this assumption – that human behavior can be treated as a constant, regardless of design – that accounts for the failure of conventional safety practice (Dumbaugh 2005b; 2006). If safety is to be meaningfully addressed, we must begin to develop our understanding of how the built environment influences the both the incidence traffic-related crashes, injuries, and deaths, as well as the specific behaviors that cause them.