Urban Street Cross Section and Speed Issues

J. L. GATTIS
Mack-Blackwell Transportation Center
4190 Bell Engineering Center
University of Arkansas
Fayetteville, AR 72701
jgattis@engr.uark.edu

ABSTRACT

This paper discusses some impacts of restricted cross section design choices (traveled way width, parking on narrow streets, appurtenances and vegetation close to the curb) on travel speed, safety, and driver convenience.

INTRODUCTION

More is better—or is it? Thoughtful criticism has been directed toward a number of longstanding cultural assumptions in the latter part of the 20th century. Some of the earliest challenges that appeared on America's social radar screen were the Volkswagen ads, which told the public that small cars were okay. We have seen alternative perspectives emerge for not only consumer products and lifestyles, but even street design. Instead of wider, larger streets, some were calling for narrower, more confined streets.

These "less is better" designs are founded on a number of underlying perspectives, ranging from simple objections to automobile traffic speeds and volumes on a specific street to a general dislike of the automobile. Two types of issues related to urban street cross section width are examined in this paper:

1. A quantitative consideration of the amount of cross section width made available for automobile movements—will narrower traveled ways produce lower speeds?
2. An anecdotal look at the allocation of cross section space and use at the edge of the traveled way—what are the effects of narrower horizontal (i.e., side) clearances?

BACKGROUND

Many of the differences expressed about street right-of-way and pavement width can be traced to fundamentally different perspectives. A few of these perspectives result in placing higher values on

1. A slower pace of life (including slower speeds, at least on the street in front of one's house);
2. A certain aesthetic or "look" to the streetscape;
3. An unencumbered, unconstrained trip; or
4. A trip with a minimal number of potential hazards.

It is not uncommon to find people who value one of these attributes to the exclusion of others. If some groups do not recognize, much less value, one or more of these design perspectives, then it is not surprising that conflict in the arena of street design does arise among groups.

Some of these conflicts were expressed in the Transportation Research Board's *Special Report 254*: *Managing Speed*, in this way:

> Drivers, neighborhood residents, traffic engineers, law enforcement officials, and legislators may differ as to what constitutes a reasonable balance between risk and travel efficiency. For example, local governments frequently receive requests to lower speed limits from neighborhood residents who seek to reduce speeds on local streets. Traffic engineers may not find the reduction to be justified by an engineering study. Drivers themselves—depending on their age, risk tolerance, trip purpose, and familiarity with particular roads—may not agree on what speed best balances risk with travel efficiency.

In discussing ways to reach agreement or consensus, the report went on to say:

> Consultation [among various affected groups], however, does not ensure that . . . tensions will be resolved between different interests, such as between commuters and residents on appropriate speed limits on residential streets.

Advocates of narrower urban streets criticize established U.S. criteria, stating Americans are designing for a worst case (Ewing et al. 1995). The worst case includes cars parked on both sides of the street, peak traffic volumes, and vehicles larger than passenger cars (such as service and emergency vehicles). Their contention is that urban streets designed to be more constricted can still function adequately.

Australia and some European countries have developed urban street standards that restrict automobile travel more than most standards in the United States do. In a comparison of American street design criteria with those of Britain and Australia, Ewing (1994) stated that British and Australian design speeds are about the same as those in the U.S., but that U.S. minimum pavement widths and maximum curve radii are much larger. The wider U.S. streets allow parking on both sides of the street, while the narrower standards of other countries may be accompanied by on-street parking limitations.

A few locales in the U.S. have adopted more restrictive street design criteria. A Florida publication advocated 32 km/h (20 mph) speeds on local streets, and limiting arterials to 56 km/h (35 mph) through communities. Subcollector streets 7.9 m (26 ft) wide, with parking on one side, and 5.5 m (18 ft) wide access streets were specified (Ewing et al. 1995). The Eugene, Oregon, Local Street Plan lists 10 different local street configurations, with street widths as low as 6.1 m (20 ft) (West and Lowe).

Defenders of established (i.e., wider) street design practices can point out that even though emergencies are not an everyday event on every street, when an emergency does arise, adequate response times by fire and ambulance vehicles are imperative. Garbage trucks traverse the entire street network once or twice a week. And since peak period traffic is a daily occurrence, designing for a daily peak is not an extreme measure.

Traffic Calming

Those who wish to diminish the felt presence of the automobile in the urban streetscape may embrace traffic calming. Again, referring to *Managing Speed*:

> Traffic calming refers to a variety of physical measures to reduce vehicular speeds. . . . A primary reason for the approach is concern for pedestrian and bicycle safety on local streets. . . . The ineffectiveness of speed limits in these situations and the high cost of enforcement have led some communities to adopt traffic calming measures that physically constrain vehicle speeds.

Traffic calming techniques include partial or total blocking of certain streets or intersections, installing traffic roundabouts at intersections, or street narrowing.

Proponents of narrow streets list other benefits besides lower speeds (Ewing et al. 1995). Drivers are said to behave less aggressively on narrow streets and run fewer traffic signals. Eliminating what has been termed overdesign of local streets is a measure that is both cost and energy efficient.

Street Width and Speed Research

Various research studies have not all reached the same conclusions about the effects of narrower streets on speeds (Gattis and Watts). One potential pitfall in studies of speed as a function of street width is confounding factors: there may be (and probably are) other unaccounted-for factors which are correlated to speed or otherwise unknowingly affect research results.

When examining street width and speed relationships, one such confounding factor is the “traffic function.” As used herein, traffic function is not the same as “street function.” “Traffic function” reflects the nature of the traffic (i.e., arterial or through traffic versus local traffic). Street function refers to how the street is classified, perhaps in the city master street plan. Ideally, the street function is the same as the traffic function, but there are many cases of mismatches, such as arterial traffic operating on a street designed as and built to local or collector street standards. It is necessary to differentiate between these two terms in this paper because some planners and engineers mistakenly think that the cross section defines the function, such as six lanes means arterial and two lanes means local, when in reality cases of two-lane urban streets functioning as arterials abound. Attributes of traffic, not geometry alone, define function.

Side Clearance Practices

Reasons for recommending minimum setbacks from the traveled-way or curb edge include allowing space so that:

1. Passengers in parked cars trying to open doors on the right will not find an object blocking the door;
2. Side mirrors or other overhanging vehicle parts of moving vehicles will not strike roadside objects;
3. Even if the roadside object should lean or otherwise change position in the future, it will not encroach upon the roadway;

4. Drivers' views of roadside traffic control devices will not be blocked; and
5. Errant vehicles do not strike fixed objects.

The AASHTO Green Book (1994) calls for horizontal or side clearances of at least 0.5 m (1.6 ft) beyond the curb face, and desirably 1.0 m (3.3 ft) on urban arterials. On urban collectors, a 0.6 m (2.0 ft) setback is recommended "to avoid interference with opening car doors" (AASHTO Green Book 1994). The 1988 *Manual on Uniform Traffic Control Devices* recommends a minimum 2 foot (0.6 m) clearance from the curb face to a sign edge, although it does also make provisions for a 1 ft (0.3 m) clearance.

The narrower streets advocated by some may not only provide less width for the traveled way but also narrower widths for the border area. A more confined border will necessitate "squeezing in" street signs, utility poles, and landscaping, possibly resulting in decreased side clearances from the edge of the traveled way.

EXAMINATION OF SPEED, WIDTH, AND FUNCTION

A small-scale research effort conducted to examine speed and width relationships also considered the effects of traffic function. The streets studied were in Fayetteville, Arkansas, a town of over 50,000, which anchors the south end of an urban area of about 150,000.

Lafayette Street, Maple Street, Washington Avenue, and Willow Avenue are all in the old, grid neighborhood. All have 40 km/h (25 mph) posted speeds. Buckeye Street, in a moderately priced subdivision of the late 1900s, terminates at a T-intersection with a collector street. Pembroke Avenue serves an upscale 1950s–1960s neighborhood. Speed limits are not posted on either Buckeye or Pembroke. The default speed limit for nonposted streets is 48 km/h (30 mph). All streets have curb-and-gutter and an asphalt concrete surface. All of these streets are almost completely abutted by residential land uses. Maple has one low volume business, and a church-with-school occupies a half-block at the corner of Lafayette and Willow.

In addition to the six residential streets, data were collected on two segments of Poplar Street. The posted speed limit is 40 km/h (25 mph). The west segment (Poplar W) is in a light industrial-commercial area, has curb and gutter, and has a portland cement concrete surface. The narrower east segment (Poplar E) is an asphalt surface road, similar to many local rural roads. The east segment has narrow unpaved shoulders and ditches on the side. This street is fronted by mixed rental-residential and light industrial-commercial uses.

Major Streets

The pair of Maple and Lafayette both function as arterials, although they also serve as collectors for the immediate neighborhood. They accommodate traffic from the major north-south arterial (College Avenue) to Mission Avenue, a major arterial to the east. They are in a grid layout, are parallel to each other, and are one block apart.

Even though Lafayette is the designated through route (Highway 45), many drivers are aware that Maple will also take them to their destination. An all-way stop located on Maple midway between College and Mission is somewhat of a deterrent to through traffic; Lafayette drivers do not encounter any stop signs.

Poplar Street serves not only abutting businesses, apartments, and houses, but also through traffic trying to find a route across an area with a somewhat random street pattern.

Minor Streets

Washington and Willow are both two-block-long segments. They are nominally local streets, but since they also serve cut-through traffic between College and Highway 45, these two streets carry a mixture of local and arterial traffic. They are in a grid layout, are parallel to each other, and are one block apart.

Both Washington and Willow have stop signs at each end of the segment. The south block of Willow is considerably narrower than the north block, and both are narrower than Washington. These and other factors make Washington a more desirable cut-through route than Willow.

Pembroke and Buckeye provide a contrast to the streets from the grid neighborhood. Buckeye is a "true" local, in that the immediate neighborhood "loop" street layout insures that it will not serve through traffic. Buckeye traffic stops at the east-end intersection. Pembroke is nominally a local, but due to the neighborhood layout, is really a hybrid and serves as a link in the neighborhood collector system.

Neighborhood Descriptors

Tables 1 and 2 present attributes of the streets studied and their neighborhoods. Lafayette, Maple, Washington, and Willow all have the older neighborhood appearance. Buckeye

TABLE 1 Roadway Attributes

Layout and functional class	Street name	Street width m	(ft)	Parking on street	Sidewalk one or both sides	Segment length m	(ft)
Grid							
Arterial	Lafayette	9.6	(31.4)	No	Both	602	(1975)
Arterial	Maple	6.1	(20.0)	No	Both	602	(1975)
Local	Washington	9.2	(30.1)	Yes	Both	235	(770)
Local	Willow N	8.0	(26.1)	Yes	Both	111	(364)
Local	Willow S	6.1	(20.1)	Yes	Both	124	
Remote							
Arterial	Poplar W	11.0	(36.0)	No	None	155	(510)
Arterial	Poplar E	6.4	(21.0)	No	None	320	(1050)
Local-Collector	Pembroke	8.0	(26.4)	Yes	None	436	(1430)
Loop							
Local	Buckeye	9.1	(30.0)	Yes	One	320	(1050)

Note: Although theoretically classified as Locals, Washington and to a lesser degree Willow also function as "cut through" routes for arterial traffic.

TABLE 2 Neighborhood Attributes

Functional class	Street name	Typical lot frontage m (ft)	Minimum distance curb-to-front of structure m (ft)
Arterial	Lafayette	24 (80)	9.8 (32)
Arterial	Maple	24 (80)	7.0 (23)
Arterial	Poplar W	43 (140)	9.1 (30)
Arterial	Poplar E	30 (100)	9.1 (30)
Local	Washington	27 (88)	11.3 (37)
Local	Willow	24 (80)	6.7 (22)
Local-Collector	Pembroke	30 (100)	11.9 (39)
Local	Buckeye	24 (80)	10.4 (34)

and Pembroke both have a post-World War II appearance. Poplar is a mix of older frame houses, newer brick apartments, and economical, small office-warehouses. Buckeye and Poplar have fewer trees or other front yard vegetation that effect a “closed-in” feel.

Collecting Speed and License Plate Data

For each pair of locations studied, the data collection procedure differed slightly. Speeds of passing vehicles were recorded with road tube pairs, except at one Willow Avenue location, where a radar gun was used. Speeds were collected at locations some distance from intersections at which the vehicle is required to stop.

For all except Pembroke and Buckeye, students recorded license plate numbers at both ends of the study segments. On Pembroke, a student noted if a vehicle was entering or leaving any one of the four residences on either side of the road tube, or if the vehicle was a bicycle. The Buckeye site was unmanned, and the classifier collected data from mid-morning through the evening.

Results

The data were processed with the objective of comparing and contrasting speeds and crash histories of the targeted streets.

An initial analysis consisted of a graphical comparison of the data. Figure 1 plots the average speed for all vehicles verses street width. Even though the widest street had the highest average speed, the second highest speed came from the narrowest road. This graph shows no real correlation between the width of the road and the speed of the traffic. A linear regression resulted in R^2 (coefficient of correlation) = 0.09. Figure 2 plots average speed of only through vehicles against street width. Again, no real correlation appeared ($R^2 = 0.03$).

The investigation was redirected to examine vehicle speed and traffic function. Since function is not a scaled variable, streets were ranked (Figure 3) in ascending order,

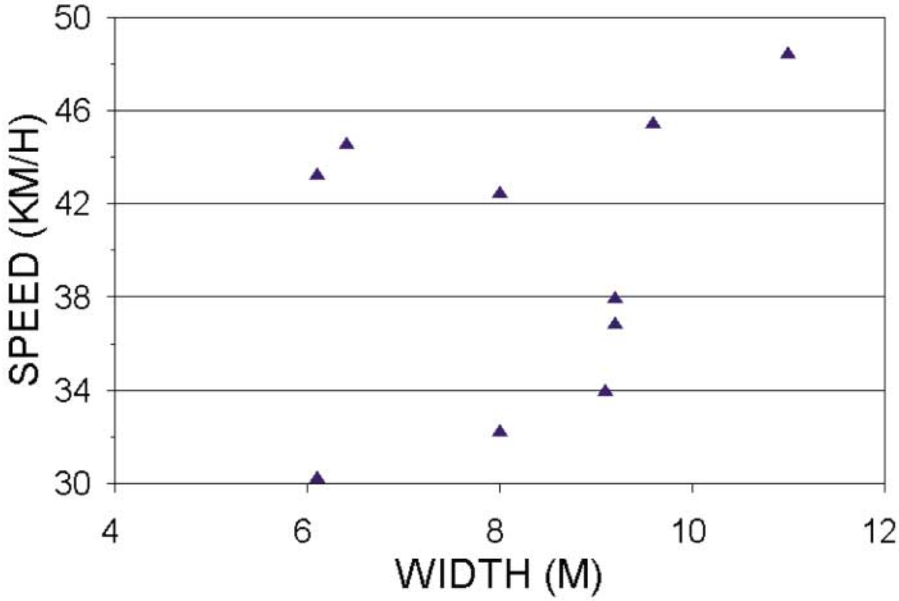

FIGURE 1 Average speed versus width for all traffic.

local to arterial. The graph suggests some relationship between nature of traffic on the street and average speed.

Speed of All Vehicles

Table 3 presents comparisons of all speeds on all streets. Average speed on the wider section of Poplar was the highest of all 10 sections, and 3.0 km/h (1.9 mph) higher than on Lafayette. Poplar East average speed fell between those on Lafayette and Maple For all vehicles, Lafayette mean speeds were 2 km/h (1.4 mph) greater than those on Maple.

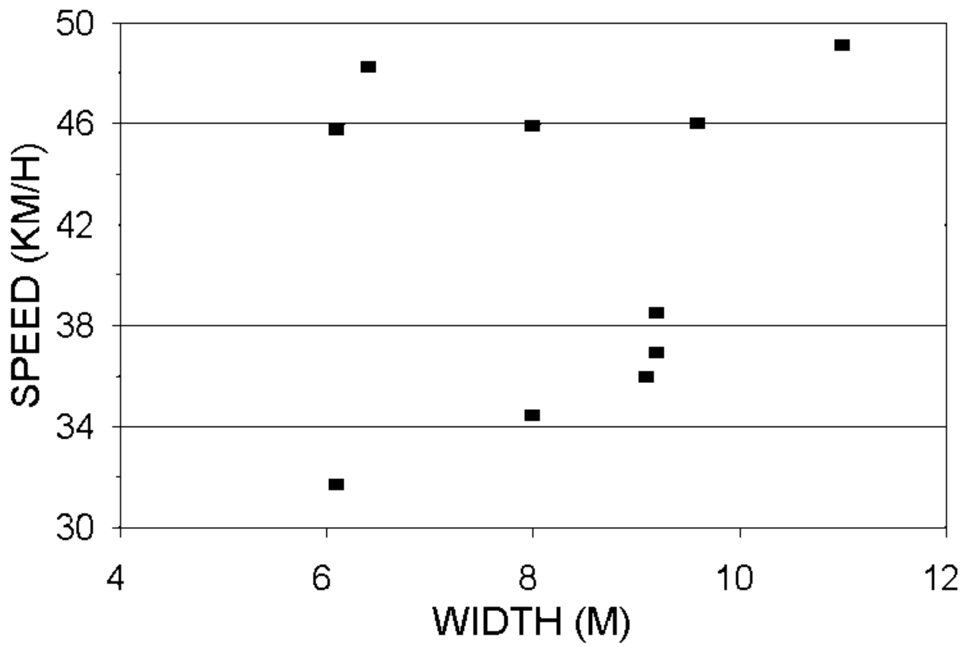

FIGURE 2 Average speed versus width for only through traffic.

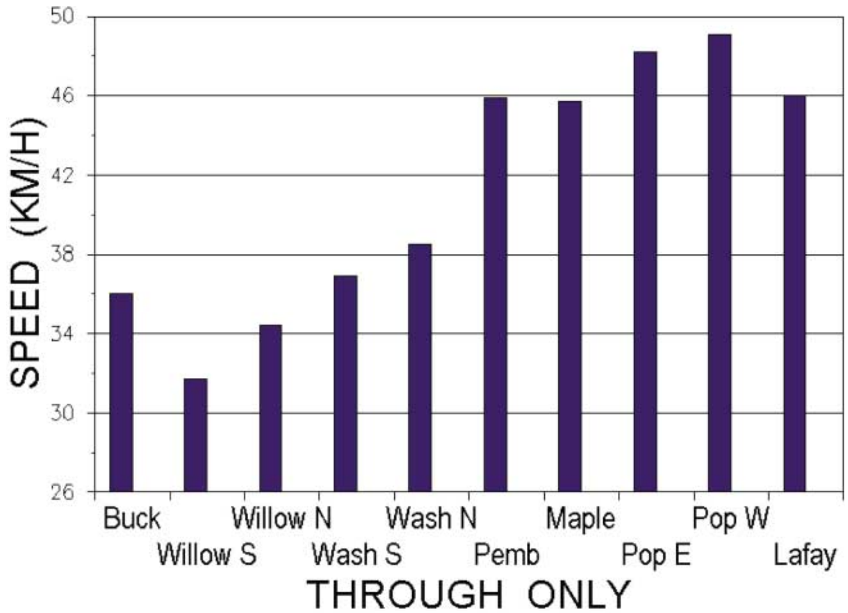

FIGURE 3 Average speed against street function.

The mean speeds on Washington were higher by 5 to 7 km/h (3 to 4 mph) than those on Willow. For both streets, the speeds on the north end were about 2 km/h (1 mph) greater than those on the south end. The Washington Avenue northbound volume was much greater than the southbound volume. However, Willow directional volumes were evenly split.

Speeds on Pembroke were similar to those on Lafayette, Maple, and Poplar. The speeds on Buckeye Street were slightly lower than those on Washington, but slightly higher than those on Willow.

Speed of Through Vehicles

Those vehicles whose license plates were observed at both recording stations were categorized as through vehicles. Table 4 presents comparisons of only the average speeds of the through vehicles.

Average speeds of through vehicles were higher on both Poplar sections than on any other. The difference between average speeds on the two Poplar sections was 0.9 km/h (0.5 mph). The Lafayette mean speed was 0.3 km/h (0.2 mph) greater than the Maple mean.

Considering only the through vehicles, Washington mean speeds were 3 to 5 km/h (2 to 3 mph) higher than those on Willow. The speeds at the north ends of both streets were about 2 to 3 km/h (1 to 2 mph) greater than those on the south ends. However, the differences between the paired data (between the south end and the north end) for only the northbound direction showed a mean difference of 1.6 km/h (1.03 mph) for Washington and a mean difference of 1.3 km/h (0.83 mph) for Willow.

Mean speeds of Pembroke vehicles that did not slow to turn into a driveway near the data collection point were about the same as those of the through vehicles on

TABLE 3 Speeds (All Vehicles)

Street Name	Width (m)	Sample size	Speed: Mean km/h (mph)	Speed: Standard deviation km/h (mph)
			(a) Grid, Arterial	
Lafayette	9.6	430	45.5 (28.3)	6.1 (3.8)
Maple	6.1	272	43.3 (26.9)	8.4 (5.2)
			(b) Remote, Arterial	
Poplar W	11.0	264	48.5 (30.2)	8.2 (5.1)
Poplar E	6.4	272	44.6 (27.7)	11.8 (7.3)
			(c) Grid, Local (with cut-through traffic)	
Washington N	9.2	303	38.0 (23.6)	7.2 (4.5)
Washington S	9.2	280	36.9 (22.9)	6.1 (3.8)
Willow N	8.0	97	32.3 (20.1)	8.2 (5.1)
Willow S	6.1	84	30.3 (18.8)	8.0 (5.0)
			(d) Remote, Local-Collector	
Pembroke	8.0	49	42.5 (26.4)	11.1 (6.9)
			(e) Loop, Local	
Buckeye	9.1	85	34.0 (21.1)	9.8 (6.1)

Lafayette and Maple, but higher than speeds on the other streets. Excluding vehicles below 21 km/h (13 mph), Buckeye speeds were similar to those of through vehicles on Washington Avenue.

Environment

An attempt to quantify the subtle cues a driver senses about the nature and environment of the particular street was not conclusive. The segment with the most “confining environment” (see Tables 1 and 2), the south end of Willow, certainly had the lowest speeds. On the other hand, both the numbers and the qualitative sense one gets from driving on Maple suggest it should be classified as more confining than Buckeye or Lafayette, but the Maple through vehicle speeds were higher than those on Buckeye and similar to those on Lafayette. Poplar and Pembroke have the least confining environment, and did tend to exhibit speeds in the higher ranges of those measured.

TABLE 4 Speeds (Only Through Vehicles)

Street			Speed	
Name	Width m	Sample size	Mean km/h (mph)	Standard deviation km/h (mph)
(a) Grid, Arterial				
Lafayette	9.6	380	46.0 (28.6)	5.6 (3.5)
Maple	6.1	122	45.7 (28.4)	6.6 (4.1)
(b) Remote, Arterial				
Poplar W	11.0	192	49.1 (30.5)	7.3 (4.5)
Poplar E	6.4	192	48.2 (30.0)	8.3 (5.2)
(c) Grid, Local (with cut-through traffic)				
Washington N	9.2	261	38.5 (23.9)	6.6 (4.1)
Washington S	9.2	261	36.9 (22.9)	6.1 (3.8)
Willow N	8.0	58	34.4 (21.4)	7.2 (4.5)
Willow S	6.1	58	31.7 (19.7)	7.2 (4.5)
(d) Remote, Local-Collector				
Pembroke	8.0	42	45.9 (28.5)	7.4 (4.6)
(e) Loop, Local				
Buckeye	9.1	76	36.0 (22.4)	8.2 (5.1)

Note: "Through" vehicle speeds on Pembroke were generated by deleting vehicles observed to turn in to nearby driveways, to slow down, or to be bicycles; "through" vehicle speeds on Buckeye were generated by deleting vehicles traveling less than 21 km/h (13 mph).

Vehicle Crashes

Table 5 offers a comparison of three-year crash data for the two parallel through streets (Lafayette and Maple). The number of crashes on Lafayette is somewhat higher, but since Maple volume is much lower than that of Lafayette, Maple has a much higher crash rate.

EXAMINATION OF SIDE CLEARANCE WIDTH

The preceding examination of traveled-way width was analytical; the following consideration of narrow side clearance effects is anecdotal. A series of photographs show effects of narrow cross sections or otherwise constrained side clearances.

The border between the curb and the right-of-way line serves as a place for traffic control devices, various utility poles, landscaping, and sidewalks. Without giving

TABLE 5 Recent Crash History

(1)	Intersection crashes (2)	Non-intersection crashes (3)	Total number of crashes (4)	Number of injury crashes (5)	Crash rate (acc/10^6 veh km) (6)
Lafayette	10	6	16	4	3.03
Maple	13	1	14	3	7.08

Note: Both roadways have the same length and number of intersections.

adequate attention to the location and spacing between these devices and the curb, problems can result.

Effects of Narrow Streets and Parking

As the available street width decreases past a certain point, the margin for error on the part of various street users declines. Those driving or parking vehicles and bicyclists will have to devote more attention to controlling vehicle path, and have less attention available to devote to monitoring other peripheral activities, such as children darting out into the street. In sharp horizontal curves, the control problem is exacerbated. Figure 4 illustrates how the difficulty in parking on a sharp curve leads to the end of the parked car protruding into the space for moving vehicles. The superimposed arrow highlights the

FIGURE 4 End of car parked on curve protrudes into path of moving traffic.

protruding back bumper; the driver of a vehicle going down this street is going to have to fixate on this fraction of the overall streetscape to identify a potential hazard.

Effects of Close-to-Street Appurtenances

Many urban streets are lined by sign posts, fire hydrants, street light poles, and utility poles. Where the cross section width is limited, there may be a greater tendency to place utility poles or other vertical objects as close to the street as possible. Pole installations may conform to minimum setback guidelines, but minimum guidelines are sometimes only adequate in minimum situations. The scars on the pole in Figure 5 clearly illustrate that locating poles a minimal distance behind the curb is sometimes not enough.

Effects of Close-to-Street Vegetation

Roadside vegetation competes for space with roadside appurtenances such as signs and utility poles. The following photographs show some results of this competition.

Figures 6 and 7 show “no right turn” and “one-way” signs that were installed on a through street where it was intersected by a one-way street. These signs were intended to deter drivers from going the wrong way on the one-way street serving a post office. The location chosen for tree planting in early 1995 proved to be a bad one, as within two years the growing tree was well on its way to blocking drivers’ view of the two signs.

Figure 8 shows a hedge planted along the inside of a curve leading to a stop-controlled intersection. This situation was pointed out by a driver who, coming around the curve, could not see the stop sign for the hedge and ran the stop sign.

FIGURE 5 Fixed object close to curb exhibits signs of many strikes.

FIGURE 6 Tree planted in front of signs in 1995.

Figure 9 presents a streetscape where trees are set back from the street edge, but the limbs extend over the sidewalk. The limbs block the drivers' view of the stop sign at the intersection. While traveling on the crossing street on two separate occasions in mid-1999, cars were observed running the obscured stop sign.

Figure 10 shows how a row of trees planted between the curb and sidewalk, when mature, block the view of a driver trying to pull out from a driveway or side street into

FIGURE 7 Tree grew in two years to block drivers' view of signs.

FIGURE 8   Drivers ran the stop sign hidden by this hedge.

FIGURE 9   Vehicles were observed running this stop sign hidden by the tree.

FIGURE 10 Row of trees close to curb prevents driver from seeing oncoming traffic.

through traffic. The trees act as a barrier wall, preventing the driver from seeing oncoming vehicles and judging whether it is safe to pull out.

The bark missing from the tree in Figure 11 shows that even single, isolated trees that are too close to an urban street are hazards. The minor arterial street in this picture had been opened a few months when signs of vehicle hits were clearly apparent.

FIGURE 11 Tree too close to edge of new street shows evidence of being struck.

CONCLUSIONS

The current criticism and reexamination of urban street cross section design widths may lead to conclusions that either narrower traveled ways, more constrained borders and horizontal side clearances, or both are in order.

The impacts of these narrowings on vehicle speed and personal safety should be realistically evaluated before standards are revised. The following ideas are offered.

1. Street width may have some effect on vehicle speed, but from the examples studied, one may postulate that average speeds are more influenced by traffic function (longer distance, through travel versus the shorter distance, initial/termination stages of a trip) than by width. An attempt to quantify the subtle speed selection cues a driver receives from the nature and environment of the particular street was not conclusive.
2. These findings suggest the need to separate through vehicles from local vehicles when collecting speed data for the purpose of comparing the speeds on various streets.
3. Documents advocating narrower streets need to recognize the combined effects of narrow streets, on-street parking, and horizontal curvature, and restricted horizontal clearances. A street width that may be marginally adequate so long as the street is straight may be inadequate in a horizontal curve.
4. Physical scars on roadside objects show that it is desirable to set back fixed objects from the curb edge more than some minimum distance. Vehicles making turning or parking maneuvers can and do strike the poles. To reduce both nuisance and hazard factors, the border width needs to be large enough so that an adequate setback can be provided for streetside poles, posts, signs, and hydrants.
5. Although shrubs and trees can beautify the streetscape, when planted in inappropriate locations, they contribute to safety problems.

The selection of a particular cross section design can affect a street's aesthetics, driving convenience, and safety. More study of the actual effects, not just hypothesized or perceived effects, needs to be done to assess tradeoffs in urban street cross section design, to identify to what extent urban street cross section widths can be safely reduced, and to identify landscaping methods that do not pose safety problems.

ACKNOWLEDGMENTS

This research was made possible by the support of the Mack-Blackwell Transportation Center at the University of Arkansas (through a grant from the U.S. Department of Transportation University Centers Program), and by a Research Experience for Undergraduates program funded by the National Science Foundation.

REFERENCES

American Association of State Highway and Transportation Officials, *A Policy on Geometric Design of Highways and Streets*, Washington, D.C., 1994, pp. 477, 525.

Ewing, R., C. C. Heflin, M. DeAnna, and D. R. Porter. *Best Development Practices: Doing the Right Thing and Making Money at the Same Time*. Florida Department of Community Affairs, Tallahassee, 1995, pp. 66, 67.

Ewing, R. Residential Street Design: Do the British and Australians Know Something Americans Do Not? In *Transportation Research Record 1455*, TRB, National Research Council, Washington, D.C., 1994, pp. 42–49.

Federal Highway Administration. *Manual on Uniform Traffic Control Devices*, Washington, D.C., 1988, pp. 2A–10.

Gattis, J. L., and A. Watts. Urban Street Speed Related to Width and Functional Class, *Journal of Transportation Engineering*, American Society of Civil Engineers, Vol. 125, No. 3, 1999, pp. 193–200.

Special Report 254: *Managing Speed.* TRB, National Research Council, Washington, D.C., 1998, pp. 23, 169, 192.

West, J. E., and A. Lowe. Integration of Transportation and Land Use Planning Through Residential Street Design, *ITE Journal*, Institute of Transportation Engineers, Vol. 67, No. 8, 1997, pp. 48–51.