Effects of Design Criteria on Local Street Sight Distance

J. L. GATTIS

Of the three roadway functional classes (arterial, collector, and local), the local road is the one intended to provided access. Local street design criteria interact to affect the available sight distance. Urban residential streets of the type often found in newer subdivisions tend not to be laid out in the traditional grid pattern, but rather in a more free-form pattern incorporating elements of discontinuity and curvilinear alignment. In these settings, on-street parking, whether on both sides of the street or only on one side, forces vehicles traveling in opposite directions to operate in the same lane. The presence of vegetation or other objects at the curbside can also limit the available head-on sight distance. Where two lanes of traffic moving in opposite directions operate in one lane, the amount of sight distance needed is greater than under normal conditions. The design needed is analogous to one that permits two locomotives to approach head-on on a single track and to stop before colliding. Roadway designers should recognize situations that require adequate head-on sight distance and provide a sight distance sufficient for the two approaching vehicles to react and stop before colliding.

Of the three roadway functional classes (arterial, collector, and local), and local road is the one intended to provide access. Desirable attributes of local streets serving residential lots include safety, efficiency, and enhancement of the "livability" (*1*) of the residential area. In addition, they must be built with a recognition of economic considerations.

Certain local street design criteria act in concert to affect the available sight distance. Included is a brief review of certain design guidelines for residential streets and observations about the actual applications of these criteria. This is followed by a discussion of the interactions of various criteria when they are incorporated into a design and resulting deficiencies that may not be specifically addressed by current design practices.

The local roads discussed are the type of urban residential streets often found in newer subdivisions. These streets tend not to be laid out in the traditional grid pattern, but rather in a more free-form pattern that includes elements of discontinuity and curvilinear alignment.

SELECTED LOCAL STREET DESIGN CRITERIA

The function of the local or residential street is to furnish access to abutting properties, not to provide high levels of movement. The recommended design criteria for residential streets reflect these needs. Although not all published design guidelines agree on all aspects of residential area layout and street design (*2*), certain perspectives and attributes seem to be predominant.

Sight Distance

Sight distance refers to a distance along the roadway ahead of the driver for which the driver has a specified needed visibility. Three types of sight distance are stopping sight distance (SSD), passing sight distance (PSD), and decision sight distance (DSD). The AASHTO Green Book states, "The minimum sight distance available on a roadway should be sufficiently long to enable a vehicle traveling at or near the design speed to stop before reaching a stationary object in its path" (*3*). Furthermore, it states that "it is normally of little practical value to provide passing sight distance on two-lane urban streets" (*3*). If adequate SSD is to be available on a residential street, then the available sight distance (S) must exceed the needed SSD (*4*).

SSD has two components. The initial component, the distance traveled while the driver recognizes the need to stop and activate the brake pedal, has been called the perception, identification, emotion, and volition (PIEV) time (*5*), or the perception-reaction time (PRT). The second component is the actual braking distance over which the vehicle decelerates. The sum of the two distances, or the SSD, is

$$SSD = 1.467 * V * t_{PR} + V^2/[30 * (f \pm G)] \quad (1)$$

where

V = initial velocity (mph),
t_{PR} = perception-reaction time (sec),
f = braking friction coefficient, or friction factor, and
G = grade in decimal form.

Minimum acceptable residential street sight distances are in the range of 110 ft or more (*1,6*).

Even after the velocity and grade are defined for a given situation, the calculated SSD will vary according to the chosen t_{PR}- and f-values. The current t_{PR} design value is 2.5 sec, or 1.0 sec for reacting to traffic signal changes. Use of the lesser value for reactions to signal change intervals is based on the presumption that the driver approaching a signal is more prepared to react to a change from green to yellow. A review by Taoka (*7*) showed the mean signal change t_{PR}-values found by other researchers to range from 1.1 to 1.3 sec. Investigations of the response times of older or impaired drivers or of the braking capabilities of newer vehicles may eventually lead

Oklahoma Transportation and Infrastructure Center, University of Oklahoma, 202 W. Boyd, Room 334, Norman, Okla. 73019.

to changes in the current t_{PR}- and f-values, which will in turn affect SSD values.

Layout and Length

The street layouts in many newer residential areas are influenced by the concept of functional hierarchy. Although this concept may be misunderstood by some who attempt to use it, the concept dictates the setting of certain objectives. Two such objectives are to discourage excessive volumes and to provide a discontinuous internal-local street system that discourages through traffic (*8*). The length of a continuous residential street can influence the degree to which these objectives are met.

Some recommended design criteria set a maximum length for residential streets. One publication (*8*) suggests maximum lengths of 750 ft for cul-de-sacs and 1,300 ft for other local streets. Others would allow longer maximum lengths (*1*,*9*).

The maximum residential street length should be a function of the intensity of development. With more intense development, more traffic can be expected per unit of length. Therefore, the maximum length should decrease when higher development intensities exist, assuming that other factors, such as street width, remain constant.

Width

Commonly recommended design widths for residential streets, face of curb to face of curb, range from 26 ft (*3*) to 28 ft (*8*), although lesser (*1*,*9*) and greater values can be found (*6*). The common residential street widths are not intended to accommodate vehicles parked on both sides nor two lanes of traffic moving in opposite directions. Rather, the width is sufficient to accommodate automobiles parked on both sides of the street with one moving lane between them (*3*), which is acceptable because traffic volumes are light.

The street right-of-way should be wide enough to accommodate not only the traveled way, but also sidewalks and utilities. A commonly recommended right-of-way width for residential streets is 50 ft (*3*), with some sources listing values of 60 ft (*1*,*6*,*8*).

Design Speed

Recommended residential street design speeds range from 25 to 30 mph (*1*). These low design speeds permit alignment with greater horizontal and vertical curvature than would be allowed on roadways with higher design speeds. Table 1 presents combinations of design speeds, needed SSDs, and minimum allowable radii based on speed and superelevation or crossfall. Calculations are presented for both the standard 2.5-sec PRT and an assumed 1.2-sec PRT for alerted-driver situations. The 1.2-sec PRT calculations are included to show the sensitivity of the formula to a less conservative PRT value.

APPLICATIONS OF CURRENT CRITERIA

A review of how the various design criteria are applied in actual practice helps to identify design criteria interactions. The street system that results from interactions of design elements should not compromise the safety levels intended for the individual elements. Such a system should function well from the perspective of both the driver and the area residents. One author stated, "Elements in the local circulation system should not have to rely on extensive traffic regulations in order to function efficiently and safely" (*1*).

Sight Distance

The amount of sight distance available is not a design input, but rather a result of other inputs. Combinations of horizontal and vertical alignment, vegetation, parked cars, and fences limit the sight distance along some streets. In a local residential street setting, a limited sight distance that restricts passing maneuvers is acceptable.

TABLE 1 SELECTED RESIDENTIAL STREET DESIGN CRITERIA

Assumed Speed (mph)	Perception-reaction time (sec)	Distance during P-R (ft)	Wet[1] braking distance (ft)	Stopping sight distance (ft)	Minimum[2] allowable radius (ft)
25	1.2	44.0	54.8	99	114
25	2.5	91.7	54.8	146	114
30	1.2	52.8	85.7	139	179
30	2.5	110.0	85.7	196	179

[1] Braking distance calculated assuming 0 grade.

[2] Minimum allowable radius assumes -3/16 inch/ft crossfall, side f=0.252 for 25 mph, side f=0.221 for 30 mph

When using the SSD formula, the engineer measures or estimates the velocity and grade for each situation because these variables are site specific and relatively easily determined. However, for PRT and friction factors the engineer would probably rely on values obtained from a table, in effect conclusions of published research or engineering practice guidelines.

Layout and Length

The combination of short lengths and a hierarchical layout, which directs residential neighborhood traffic onto collector streets, should lower the possibility that two vehicles traveling in opposite directions will encounter each other on a residential street. However, if the subdivision layout does not provide true collectors, some residentially designed streets are forced to function as collectors. Under such conditions, the frequency with which vehicles traveling in opposite directions may meet at or near parked cars may increase.

Many residential streets are longer than the recommended minimums. A review of street layouts in place shows that some designers are either unaware of or have ignored the hierarchical layout concept. Some of the subdivision streets built to residential design criteria are functioning as collectors.

Width

Within the confines of the allocated residential street width, cars may be parked at irregular intervals on one or both sides. A vehicle traveling on the street will stay on the right side except when encountering a vehicle parked on the right side; the moving vehicle will then use the center portion of the road to, in effect, pass the parked vehicle.

The amount of parking on the street will vary according to the density of the development, amount of space provided for off-street parking on each lot (e.g., single or double driveways), and social patterns of the residents. A vehicle parked along the curb "takes up space and blocks views and sight lines" (*6*).

The residential street right-of-way may or may not include sidewalks or utility poles. The rights-of-way of some neighborhoods contain liberal amounts of shrubs and trees. One author (*2*) called for steady rows of trees in a residential area, going on to state, "Since the tree canopies must be clear of the building line . . . the trees must be placed as close as possible to the curb." Other studies may lead to a different view of the urban clear-zone issue (*10*). In any event, there are plenty of tree-lined urban streets, some with vegetation of sufficient size and density to create the effect of a wall beside the traveled way.

Design Speed

Anyone who has worked as a city traffic engineer has probably received calls from citizens complaining about speeders on their street. An investigation of the situation will reveal that most drivers are driving close to the speed limit; only a few vehicles significantly exceed the speed limit.

In other situations, higher speeds may occur, especially on those streets designed as local residential but functioning as collectors. For the purposes of the following illustrations, design speed operation is assumed.

COMBINED EFFECTS

Consider the effects of these design criteria when combined in a residential street setting:

1. The length of some residential streets or the layout of the subdivision will cause a higher traffic volume on some parts of the local street system.
2. Within the street and right-of-way widths provided, cars will be parked intermittently on both sides of the street, effectively creating one-lane operation on some stretches. Trees, shrubs, or fences may be along or even in the right-of-way.
3. The roadway design speeds will be 25 to 30 mph, with expected operating speeds in this same range.

These combined factors can create the following scenario. Two vehicles traveling in opposite directions at 25 mph approach each other on a horizontal curve with a 150-ft radius. Parked cars line both sides of the street. The curve length is 220 ft. As the two vehicles enter their respective ends of the curve, the two drivers cannot see each other approaching. There is adequate SSD. How safe is the situation?

Figures 1 and 2 show residential streets with sharp horizontal curvature. In Figure 1, cars are parked along the curbs, leaving only the middle of the street available for moving traffic; vegetation in the margin blocks the view on the inside of the curve. In Figure 2, an oncoming moving vehicle is traveling in the center of the street, threading its way among cars parked on both sides of the street. Both photographs show how design element interactions in a real-world environment can limit the sight distance around the curve.

NEEDED SIGHT DISTANCE AND DESIGN CONTROLS

The practice of permitting parking on both sides of a residential street, combined with a 26- to 28-ft-wide paved sec-

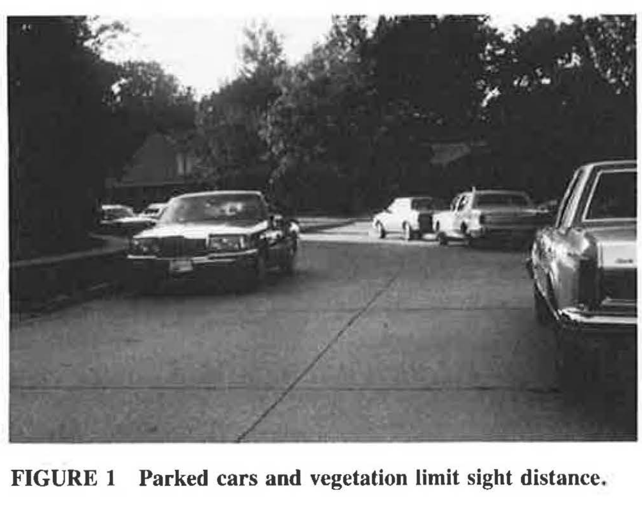

FIGURE 1 Parked cars and vegetation limit sight distance.

FIGURE 2 Vehicles traveling in center of residential street.

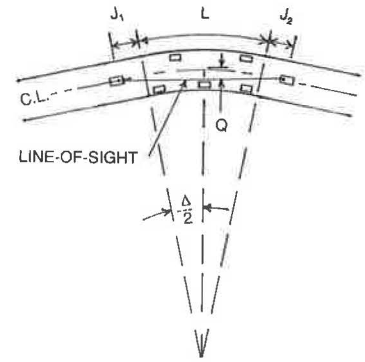

FIGURE 3 Geometric layout.

tion, will occasionally cause the street to operate as a one-lane street with two-way traffic. The resulting effect is that normal SSD may not always be an adequate design control. Adequate SSD permits a vehicle to stop before colliding with a stationary object in its path. The "one lane street with two-way traffic' phenomenon necessitates that sight distance be adequate to permit two vehicles moving toward each other to be able to stop before colliding. Designing for normal SSD is analogous to permitting two locomotives approaching head-on, on a single track, to stop before colliding.

Table 2 contrasts the sight distance needed for these head-on situations with the currently recommended SSD values.

Using an approach that complements the concept contained in "Sight Distance on Horizontal Curves" in the AASHTO Green Book (*3*), Figure 3 shows schematically the geometric considerations on a residential street horizontal curve. The following factors are assumed:

1. Face-to-face residential street width is 28 ft;
2. Cars parked along the curb have an effective "view-blocking" width of 8 ft, so a clear line of sight that passes (28/2) − 8 = 6 ft from the centerline is needed;
3. Vehicles and drivers are positioned so that needed head-on sight distance (HSD) is measured along the centerline;
4. Vehicles approaching the curve of length L are the same distance away from the middle of the horizontal curve (i.e., $j_1 = j_2 = j$); and
5. Vehicles are parked along both curbs, particularly on the inside of the middle of the curve.

For a given design speed, there is a minimum allowable HSD. This HSD equals $2 * j + L$. For a given radius, the central angle Δ must be limited so that the resulting offset distance (Q) from the curve centerline to the line of sight is no more than 6 ft. Said another way, if certain limits are exceeded, a horizontal curve will "bend out of sight" and result in a deficient HSD.

The offset distance from the centerline to the line of sight can be expressed as

$$Q = R * (1 - \cos \Delta/2) + j * \sin \Delta/2 \qquad (2)$$

Substituting,

$$Q = R * (1 - \cos \Delta/2) + [(\text{HSD} - 100 * \Delta * R/5729.578)/2] * \sin \Delta/2 \qquad (3)$$

TABLE 2 SIGHT DISTANCE COMPARISON

Assumed Speed (mph)	Perception-reaction time (sec)	Distance during P-R (ft)	Wet[1] braking distance (ft)	Needed total S for two approaching vehicles (ft)	Currently[2] recommended SSD (ft)
25	1.2	44.0	54.8	198	146
25	2.5	91.7	54.8	293	146
30	1.2	52.8	85.7	277	196
30	2.5	110.0	85.7	391	196

[1] Braking distance calculated assuming 0 grade.

[2] Currently recommended per Green Book Table III-1, using t_{PR} = 2.5 sec

By establishing the maximum or limiting value of Q and the needed value of HSD, one may solve for Δ.

Using the criteria from this example, Table 3 provides example limiting design values. The radius and design speed are assumed, and from them an HSD value and then a maximum allowable Δ are found. Using a PRT longer than the 1.2 sec used in Table 3 would result in smaller values of maximum Δ.

DESIGN CONSIDERATIONS

The probabilities of a potential HSD problem need to be evaluated when design controls are set. Certain design and operational considerations should also be studied before design criteria are established for situations with two-way operation in one lane.

Probability of Encounter

Even though a theoretical geometric deficiency exists, the various contributing factors must be present simultaneously before adverse results become a reality. The probability of experiencing operating problems caused by deficient HSD will vary from location to location. Given the lower volumes on the residential street, many of the vehicles that enter a curve will not simultaneously encounter wet pavement, cars parked on both sides creating a one-lane segment, parked cars or vegetation restricting sight distance, and a vehicle coming from the opposite direction. A low probability of encounter may justify less conservative design assumptions.

Driver Perception-Reaction Time

For short lengths of two-way in one-lane operation, the driver should be alerted to the potentially precarious situation, which should lower the driver's reaction time.

On the other hand, the driver is faced with an object contrast problem (*11*) in which he must search out and identify the front parts of an oncoming vehicle from the row of parked cars along the curb. This may tend to increase the amount of t_{PR} needed.

TABLE 3 MAXIMUM ALLOWABLE CENTRAL ANGLE FOR GIVEN RADIUS

Radius (ft)	Design Speed (mph)	Head-on Sight Distance[1] (feet)	Maximum Δ (degrees)
150	25	198	7.30
300	25	198	7.74
450	25	198	8.33
450	30	277	5.38
600	30	277	5.55

[1] Head-on sight distance calculated using t_{PR} = 1.2 sec

Speed

Some motorists may slow down when encountering short lengths of one-lane operation between parked cars on residential streets. If so, the design V used in the stopping equation can be decreased. If studies find that other motorists travel through small-radius horizontal curves at higher than design speeds, then a higher speed should be entered into the equation. Perhaps drivers are more likely to exceed design speed on a 25-mph local residential street than they are on a 30-mph section.

Appropriate Friction Factors

Friction values used in the SSD formula tend toward a worst-case scenario—tires with minimal tread on a wet, slick pavement. With two approaching vehicles, is the probability that both will have minimal tread great enough to justify using near-worst-case f-values?

Another friction issue is decreased available deceleration on a horizontal curve (*11*). A vector analysis of braking on a curve (*12*) suggests a longer stopping distance for horizontal curves than for tangents:

$$f_H^2 = f^2 - [V^2/(15 * R) - e]^2 \quad (4)$$

where

f_H = braking friction coefficient available on a horizontal curve,
f = braking friction coefficient available on a tangent,
V = velocity (mph),
R = radius (ft), and
e = superelevation rate.

Using the values from the previous case and calculating for a vehicle on the inside of the curve (positive superelevation or crossfall),

$$f_H^2 = 0.38^2 - [25^2/(15 * 150) - 0.015625]^2$$
$$= 0.1444 - (625/2{,}250 - 0.015625)^2 = 0.075675$$
$$f = 0.275092 \quad (5)$$

This methodology finds an available friction of 0.275092/0.38 = 0.724, or 72.4 percent of the original. This would increase the calculated stopping distance of one car from 99 to 119.7 ft. The combined stopping distance for two oncoming vehicles, or the HSD, would change from 198 to 239 ft. The calculated sight distance deficiency becomes greater than indicated by the initial analysis, which used f = 0.38 for 25-mph urban operation.

Vertical Curvature

In addition to problems associated with local residential street horizontal curves, there are potential problems at vertical curves (VCs). Crest vertical curves at intersections of steep grades may have adequate SSD, but inadequate HSD. Three mitigating factors work to counteract limited HSD over crest curves:

1. Vehicles traveling uphill require shorter stopping distances.
2. In the design of a VC for SSD in accordance with the Green Book (*3*), the driver's eye height is taken to be 3.5 ft and an object on the road, 0.5 ft high. A VC designed for HSD would instead use the 4.25-ft PSD object height.
3. A t_{PR} of less than 2.5 sec may be acceptable if drivers are more alert while maneuvering through short sections on local residential streets with inadequate HSD.

One would not expect a properly designed sag vertical curve to have inadequate HSD.

SUMMARY AND RECOMMENDATIONS

Where two lanes of traffic moving in opposite directions operate in one lane, as happens on many residential streets, an amount of sight distance greater than SSD is needed. Approaching motorists must be able to react and stop before colliding.

Design standards should recognize the need for and provide sufficient HSD for the two approaching vehicles to react and stop before colliding on both horizontal and vertical curves. The need may exist when parking occurs on both sides of a residential street, or even when parking exists on only one side of more narrow streets. The presence of vegetation or other large fixed objects at the side of the curb may obstruct the driver's view and can help create these situations.

If a simple horizontal curve is short (curve length much less than SSD) and has only a slight deflection, the head-on sight deficiencies would be less likely to occur. The driver's view ahead would include the forward tangent, so the roadway would not continue to curve until it is out of the sight line.

Where HSD is deficient on local residential streets, parking restrictions may provide a remedy. Removing view-obstructing objects along the roadway may also be in order. Each agency responsible for roadways must be empowered with suitable ordinances and effective enforcement in order to remove sight-blocking vegetation, fences, and other obstacles.

More study is needed to determine the proper PRT for certain local residential street situations. For short lengths of two-way-in-one-lane operation, perhaps an alerted reaction time of less than the standard 2.5 sec would be appropriate, although the current 1.0 sec used for traffic signal timing may be too short. Other parameters, such as the proper tire friction values at lower speeds on a curve, the amount of sight clearance around a parked car needed to perceive another moving car, and the suitable assumed lateral position of the driver's eye (from the row of parked cars or inside curb) will need definition in order to design for these situations.

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Publication of this paper sponsored by Committee on Geometric Design.