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INTERSECTION ANGLES AND THE DRIVER'S FIELD OF VIEW

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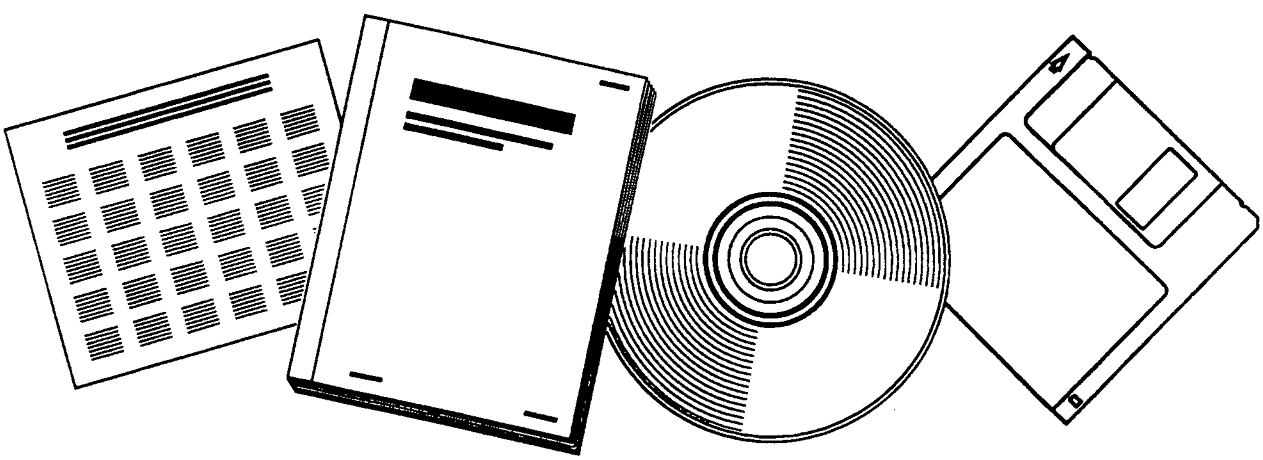

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INTERSECTION ANGLES AND THE DRIVER'S FIELD OF VIEW

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J. L. GATTIS and SONNY T. LOW

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16. Abstract

At a skewed-angle intersection with the acute angle to the right of a driver on the minor roadway (the approach required to stop or yield), the vehicle body may obstruct the minor-road driver's line-of-sight. Body parts that may obstruct the line-of-sight include the door frame, a panel aft of the door, or the cargo "box" of a single unit truck.

In this research project, the angles at which drivers' lines-of-sight were obstructed by the body of their vehicles were measured. Two driver positions, a "sit back" and a "lean forward", were used. A 13.5° vision angle (with respect to a line perpendicular to the vehicle path) was selected to represent an intermediate posture, between the sit back and the lean forward positions. With a 13.5° vision angle in some restrictive vehicles, the 60° minimum intersection angle allowed by *A Policy on Geometric Design of Highways and Streets* (*Green Book*) will cause the driver's line-of-sight to be obstructed by the vehicle itself and reduce the sight distance available to the driver. The report suggests that, depending upon the through-road speed, minimum left-skew intersection angles of 70° or more may be more appropriate.

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INTERSECTION ANGLES AND THE DRIVER'S FIELD OF VIEW

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INTERSECTION ANGLES AND THE DRIVER'S FIELD OF VIEW

by J. L. Gattis, Ph.D., P.E. and Sonny T. Low

CHAPTER 1
INTRODUCTION

The "normal" intersection consists of two streets intersecting and crossing at near-90° angles. The current *A Policy on Geometric Design of Highways and Streets* (the *Green Book*) by the American Association of State Highway and Transportation Officials (AASHTO) recommends that intersecting legs of three-leg and four-leg intersections meet at or nearly at right angles (*1*). However, there are many instances where the intersection angle of crossing streets is not close to 90°. These intersections are termed "skewed intersections". Skewed intersections may have some less-desirable attributes.

Skewed Intersection Nomenclature

Skewed intersections can be grouped into the two categories shown in Figure 1, the "left skewed" intersection and the "right skewed" intersection. The left skewed intersection is skewed such that the obtuse angle created (the one greater than 90°) is to the left of a driver on the minor road approach. With the right skewed intersection, the obtuse angle is to the right of the driver on the minor road approach (*2*). The "minor" or "side road" approach is the one required to stop or yield to crossing, through roadway traffic.

At a skewed-angle intersection, the intersecting legs form both acute and obtuse angles. In order to avoid confusion, the intersection angle is referenced by the smaller of the two angles formed between the two intersecting roadways. As an example, a "60° angle intersection" refers to a location at which the angle between minor and the major roadways is 60°. By necessary inference, a 60° intersection angle means the minor road approach is at a 30° angle to a perpendicular from the major road.

Potential Problems at Skewed Intersections

When roadways intersect at skewed angles, a number of operational issues are raised. When contrasted to the operation of a "normal" near-90° intersection, a skewed intersection may experience the following problems.

1. Vehicles crossing a skewed-angle intersection may have a longer distance to traverse while crossing the intersecting roadway. The longer distance will result in an increased time

of exposure to the cross street traffic. This in turn may call for an increased amount of intersection sight distance. This exposure is more significant for some longer combination vehicles (or other "non-passenger car" designs) because of their lower acceleration rates and longer vehicle lengths.

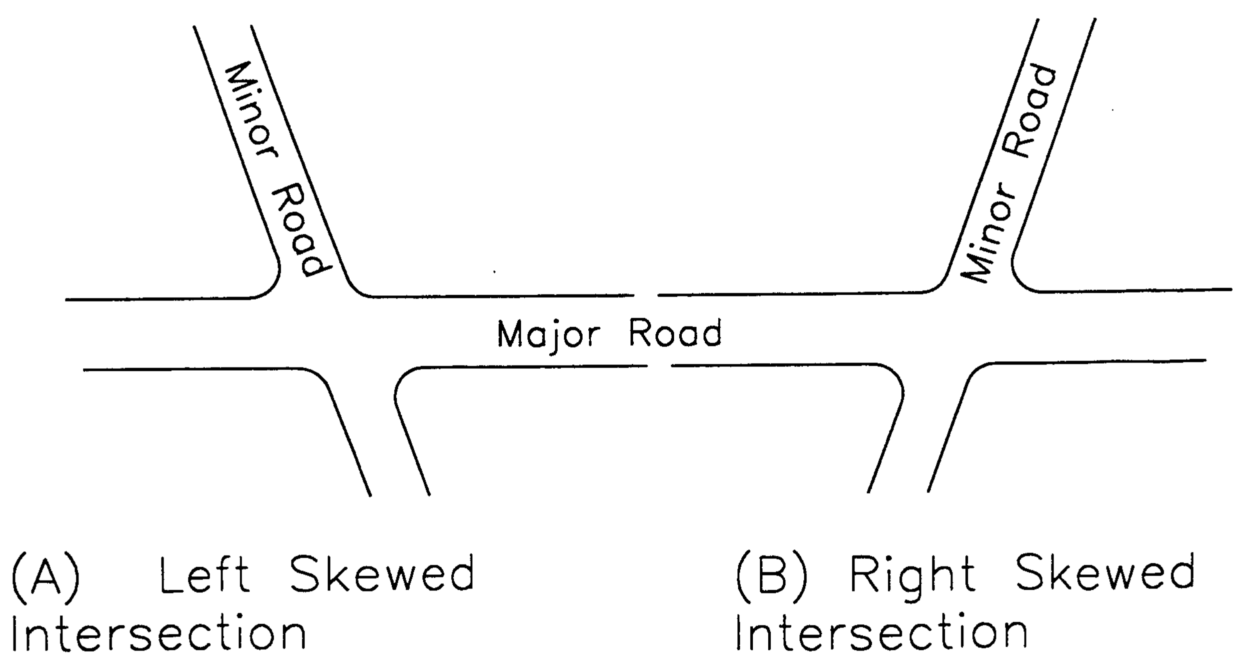


FIGURE 1 Skewed Intersection Nomenclature

2. The geometry of a skewed-angle intersection may result in a longer distance for pedestrians to cross, increasing their time of exposure to through traffic.
3. Drivers with certain physical limitations may find it more difficult to turn their heads, necks, or upper bodies in order to have an adequate line-of-sight down an acute angle approach.
4. Drivers making right or left turns at skewed-angle intersections may have more difficulty aligning their vehicles as they turn onto the cross street.
5. Unless adequate attention was given to the geometric design of the intersection radii, drivers making right turns around an acute angle radius may encroach upon lanes intended for oncoming traffic from the right.
6. Properly designed skewed intersections often require a larger intersection area to accommodate the turning paths of larger design vehicles through the acute angles. This larger intersection area may confuse drivers and also cause them to deviate from the intended path.
7. When intersection angles are skewed, valley gutters parallel to one roadway will not be perpendicular to the crossing roadway. For vehicles crossing a skewed valley gutter, the tires on each end of the axle will not cross the gutter simultaneously as they would have with a perpendicular valley gutter, but instead the tires will cross at different times. Each time an axle crosses the valley gutter, two bumps instead of a single bump will result.
8. Through roadway drivers making left turns across an obtuse angle may attempt to maintain a higher than normal turning speed and cut across the oncoming traffic lane on the intersecting street.
9. The line-of-sight of drivers with an acute angle approach to their right may be obstructed by the body of certain vehicles. Vehicle body parts that can obstruct the driver's line-of-sight include the door frame, a panel aft of the door, or the cargo "box" of a single unit truck.

Some of these problems as described may exist only when the driver is located on the left side of the vehicle. When the driver is positioned on the right side of a vehicle, the operational problem resulting from a skewed-angle intersection may take place to the left instead of to the right.

Research Scope

If the combination of vehicle design and intersection skew angle restrict a driver's line-of-sight to the right, safety may be compromised. This research project evaluated obstructions caused by the bodies of a number of vehicles at "left skewed" intersections. The researchers measured the angles at which the driver's line-of-sight was obstructed by the vehicle body. Based on these measurements, the report suggests recommended minimum sizes of left-skew intersection angles.

CHAPTER 2

LITERATURE REVIEW

A search was conducted to identify and review literature related to the skewed-angle intersection issue. Topics related to the issue of intersection angles include human factors, vehicle performance, and geometry.

Human Factors in Roadway Design

A recognition of human factors should be incorporated into the design of all public facilities. The *Human Factors Design Handbook* stresses that the layout of the street and roadway system is important to both local users and visitors, because the layout affects how easily drivers can locate themselves and decide where they want to go. One of the important factors is the use of rectilinear north-south-east-west plan. Drivers are more positive in their sense of direction when the roadways are at right angles to each other. Conversely, drivers become more confused as they traverse curved or angled streets. Not only do they lose track of direction, but all intersection cues become distorted -- nothing is "equal or square anymore" (*3*).

Visual Field and Head Movements of Drivers

The study of human visual sense and head movement are both involved disciplines. Some of these factors are relevant to driving tasks. According to theory, by utilizing peripheral vision a normal human being can perform simple discrimination tasks across a field of vision (display field) of about 20° to 30°, without moving the eyes. For tasks requiring a field (eye field) of 80° to 90°, eye movements are required to insure proper performance. Beyond this angle, head movements (head field) are required. The complexity of the task affects the border or boundary angle between these states (*4*).

Drivers regularly move their heads (vertical, horizontal and tilting) in order to perform complex driving tasks. In Sweden, Aberg and Rumar reported (*4*) the maximum horizontal head movement to be approximately 109° (83° when turning left, and 26° when turning right). With eye and head movement coordination, a driver's viewing range can cover over 180° of visual field. Thus, it can be concluded that for many scenarios, a driver's visual field will only be obstructed by the vehicle itself and not by human or natural limitations.

Minimum Intersection Sight Distance

For all intersections (included skewed intersections), there is a basic need to fulfill the minimum intersection sight distance requirement. Because drivers would be required to turn their heads considerably across an acute angle, the *Green Book* recommends that Case I (no control) not be used at skewed intersections. The sight distance required by Case II (yield control) or Case III (stop control), whichever gives the larger requirement, should be used at skewed intersections. As an approximation from *Green Book* Figure IX-41, the sight distance for a passenger car to turn left onto a two-lane highway and attain 85% of a 70 km/h posted speed is 205 m (*1*).

Some critics have deemed the *Green Book* intersection sight distance method too conservative and impractical for roadway design. For instance, the intersection sight distance for the major road design speed of 110 km/h (68 mph) is 451 m (1480 ft) (*1*). Fitzpatrick et al. quote Turnnard and Pushkarev as reporting that an individual cannot perceive vehicle movement much beyond 244 m (800 ft) or discern detail beyond 427 m (1,400 ft) because the size of a vehicle at such a long distance is too small (*5*). This suggests that providing sight distances beyond 244 m may not necessarily increase the safety factor to road users and may reduce the overall cost effectiveness. Fitzpatrick et al. also concluded that further review is needed of driver visual limitations and factors that could be used to select realistic intersection sight distances (*5*).

McCoy et al. examined skewed intersection issues. They reported that for intersections with skew angles less than 75°, the vehicle itself can cause the available sight distance to the right, across the quadrant with the acute angle, to be restricted to less than the required sight distance (*6*).

Some states' departments of transportation have approved smaller intersection sight distances than the *Green Book* recommends. The Arkansas Highway and Transportation Department (AHTD) uses 107 m (350 ft) as the acceptable intersection sight distance for a 56 km/h (35 mph) design speed instead of the 140 m (459 ft) recommended by the *Green Book*. As a minimum requirement, the sight distance for skewed intersections needs to be at least 107 m.

Vehicle Stopping Position

The *Green Book* uses sight triangle geometry to calculate the required intersection sight distance for both Case II and III. In the Case II sight triangle, the lengths of both legs are established by the stopping sight distance on each approach (*Green Book*, Figure IX-32A). For the Case III sight triangle, the intersection sight distance establishes one leg of the sight triangle (*Green Book*, Figure IX-32B), while the length of the other triangle leg is determined by how far the driver's eye is assumed to be back from the edge of the major road traveled way. The assumed distance from the edge of the major road traveled way to the driver's eye is given as 6 m (20 ft) (*1*). The 6 m distance is based on two assumptions. The first assumption is that the front bumper of a stopped vehicle will be 3 m (10 ft) from the edge of the major roadway. The second assumption is that the driver's eye is assumed to be 3 m behind the front bumper.

Appendix H to NCHRP Report 383, *Intersection Sight Distance*, reports the findings of recent field studies that re-examined the positions of stopped vehicles (*7*). For 85% of the vehicles observed, the distance from the edge of traveled way to the front bumper was found to not exceed 2.0 m (6.6 ft). To establish the distance from the front bumper to the driver's eye, two component measurements were used. The first component was the maximum distance from the driver's eye to the center of the steering wheel. Based on a sample of 10 drivers (different heights, 5 male and 5 female), this distance was found to be 394 mm (15.5 in). The second component, the distance from the front bumper to the center of the steering wheel, was based on 101 vehicles which included passenger cars, pickup trucks, and minivans. Both the 85th and 90th percentile values were 2.4 m (7.9 ft). The sum of these two components, the distance form the driver's eye to the edge of the cross street, was 4.4 m (14.4 ft). However, NCHRP Report 383 recommended 5.4 m (17.7 ft) as a more conservative assumption to be used in intersection sight distance calculation. For constrained situations, 4.4 m is acceptable (*8*).

Safety Effects of Skewed Intersection

Traffic operations at unsignalized, skewed intersections are generally believed to be less safe than those at right angle intersections because of larger conflict areas, longer sight distance requirements, and awkward, often restricted, lines-of-sight at skewed intersections.

McCoy et al. reviewed accident reports from 68 two-way stop-control intersections with similar traffic volumes (*6*). Twenty-nine of the intersections were skewed intersections, with the skew angles ranging from 80° to 45°. The Poisson regression analysis was used to model the relationship between the number of accidents, skew angle, and traffic volume. It was reported that the number of accidents per year increased with traffic volume and skew angle.

Minimum Intersection Angle

The *Green Book (1)* recommends that roadways intersect at right angles whenever possible. The operational and safety effects of skewed intersections are only mentioned in very general, non-quantitative terms. However, for costly and constrained right-of-way conditions, the *Green Book* suggests a 60° minimum intersection angle (*1*). In contrast, the Canadian Transportation Association's manual limits the intersection angle to 70° (*9*). McCoy et al. stress that there are no justifications for the use of 60° as the minimum intersection angle. There have been no published studies of accident characteristics or operational effects of skewed intersections (*6*).

McCoy et al. also included a summary of design practice with respect to the allowable skew angle for 12 states. He found that most of the states had a minimum allowable intersection angle of 60°, as recommended by the *Green Book*. Minnesota and Missouri recommend a minimum allowable intersection angle of 70°, which is consistent with Canadian design practice. Ohio recommends 70° as the minimum angle, but 60° is satisfactory. Alaska, Illinois, and Wisconsin recommend 75° as a desirable minimum angles, but allow the minimum angle to be 60°. Iowa does not have a recommended minimum intersection angle, but uses sight distance adjustment factors for intersection angles listed in Table 1 (*6*).

TABLE 1 Iowa Sight Distance Correction Factors for Intersection Angles

Intersection Angle (degrees)	Correction Factor
90	1.00
80	1.01
70	1.03
60	1.06
45	1.17

Factors Affecting the Minimum Intersection Angle

According to McCoy et al. (*6*), the minimum intersection angle should be a function of traffic volumes and economic considerations. For example, at intersections of low volume roadways, a minimum allowable intersection angle of less than 60° may be tolerable. At intersections of higher volume roadways, the minimum allowable intersection angle may be greater than 60° (i.e., closer to 90°).

Two categories of economic considerations that affect the minimum desirable intersection angle were offered. First, the minimum allowable intersection angle is directly related to the cost of realigning the intersection. Higher realignment costs reduce the cost effectiveness of realignment and therefore invite a greater deviation from 90°. Second, the allowable deviation from 90° is inversely related to road user cost savings (running, travel time, and delay costs) from such a realignment. Higher resultant road user savings suggest an angle closer to 90° (*6*).

CHAPTER 3

RESEARCH METHODOLOGY

The obstruction of a driver's line-of-sight by parts of the driver's own vehicle may be an important factor in determining the minimum acceptable intersection angle. The objective of this research was to identify constraints on the angle of a left-skewed intersection, as affected by the vehicle body limiting a driver's line-of-sight to the right. This was done by measuring, in a variety of vehicle types, the maximum vision angle to the driver's right that the vehicle structure (i.e., body) allowed the driver to have.

Design Vehicle

The driver's view of oncoming cross street traffic at an intersection may be restricted by a car roof post, the door frame, or a panel aft of the door. If such a restriction limits the driver to a less-than-adequate time to detect oncoming vehicles before deciding to pull out into or cross the through traffic stream, safety may be compromised.

For the purposes of this study objective, several vehicle design types were identified as having the potential to more readily restrict a driver's line-of-sight than most other vehicle types. These types include an

ambulance,
dump truck,
motor home,
school bus,
small bus on a van chassis,
single unit truck mounted with container (rental moving truck),
truck tractor (cab of an "18 wheeler").

The research team located an example of each vehicle type, then made arrangements with the owner to allow measurements to take place. An attempt was made to also include a "cab over camper", where the camper body extended well outside of the sides of the pickup truck, but one was not located. Additional design vehicle information is listed in Appendix A.

Driver Position

Defining the assumed posture of a driver in a vehicle is a somewhat subjective activity. Two different driver positions were assumed, and data were collected for both driver positions.

The first posture was called the "sit back" position. The driver was in a fully leaned-back position, with his back against and touching the seat-back. In this position, the driver relies mainly on head and neck movement to get the maximum viewing angle to his right. This position permits the driver to remain comfortably seated against the seat back.

The other posture was the "lean-forward" position. In this position, the driver leaned forward so that the driver's eyes were over the juncture where the steering wheel is attached to the column. So, in addition to using head and neck movements, the driver leaned his upper body far forward to get a greater viewing angle to the right. In such a position, the driver's chest was often pressing the driver's arms against the steering wheel, thus confining the movement of the driver's arms. The driver's ability to control steering and other vehicle functions is somewhat diminished in this position. It may even be unlikely that some drivers could lean this far forward.

These "full sit back" and "full lean forward" postures were chosen for measurement because these positions can be established and replicated with much less subjectivity than intermediate lean forward positions. Based on informal observations of driver behavior, it was assumed that the limiting position that determines the line-of-sight angle for a majority of drivers probably lies between these two driving postures.

Field Measurements

After procuring each design vehicle in a stationary position on a level parking surface and seating the driver, the following steps were taken to produce the measurements needed to determine the maximum angle of the driver's line-of-sight with respect to the vehicle. For informational purposes, the researchers measured the distance between the sit back and lean forward postures, along with the distance from the sit back position to the front bumper. These data are in Appendix B.

In order to strike off a line perpendicular to the vehicle from the driver's position, certain aspects of the vehicle were measured. First, the researchers measured the lengths of both the front and the rear axles, as defined by the distance between the two front tires, and the distance between two rear tires. For most measured vehicles, the rear axle was wider than the front axle. The difference between these two widths was found and divided by two. This half-of-the-width-difference was added to the front axle width and this dimension was marked on the parking lot surface to the outside of the right front tire. By connecting a line from this point to the edge of the right rear tire, a line parallel to and at the right edge of the vehicle body was drawn. This line was called the "right-edge parallel line".

Next, using a large cardboard jig, the researchers constructed two lines perpendicular to the right edge of the vehicle. The first perpendicular line was projected from the driver's eyes with the driver in the sit back posture. The other perpendicular line was projected from the lean forward position. Each line was projected outward to a point that was 1.2 to 3 m (4 to 10 ft) to the right of the previously-constructed right-edge parallel line. Points were marked where the perpendicular lines crossed the right-edge parallel line. The distance from the driver's position to the right-edge parallel line was measured. Trigonometric measurements were made to check and verify that the perpendicular lines were at 90° to the right-edge parallel line. In most cases, the angle drawn with the jig was found to be surprisingly close to a 90° angle. Figure 2 shows the process of drawing such a perpendicular line.

Again using a large cardboard jig, a second parallel line offset to the right of the vehicle was drawn. After marking this "right-offset line" on the pavement, dimensions were checked to verify that this new line was parallel to the original right-edge parallel line. Figure 3 shows a right-offset line being marked.

Once these lines had been marked, the researchers were ready to mark the limits of the driver's line-of-sight. A surveying range pole with an attached level was placed on the right-offset line, within the seated driver's field-of-view. As it was slowly moved backward (along the right-offset line), the person in the driver's seat signaled when a vehicle body obstruction caused him to lose sight of the pole. The position of the pole when the line-of-sight first became obstructed was marked on the pavement. This procedure was performed three times each for both the sit back and the lean forward positions. Figure 4 shows the marking of a point at which the driver's line-of-sight became obstructed. Figure 5 shows researchers recording the resulting dimensions.

Data Analysis

The process of marking lines on the pavement and measuring the points previously described produced values for K, SB, and LF, shown in Figure 6. Using the following equations, the "vision angle" (VA) at which the driver's line-of-sight was interrupted by the vehicle body was found for each vehicle.

$$VA_{SB} = \arctan\,[SB/(L+K)]$$

$$VA_{LF} = \arctan\,[LF/(L+K)]$$

The vision angle for the sit back position was denoted VA_{SB}, and the vision angle for the lean forward position was called VA_{LF}.

FIGURE 2 Drawing Perpendicular Line

FIGURE 3 Drawing Right-Offset Line

FIGURE 4 Locating Where Vision Becomes Obstructed

FIGURE 5 Resulting Marks on Parking Lot Surface

Calculations were also performed to estimate the intersection angle at which the blocked line-of-sight would yield inadequate sight distance. This stage of the analysis incorporated a number of assumptions. First, the distance from driver's eye to the edge of cross road was set. Two values from NCHRP 383 were used, E = 5.4 m (17.7 ft) and E = 4.4 m (14.4 ft). This distance was measured along the centerline axis of the side-road vehicle. Second, assuming a two-lane roadway, the distance from the near road edge to the center of the path of the oncoming vehicle from the right was calculated as the width of 1.5 lanes, or 5.4 m (3.6 + 3.6/2), measured normal or perpendicular to the major cross street.

Figure 7 shows the components to the sight distance--speed calculation. The following terms and abbreviations were used.

VA = vision angle (either 4.5° or 13.5°)

IA = intersection angle (from 55° to 75°)

ASD = resulting available sight distance

Inspection of the applicable triangles leads to the following calculations.

$\alpha = 90° - IA - VA$

$A = E + [5.4 / \sin IA]$

$\beta = 90° + VA$

Employing the Law of Sines will produce B, the resulting sight distance available to the side road driver.

$\sin \alpha / A = \sin \beta / B$

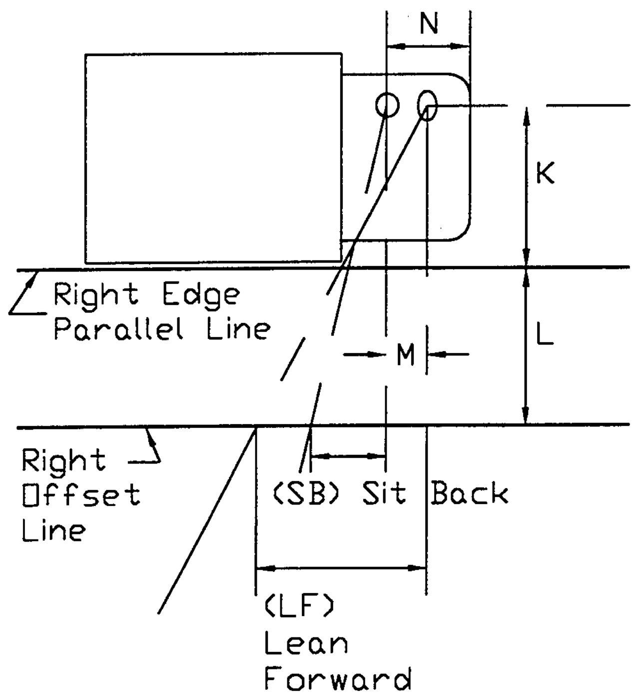


FIGURE 6 Vision Angle Geometry

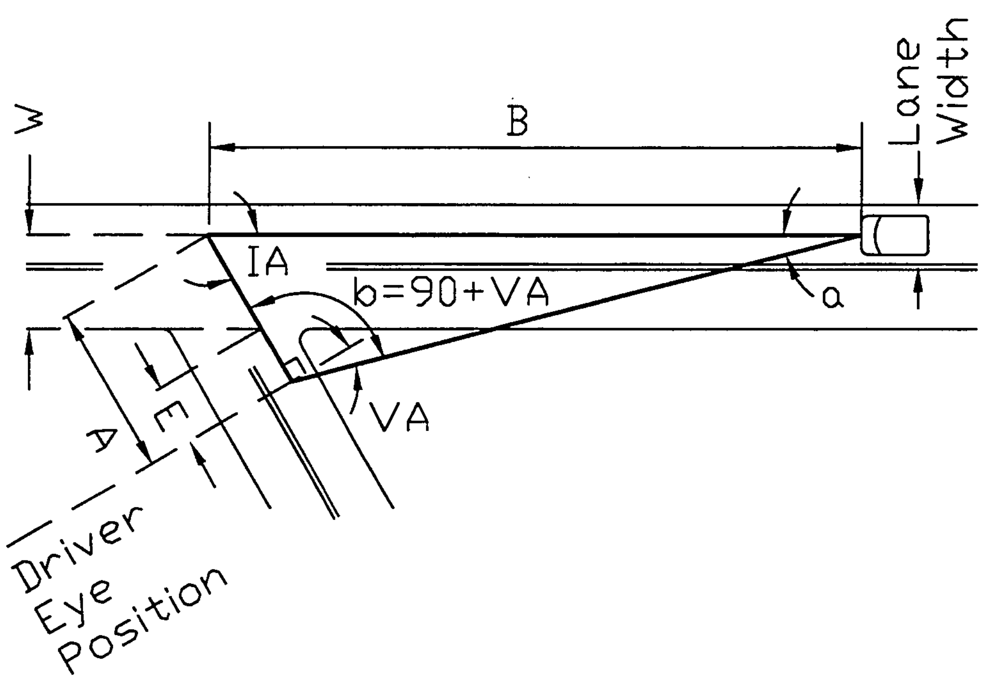


FIGURE 7 Sight Distance Triangle Geometry

CHAPTER 4
RESULTS AND DISCUSSION

The vision angles listed in Table 2 were measured with respect to a perpendicular from the right of a seated driver. In the sit back posture, the vehicle body blocked the driver's line-of-sight at angles ranging from 2° to 15° from perpendicular to the vehicle. In the lean forward posture, the line-of-sight was not blocked until an angle of between 19° and 31° was reached.

TABLE 2 Vision Angles

Vehicle type	Position	
	VA_{SB} Sit back (degrees)	VA_{LF} Lean forward (degrees)
Ambulance with box behind cab	2.1	20.3
Motor home	2.2	19.2
Truck tractor with sleeping area (for 18 wheeler)	3.8	22.3
SU rental truck with box behind cab 18,000 lb	4.0	21.9
SU rental truck with box behind cab 11,000 lb	7.0	23.4
School bus - 65 passengers, type C	8.1	25.0
Dump truck	14.1	31.0
Bus - 16 passengers	14.8	23.1
School bus - 15 passengers	14.9	24.6

After initial analyses, it was decided to exclude the dump truck, the 16 passenger bus-on-van-chassis, and the 15 passenger school bus from further calculations. This is because these three vehicles offered a much less restricted view in the sit back posture than the other vehicles tested. Among the remaining vehicles, the average vision angle (measured from a line perpendicular to the vehicle) was found to be 4.5° for the sit back posture and 22.5° for the lean forward posture.

As previously mentioned, a driver leaning fully forward might be in an awkward position. However, a driver may not have to remain in a sit back position but could lean somewhat forward to see oncoming cross street traffic and still control the vehicle. After discussion, which included seating the research project oversight panel members behind the wheel in various positions, it was decided to employ two vision angles for calculation purposes:

1. a "desirable" VA_{SB}, based on the sit back position, and
2. a "minimum" VA_{MLF}, based on the modified or intermediate lean forward posture, producing a line-of-sight that is blocked at a 13.5° angle from perpendicular.

Effects on Sight Distance at Intersections

The available sight distances at skewed-angle intersections that are produced with both the desirable and the minimum vision angles were calculated. Intersection angles ranging from 55° to 75° were used as independent variables to find the resulting sight distance available to the stopped vehicle. A departure-sight triangle was used to model the resultant sight distance.

As Table 3 shows, with E = 5.4 m (17.7 ft) and the driver in the intermediate lean forward posture, the resulting available sight distances for 60° , 65° , 70°, and 75° were found to be 40, 55, 96, and 408 m (131, 180, 315, 1339 ft) respectively. It was noted that the currently recommended minimum intersection angle, 60°, has a resulting available sight distance equal to the stopping sight distance for 37 km/h (23 mph) travel on the major roadway. This speed is considered low, even for local street design speed. However, if the driver leans forward to the modified intermediate posture, the resulting available sight distance for a 75° left skewed intersection exceeds the stopping sight distance for 120 km/h (75 mph). The 65° and 70° intersection angles are suitable for stopping sight distances of 46 to 65 km/h (29 to 40 mph), which are in the range of many urban local, collector, and arterial roadways.

Designers should recognize that some drivers will, either because of habit or vegetation and other roadside obstacles that block their line-of-sight, position themselves so they are less than 5.4 m (17.7 ft) from the edge of the through-road traveled way. Table 4 lists the ASD and design speeds calculated with E = 4.4 m (14.4 ft). By comparing Table 4 values with those in Table 3, one can see that if the minor-road vehicle stops closer to the through-road edge, the resulting available sight distances and corresponding speeds that allow through-road vehicles to stop will decrease.

Comments

The sight distance calculations presented are those that allow the through-road vehicle to come to a stop and avoid a collision with a side-road vehicle that inappropriately entered the intersection. A greater sight distance may allow improved traffic operations; it may also reduce the number of

TABLE 3 Resulting Available Sight Distance for a 5.4 m Setback

			Desirable Vision Angle (VA_{SB}) 4.5°				Minimum Vision Angle (VA_{MLF}) 13.5°			
Intersection Angle	5.4m/sin(IA)		ASD		Design Speed		ASD		Design Speed	
(IA) degrees	m	(ft)	m	(ft)	km/h	(mph)	m	(ft)	km/h	(mph)
55	6.592	21.6	23.6	77.4	<30	<20	31.8	104.3	31	<20
60	6.235	20.5	26.9	88.2	<30	<20	39.8	130.6	37	23
65	5.958	19.5	32.3	106.0	32	<20	55.4	181.8	46	29
70	5.747	18.9	41.6	136.5	38	24	95.7	314.0	65	40
75	5.590	18.3	60.1	197.2	49	30	408.2	1339.2	>120	>70

Note : Based on a distance from driver's eye to edge of cross road of 5.4 m (per NCHRP 383), and a distance from the near road-edge to the center of the path of the oncoming vehicle from the right (3.6 + 3.6/2) = 5.4 m.

TABLE 4 Resulting Available Sight Distance for a 4.4 m Setback

			Desirable Vision Angle (VA_{SB}) 4.5°				Minimum Vision Angle (VA_{MLF}) 13.5°			
Intersection Angle	4.4m/sin(IA)		ASD		Design Speed		ASD		Design Speed	
(IA) degrees	m	(ft)	m	(ft)	km/h	(mph)	m	(ft)	km/h	(mph)
60	5.081	16.7	24.6	80.7	<30	<20	36.4	119.4	35	22
65	4.855	15.9	29.5	96.8	30	<20	50.5	165.7	43	27
70	4.682	15.4	37.8	124.0	36	22	87.1	285.8	61	38
75	4.555	14.9	54.6	179.1	46	29	371.1	1215.5	>120	>70

Note : Based on a distance from driver's eye to edge of cross road of 4.4 m (refer to NCHRP 383), and a distance from the near road-edge to the center of the path of the oncoming vehicle from the right (3.6 + 3.6/2) = 5.4 m.

sudden stops on the through-road, which can contribute to rear end collisions. The philosophy incorporated into the calculation for intersection sight distance somewhat reflects these needs.

It should be noted that passengers seated in the right front seat, or objects stacked on the seat may also partially or fully obstruct the driver's line-of-sight to the right. However, passengers can lean or move to give the driver an improved line-of-sight, and the driver does have discretion about placing parcels in the seat. In contrast, a driver's options are fairly well fixed by the configuration of the vehicle's body.

CHAPTER 5
CONCLUSION

The "Alinement and Profile" section in Chapter IX, as well as the "Local Road" and "Collector" chapters of the current *Green Book*, recommend an intersection angle of no less than 60°. However, the bodies of certain vehicles operated on roadways are such that when at a left-skewed 60° angle intersection, the driver's line-of-sight to the right may be obstructed and not provide an adequate amount of sight distance.

If roadway engineers are to consider the limitations created by vehicle designs, the findings from this study suggest that a minimum intersection angle of 70° to 75° will offer an improved line-of-sight. This minimum is applicable when the acute angle is to the right of the minor-road driver (the one with the stop or yield sign). This minimum angle only provides adequate stopping sight distance for the through-road vehicle. The demands of intersection sight distance, providing a line-of-sight that enables the minor-road vehicle driver to enter the through roadway and accelerate before the through-road vehicle overtakes her or him, could require intersection angles closer to 90°. Appendix C contains information and computational process suggestions to implement these findings.

REFERENCES

1. *A Policy on Geometric Design of Highways and Streets*, pp. 643, 645, 702, 719. American Association of State Highway and Transportation Officials, Washington, DC. 1994.
2. Hickerson, T. F. *Route Location And Design*, 5th ed, p. 271. McGraw-Hill, New York, NY. 1964.
3. Woodson, W. E., and B. Tillman. *Human Factors Design Handbook* (Information and Guidelines for the Design of System, Facilities, Equipment and Products for Human Use), p. 28. McGraw Hill, New York, NY. 1992.
4. Aberg, L., and K. Rumar. *Headmovement of Drivers - Equipment and Exploratory Study*. Department of Psychology, University of Uppsala, Sweden. 1975.
5. Fitzpatrick, K., J. M. Mason, and D. W. Hardwood. "Comparison of Sight Distance Procedures for Turning Vehicles from a Stop-Controlled Approach", Transportation Research Record 1385, pp. 1-11. TRB, National Research Council, Washington, DC. 1993.
6. McCoy, P. T., E. J. Tripi, and J. A. Bonneson. *Guidelines for Realignment of Skewed Intersections*, pp. i, 3, 9,10, 38, 42. University of Nebraska, Lincoln, NE. 1994.
7. Harwood, D. W., J. M. Mason, R. E. Brydia, M.T. Pietrucha, and G. L. Gittings. *Intersection Sight Distance*, NCHRP Report 383, Appendix H. TRB, National Research Council, Washington, DC. 1996.
8. Harwood, D. W., J. M. Mason, R. E. Brydia, M.T. Pietrucha, and G. L. Gittings. *Intersection Sight Distance*, NCHRP Report 383, p. 86. TRB, National Research Council, Washington, DC. 1996.
9. Walker, R. J. "Coordination of Basic Intersection Design Elements: An Overview", Transportation Research Record 1385, pp. 51-59. TRB, National Research Council, Washington, DC. 1993.

APPENDIX A

Design Vehicle Information

VEHICLE TYPE

VIN = Vehicle Identification Number

Type : 1
Comment : U-Haul, Suggested clearance = 11 ft
Model : GMC F350 CUSTOM
VIN : 5379TCD205K
Year : October 79
Front Wheel = 5.95 ft, Rear Wheel = 6.8 ft

Type : 2
Comment : U-Haul, Under 18000 lb Gross
Model : INTERNATIONAL S160D,S-series Model 1654LP.
VIN : IHTJU2RM5JH620965
Year : May 1988
Front Wheel = 7.25 ft, Rear Wheel = 7.55 ft

Type : 3
Comment : Motor Home, CVWR = 12400
Model : FORD 350.
VIN : IFDKE30G3PHB91459
Year : August, 1993
Front Wheel = 6.3 ft, Rear Wheel = 7.55 ft

Type : 4
Comment : Dump Truck, GW 28040
Model : CHEVROLET 70
VIN : IGBL7DIE4LVI03122
Year : Not Available
Front Wheel = 7.2 ft, Rear Wheel = 7.95 ft

Type : 5
Comment : School Bus, Springdale 5-7-21, GVWR 23660
Model : GMC 6000
Body : Blue Bird
VIN : 1GDJ6P1B3EV548995
Year : June-1984
Front Wheel = 6.99 ft, Rear Wheel = 7.57 ft

Type : 6
Comment : School Bus, Faytteville 5-3-26, GVWR 10,000
Model : GMC Vandura 3500, Diesel 6.2 Litre
Body : Ward Vanguard, School Bus
VIN : 2GDHG31J2H4509993
Year : March 1987
Front Wheel = 6.29 ft, Rear Wheel = 7.58 ft

VEHICLE TYPE

Type : 7
Comment : Ambulance, GVWR 11,500 lb
Central Emergency Medical Center, Ambulance #3
Model : E350 Ford
VIN : 1FDKE30M9PHA98015
Year : March 1993
Front Wheel = 6.25 ft, Rear Wheel = 7.58 ft

Type : 8
Comment : Truck Trailer
H-C Trailer Rental Inc #603
Model : Freigthliner
VIN : N/A
Year : December 198?
Front Wheel = 7.42 ft, Rear Wheel = 7.79 ft

Type : 9
Comment : Bus on van chasis, GVWR 14050
Ozark Transit, Bus # 624, 16 passengers
Model : Ford E.Super Duty, THOR
VIN : 1FDLE40G5THB34216
Year : May, 1996
Front Wheel = 6.25 ft, Rear Wheel = 7.92 ft

APPENDIX B

Field Data

FIELD DATA

					Sit Back	Lean Forward				(SB)	(LF)
	(K)	(L)	(M)	(N)	(SB)	(LF)	*adj (LF)	(H)	(I)	arctan(H)	arctan(I)
Type	ft	ft	ft	ft	ft	ft	ft	SB/(L+K)	adj(LF)/[L+K]	degree	degree
1	5.800	6.000	1.225	6.250	1.300	3.820	5.045	0.110	0.428	6.287	23.149
SU Rental Truck					1.500	3.900	5.125	0.127	0.434	7.245	23.476
with box behind					1.500	3.900	5.125	0.127	0.434	7.245	23.476
cab 11,000 lb.					1.500	3.900	5.125	0.127	0.434	7.245	23.476
				Average	1.450		5.105	0.123	0.433	7.005	23.395
2	7.000	10.000	1.650	5.450	1.175	5.050	6.700	0.069	0.394	3.954	21.510
SU Rental Truck					1.175	5.185	6.835	0.069	0.402	3.954	21.903
with box behind					1.175	5.300	6.950	0.069	0.409	3.954	22.236
cab 18,000 lb.				Average	1.175		6.828	0.069	0.402	3.954	21.884
3	6.350	6.000	1.400	5.360	0.480	2.770	4.170	0.039	0.338	2.226	18.657
Motor Home					0.480	2.950	4.350	0.039	0.352	2.226	19.404
					0.480	2.980	4.380	0.039	0.355	2.226	19.527
				Average	0.480		4.300	0.039	0.348	2.226	19.197
4	6.475	6.000	1.575	5.325	3.060	5.875	7.450	0.245	0.597	13.782	30.845
Dump Truck					3.160	5.930	7.505	0.253	0.602	14.214	31.031
					3.160	5.930	7.505	0.253	0.602	14.214	31.031
				Average	3.127		7.487	0.251	0.600	14.070	30.969
5	6.220	10.000	1.410	6.700	2.190	5.310	6.720	0.135	0.414	7.689	22.504
School Bus -					2.340	5.470	6.880	0.144	0.563	8.209	29.380
65 passenger,					2.380	5.530	6.940	0.147	0.428	8.348	23.164
type C				Average	2.303		6.847	0.142	0.468	8.082	25.016
*adj (LF) = M + LF											

FIELD DATA

					Sit Back	Lean Forward				(SB)	(LF)
	(K)	(L)	(M)	(N)	(SB)	(LF)	*adj (LF)	(H)	(I)	arctan(H)	arctan(I)
Type	ft	ft	ft	ft	ft	ft	ft	SB/(L+K)	adj(LF)/[L+K]	degree	degree
6	6.330	10.000	1.580	5.420	4.400	5.940	7.520	0.269	0.461	15.080	24.726
School Bus -					4.310	5.920	7.500	0.264	0.459	14.785	24.668
15 passenger					4.290	5.880	7.460	0.263	0.457	14.719	24.552
				Average	4.333		7.493	0.265	0.459	14.861	24.649
7	6.330	4.000	1.460	6.500	0.350	2.330	3.790	0.034	0.367	1.941	20.148
Ambulance					0.350	2.350	3.810	0.034	0.369	1.941	20.245
					0.440	2.400	3.860	0.043	0.374	2.439	20.489
				Average	0.380		3.820	0.037	0.370	2.107	20.294
8	7.500	10.000	1.670	8.580	1.030	5.420	7.090	0.059	0.405	3.368	22.055
Truck Tractor with					1.170	5.540	7.210	0.067	0.412	3.825	22.392
Sleeping area					1.250	5.540	7.210	0.071	0.412	4.086	22.392
(for 18 Wheeler)				Average	1.150		7.170	0.066	0.410	3.760	22.279
9	6.580	10.000	1.500	6.670	4.330	5.540	7.040	0.261	0.425	14.636	23.006
Bus -					4.420	5.560	7.060	0.267	0.426	14.927	23.065
16 passenger					4.400	5.600	7.100	0.265	0.428	14.863	23.182
				Average	4.383		7.067	0.264	0.426	14.809	23.084
*adj (LF) = M + LF											

APPENDIX C

IMPLEMENTATION

The following instructions and table are intended for inclusion in a design manual, to be used by engineers and technicians in the roadway design process.

INTERSECTION ANGLE GUIDELINES

The typical intersection consists of two streets intersecting and crossing at near-90° angles. The 1994 *A Policy on Geometric Design of Highways and Streets* (the AASHTO *Green Book*) recommends that intersection legs meet at or nearly at 90° angles. When the intersection angle is not close to 90°, the intersection is called a "skewed intersection". It is often recommended that an intersection angle be no less than 60°.

Skewed intersections can be grouped into the two categories shown in the figure, the "left skewed" intersection and the "right skewed" intersection. The left skewed intersection is skewed such that the obtuse angle created (the one greater than 90°) is to the left of a driver on the minor road approach. The "minor" or "side road" approach is the one required to stop or yield to crossing, through roadway traffic.

A research effort of the Arkansas State Highway & Transportation Department and the Mack-Blackwell Transportation Center at the University of Arkansas examined sight limitations at left-skewed intersections experienced by drivers in vehicles such as a motor home or a single-unit rental truck. The results suggest that if roadway engineers are to consider the restrictions created by vehicle designs, some circumstances may call for a minimum intersection angle greater than 60°. The following table presents combinations of design speed, stopping sight distance for the through road vehicle (per the 1990 and 1994 *Green Book*), and the recommended smallest intersection angle. Two intersection angles are listed: a desirable vision angle (VA_{SB} = 4.5°) permits the driver to remain leaning against the seat back, while the minimum vision angle (VA_{MLF} = 13.5°) requires the driver to lean forward about half way to the steering wheel.

The accompanying table presents an angle that is just adequate to permit the driver of the side street vehicle to view the through road vehicle coming from the right, at a distance equal to the through road vehicle's stopping sight distance. The driver of the minor road vehicle was assumed to be positioned 4.4 m back of the near edge of the through roadway, and the oncoming vehicle from the right was assumed to be centered on a line 5.4 m (about the width of 1.5 lanes) past the near roadway edge. The table shows that for a wide range of higher design speeds, an intersection angle of about 81° satisfies the VA_{SB} assumption, and around 72° is sufficient for the VA_{MLF} assumption.

If the need arises to determine a minimum angle based on different conditions, the following trial-and-error iterative sequence may be followed. *An example calculation in italics accompanies each step.*

1. Determine a realistic and appropriate design speed.

    Design speed of 50 km/hr.

2. Compute the distance B in advance of the intersection at which the minor road driver should be able to view the through roadway vehicle approaching from the right. This distance is often the stopping sight distance (SSD) or the intersection sight distance (ISD).

   SSD for 50 km/hr = 62.8 m = B.

3. Determine whether the desirable (4.5°) or minimum (13.5°) vision angles (VA) will be used. Then calculate the angle $\beta = 90° + VA$.

   Design for desirable VA = 4.5°, so $\beta = 90° + VA = 94.5°$.

4. Assume a trial intersection angle (IA).

   Assume IA = 75° (i.e, 15° "off" from perpendicular).

5. Calculate the distance A = E + [W / sin IA], where E is the distance from the side road vehicle driver to the near edge of the through roadway, and W is the distance (measured perpendicular to the through roadway) from the near edge of the through roadway to the center of the path of the through vehicle.

   A = E + [W / sin IA] = 4.4 + 5.4/sin 75° = 9.99 m

   *(If dealing with 3.6 m lanes and a 5-lane design, W = 3.5 lanes * 3.6 m = 12.6 m.)*

6. Calculate the angle $\alpha = 90° - IA - VA$.

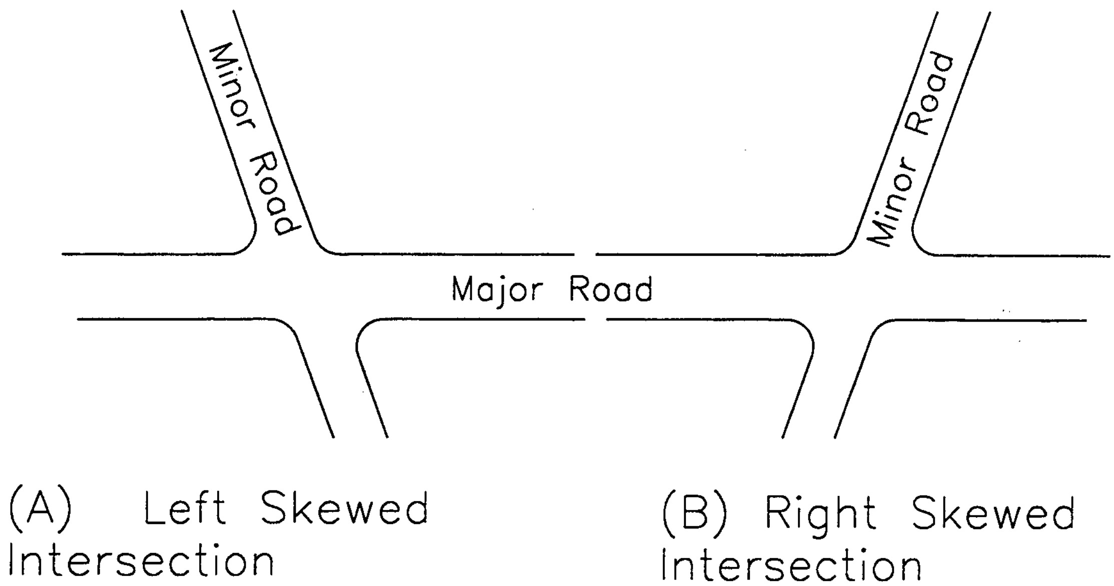
   $\alpha = 90° - IA - VA = 90° - 75° - 4.5° = 10.5°$

7. Use the Law of Sines to calculate $\sin \alpha = A * \sin \beta / B$.

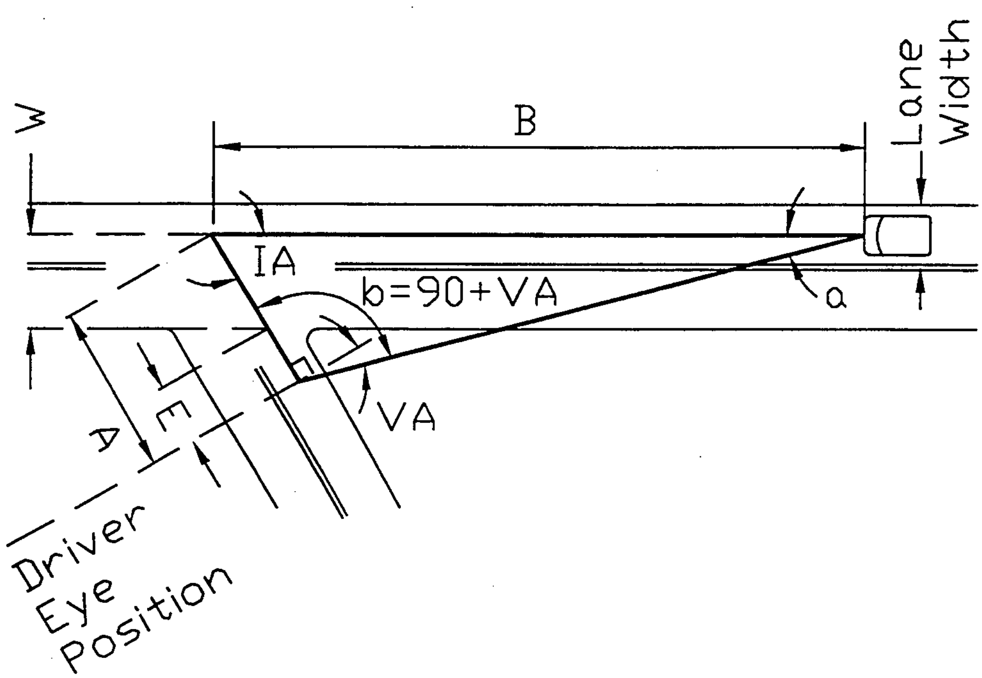
   $\sin \alpha = A * \sin \beta / B = 9.99 * \sin 94.5° / 62.8 = 0.15859$

8. Calculate the arcsin (sin α) to find the value of α, and compare this value with the α value found in step 6; when you have iterated to the correct value of IA in step 4, the step 6 α will equal the step 8 α.

   Arcsin (sin α*) = 9.12°. Since the Step 6* α *= 10.5°, the guess of IA = 75° was slightly too small by roughly 1.4° (9.12 - 10.5 = -1.38). Adding 1.4° to 75° = 76.4°, and proceeding through another iteration will verify that 76.4° is the correct "least value" for the intersection angle.*



Skewed Intersection Nomenclature



Sight Distance Triangle Geometry

INTERSECTION ANGLE MINIMUMS Rev. 11/25/97

for left-skewed intersections

Design Speed km/hr	Design Speed (mph)	B, Stop sight distance m	B, Stop sight distance (ft)	Intersection Angle: For a $VA_{SB}=4.5^{o}$ (desirable) degrees	Intersection Angle: For a $VA_{MLF} = 13.5^{o}$ (minimum) degrees
30		29.6		65.1	54.7
	20		106.7	67.2	57.1
40		44.4		72.4	62.9
	25		146.5	72.5	63.0
	30		195.7	75.9	66.6
50		62.8		76.4	67.1
	35		248.4	78.0	68.8
60		84.6		78.8	69.6
	40		313.3	79.6	70.4
70		110.8		80.4	71.3
	45		382.7	80.7	71.6
80		139.4		81.5	72.4
	50		461.1	81.5	72.4
	55		537.8	82.1	73.0
90		168.7		82.2	73.1
	60		633.8	82.6	73.5
100		205.0		82.8	73.7

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