A METHODOLOGY TO CALCULATE SIGHT DISTANCE AT SKEWED INTERSECTIONS CONSIDERING DRIVER'S FIELD OF VIEW

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Abstract : This paper describes a methodology of calculating sight distance available to drivers at skewed non-signalized intersections of which minor roads are controlled by stop signs. The methodology considers the fact that the sight distance may be variable depending on driving positions of the drivers and different types of vehicles can give the drivers different lines of sight. Through field observations, the factors affecting the sight distance available to drivers are found. The factors include intersection geometry, vehicle's dimension and driver's field of view. With sight triangle properly drawn, equations for calculating sight distance available considering the factors were developed. Values of sight distance were compared with stopping sight distance of vehicles on the cross roads by varying design speeds and intersection angles. Nomographs were developed which can be used by road designers or operators to check if a skewed intersection satisfies sight distance requirement.

Key Words : Skewed Intersections, Available Sight Distance, Stopping Sight Distance, Visual Angle

1. INTRODUCTION

A skewed intersection is defined as an intersection where the angle of crossing streets is not close to 90 degrees. When roadways intersect at skewed angles vehicles passing through the intersection have a longer distance to traverse. The longer distance will result in an increased time of exposure to the cross-street traffic. This calls for an increased amount of intersection sight distance. Furthermore, the line of sight of drivers with an acute-angle approach to their right may be obstructed by the vehicle body parts such as door frame, panel aft of the door. That means sight distance may be different for different types of vehicles. Thus, in order to provide an adequate sight distance for a skewed intersection, appropriate methodology should be given to road designers. However, current design guidelines including Green book by AASHTO and other countries design manuals describes the methods of calculating sight distance for intersections where the angle of crossing roads is near 90 degrees.
The objective behind this research is to develop a methodology of calculating sight distance available to drivers at skewed intersections assuming that the intersection is stop-sign controlled intersections of which minor roads of the intersection are

controlled by stop signs. The methodology considers the fact that the sight distance may be variable depending on driving positions of the drivers and different types of vehicles can give the drivers different lines of sight. The research conducted field observations and factors affecting the sight distance available to drivers at skewed intersections are found. The factors include intersection geometry (intersection angle, lane width, shoulder width, position of stop line), vehicle's dimension and driver's field of view.

2. SIGHT DISTANCE EQUATION DEVELOPMENT

The amount of available sight distance varies depending on following factors.

1) geometric design factors such as
- lane width
- position of stop line
- lateral clearance including curb width, pedestrian walk width

2) dimension of design vehicle
3) field of a driver's view

Considering the above factors affecting the amount of sight distance at a skewed intersection, a diagram correctly showing sight line and available sight distance was drawn and shown in Figure 1.

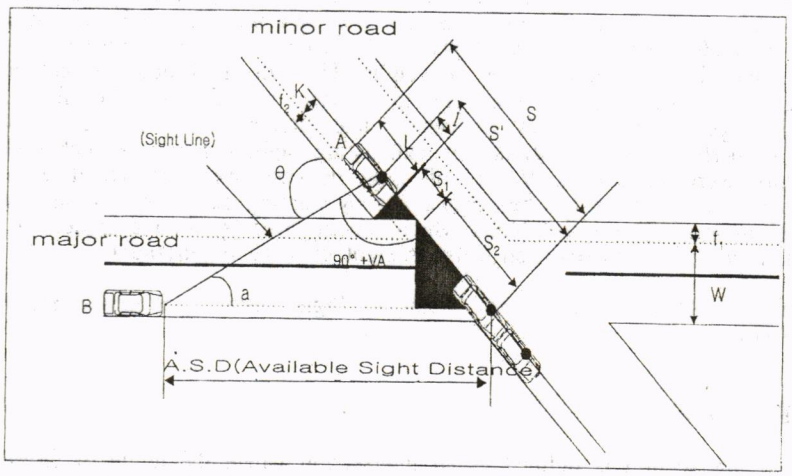


Figure 1. Diagram for Calculating Sight Distance of A Skewed Intersection

Notation for Figure 1. is as follows ;

VA : driver's field of view(degree)
θ : intersection angle
f1 : lateral clearance of major road
f2 : lateral clearance of minor road
L : length of vehicle A
l : distance between driver's eye and vehicle's front bumper (Vehicle A)
K : distance between driver's eye and end of right side of the minor road
W : road width major roadway including both direction
a : $180^\circ - (90^\circ + VA) - \theta$

Two shaded triangles in Figure 1. are used to calculate available sight distance for the skewed intersection. Two shaded triangles are magnified and shown in Figure 2.

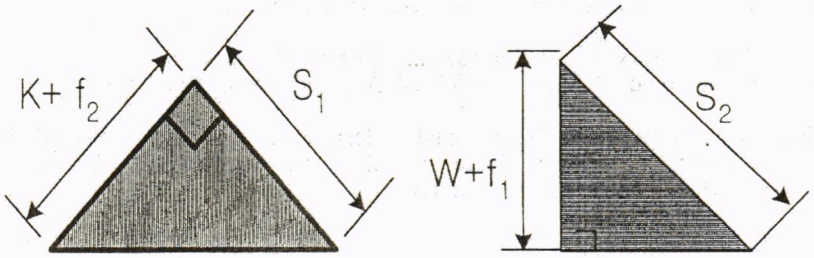


Figure 2. Triangles for Calclulating S_1 and S_2

Using simple trigonometrics, S_1 and S_2 are easily found as follows

$$S_1 = \frac{K + f_2}{\tan\theta} \tag{1}$$

$$S_2 = \frac{W + f_1}{\sin\theta} \tag{2}$$

Thus, available sight distance is calculated using equation (3)

$$A.S.D = \frac{S'}{\sin a} * \sin(90^\circ + VA) \tag{3}$$

3. DETERMINING FACTOR VALUES

3.1. Design Factor Values

In order to produce available sight distance values, several factors affecting sight distance are assumed or found. Table 1. shows factor values suggested by Korean road design guide(Korean Ministry of Construction and Transportation, 2000).

Table 1. Design Factor Values

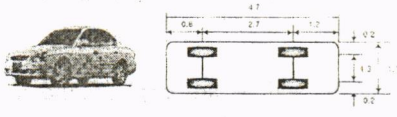
Design Vehicle	K(m)	L(m)	l(m)	f_2(m)
Passenger Car	1.3	4.7	2.35	1.5
Large Vehicle	1.85	13.0	1.20	1.5
Semi-Trailer	1.85	16.7	1.15	1.5

3.2 Visual Angle

The values of visual angle of a driver approaching on the minor road by vehicle types are also necessary for the calculation of sight distance. Finding the values were conducted by field study through steps describes as follows.

Step 1 : Selection of Vehicles Representing Design Vehicles
Step 2 : Finding Field of View and Visual Angle thorough Field Study

According to Korean road design guide, design vehicles are classified into three categories (passenger vehicle, large vehicle and semi-trailer). Figure 3 shows dimensions of the three design vehicle types.



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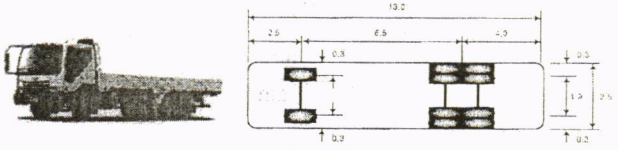

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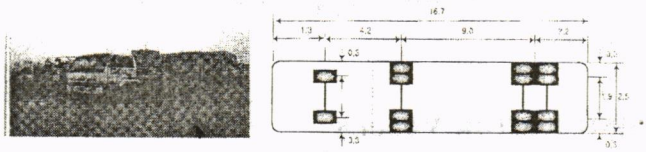

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Figure 3. Dimension of Design Vehicle
a. passenger car b. large vehicle c. semi-trailer

To select and conduct field study on driver's field of view and visual angle, vehicles representing design vehicles are selected through investigating vehicles dimensions based on Korean automobile association annual report(2000). The selected vehicles are also shown in Figure 3.
After selecting the vehicles representing design vehicles, visual angle of drivers are measured by varying driving posture of a driver. Different postures are defined as same as Gattis (1998) did, sit-back, comfort position and lean-forward.

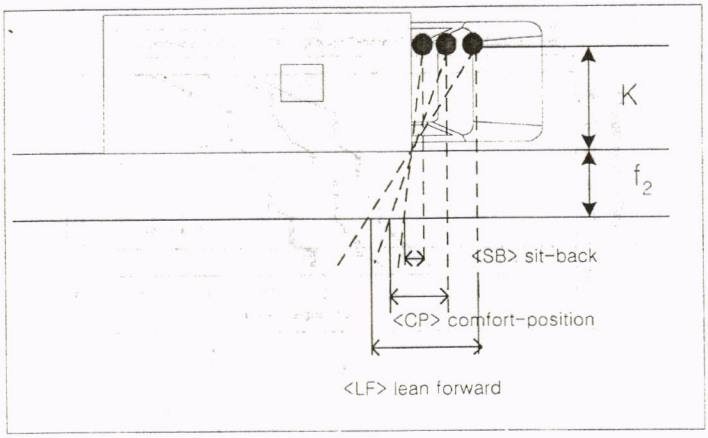


Figure 4. Vision Angle Geometry

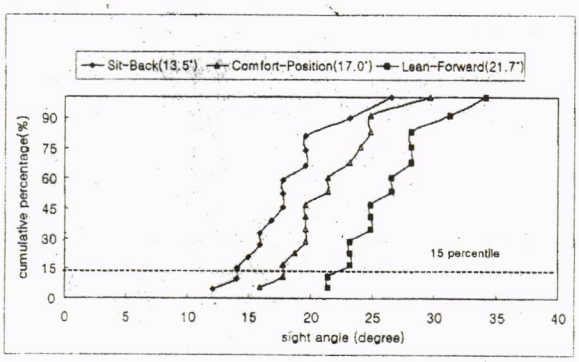
$$VA_{SB} = \arctan[SB/(K + f_2)]$$
$$VA_{CP} = \arctan[CP/(K + f_2)] \quad (4)$$
$$VA_{LF} = \arctan[LF/(K + f_2)]$$

where ;
VA_{SB} : visual angle with sit-back
VA_{CP} : visual angle with comfort position
VA_{LF} : visual angle with lean-forward

Figure 5. shows visual angles of 15 adult drivers for design vehicles. Representative visual angle values for different design vehicles are selected as 15 percentile values. Table 2. shows the selected visual angle values.

Table 2. Selected Visual Angle Values

Design Vehicle	Visual Angle (degree)		
	VA_{SB}	VA_{CP}	VA_{LF}
Passenger Car	13.5	17.0	21.7
Large Vehicle	1.3	5.4	13.1
Semi-Trailer	1.3	5.2	12.6



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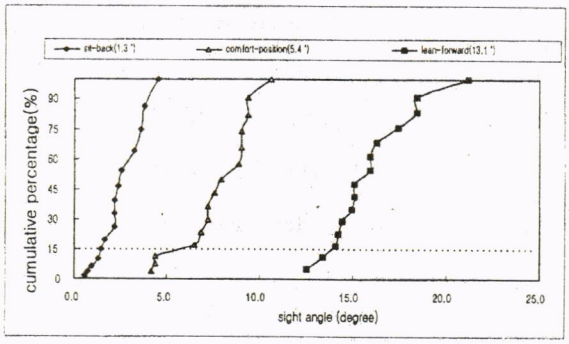

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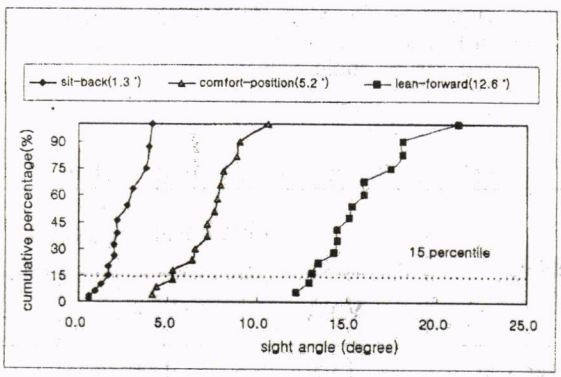

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Figure 5. Distributions of Visual Angles

a. passenger car b. large vehicle c. semi-trailer

4. AVAILABLE SIGHT DISTANCE AND STOPPING SIGHT DISTANCE

Available sight distance values are calculated by equations (1) to (3) using design factor values described in section 3. Table 3. through Table 5. are calculated available sight distance values for different types of design vehicles varying intersection angle from 55° to 75° by 5°

Table 3. Calculated Available Sight Distance Values - Passenger Car

Intersection angle (°)	A.S.D (m)		
	Sit-Back	Comfort Position	Lean-forward
55	34.12	39.80	51.94
60	41.22	51.18	77.49
65	55.50	78.20	183.68
70	92.94	197.71	N/A*
75	384.46	N/A*	N/A*

* N/A : Not Applicable

Table 4. Calculated Available Sight Distance Values - Large Vehicle

Intersection angle (°)	A.S.D (m)		
	Sit-Back	Comfort Position	Lean-forward
55	21.80	24.39	31.60
60	23.34	26.81	37.56
65	26.07	31.10	49.50
70	30.78	38.98	80.02
75	39.47	55.82	274.67

Table 5. Calculated Available Sight Distance Values - Semi-Trailer

Intersection angle (°)	A.S.D (m)		
	Sit-Back	Comfort Position	Lean-forward
55	21.71	24.15	30.86
60	23.23	26.50	36.42
65	25.94	30.66	47.40
70	30.62	38.28	74.41
75	39.26	54.41	216.74

Calculated available sight distance values can be used to see if a skewed intersection provides a sufficient sight distance. To do this, calculated available sight distance for an intersection should be compared with corresponding stopping sight distance. And the available sight distance must be greater than the stopping sight distance. Stopping sight distance can be described as the distance travelled by a vehicle on the major road at design speed during the time a vehicle on minor road traverses the distance

to clear the traffic in the lane approaching from the major road.

$$d = 0.28\ V(J + t_a) \tag{5}$$

where ;
d : stopping sight distance(m)
V : design speed of major road(km/h)
J : sum of perception and the time required to actuate the clutch or actuate an automatic shift (sec), generally 2 seconds
t_a : time to required to and traverse the distance S to clear the major roadway(sec)

Equation for t_a is

$$t_a = \sqrt{\frac{2*S}{a}} \tag{6}$$

where ;
a : accelerating rate(m/sec^2)

Table 6. to Table 8. shows calculated stopping sight distance values for different types of design vehicles varying intersection angle and design speed

Table 6. Stopping Sight Distance - Passenger Car

Design Speed(Km/h)	Stopping Sight Distance(m) intersection angle(degree)				
	55	60	65	70	75
20	35.47	34.64	34.64	33.80	33.80
30	53.21	51.96	51.96	50.71	50.71
40	70.95	69.28	69.28	67.61	67.61
50	88.68	86.60	86.60	84.51	84.51
60	106.42	103.92	103.92	101.41	101.41
70	124.15	121.24	121.24	118.32	118.32
80	141.89	138.56	138.56	135.22	135.22
90	159.63	155.87	155.87	152.12	152.12
100	177.36	173.19	173.19	169.02	169.02

accelerating rate = 1.25 m/sec^2

Table 7. Stopping Sight Distance - Large Vehicle

Design Speed(Km/h)	Stopping Sight Distance(m) intersection angle(degree)				
	55	60	65	70	75
20	56.43	55.43	54.49	54.49	53.49
30	84.65	83.19	81.73	81.73	80.23
40	112.87	110.87	108.98	108.98	106.97
50	141.09	138.58	136.22	136.22	133.72
60	169.30	166.30	163.46	163.46	160.46
70	197.52	194.02	190.71	190.71	187.21
80	225.74	221.73	217.95	217.95	213.95
90	253.95	249.45	245.20	245.20	240.69
100	282.17	277.17	272.44	272.44	267.44

accelerating rate = 0.85 m/sec^2

Table 8. Stopping Sight Distance - Semi-Trailer

Design Speed(Km/h)	Stopping Sight Distance(m) intersection angle(degree)				
	55	60	65	70	75
20	70.56	69.44	68.39	67.28	67.28
30	105.83	104.17	102.58	100.91	100.91
40	141.11	138.89	136.78	134.55	134.55
50	176.39	173.61	170.97	168.19	168.19
60	211.67	208.33	205.16	201.83	201.83
70	246.95	243.06	239.36	235.47	235.47
80	282.23	277.78	273.55	269.10	269.10
90	317.50	312.50	307.75	302.74	302.74
100	352.78	347.22	341.94	336.38	336.38

accelerating rate = 0.70 m/sec^2

In order to make easier comparisions between available sight distance and stopping sight distance, three nomographs are developed and shown in Figure 6 to Figure 8.

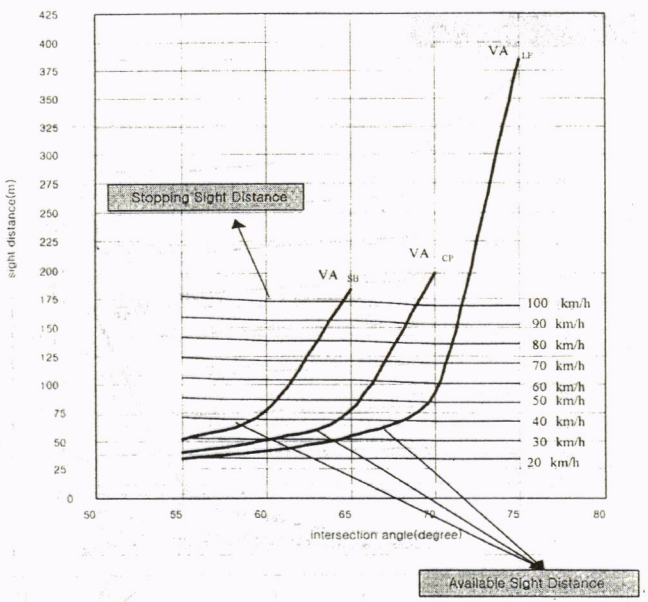

Figure 6. Available Sight Distance vs. Stopping Sight Distance - Passenger Car

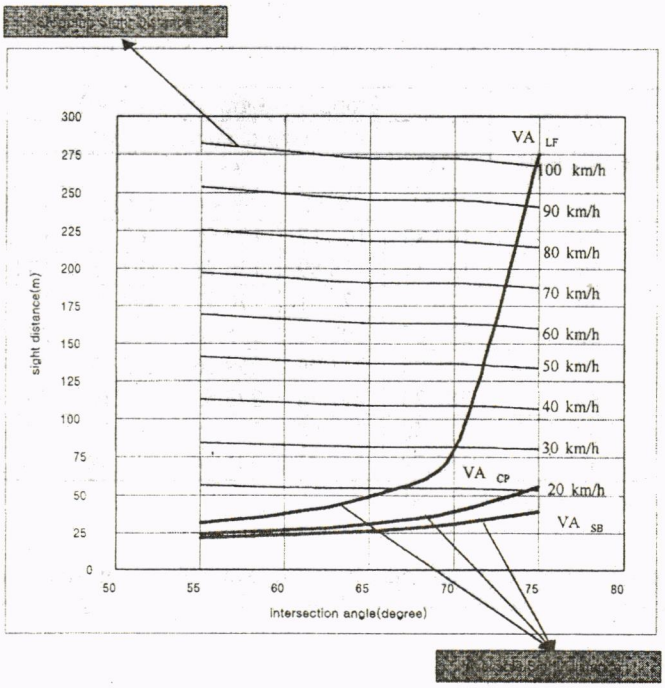

Figure 7. Available Sight Distance vs. Stopping Sight Distance - Large Vehicle

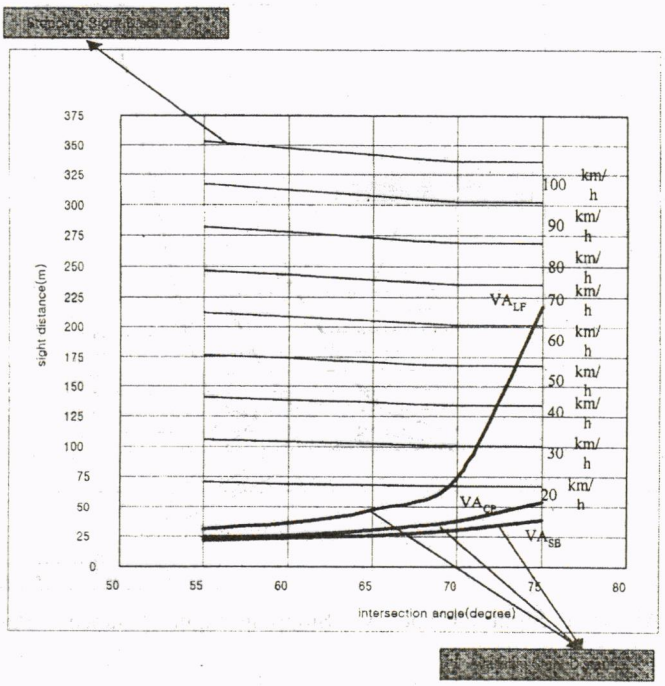

Figure 8. Available Sight Distance vs. Stopping Sight Distance - Semi-Trailer

Findings drawn from Figure 6. to Figure 8., are
1) among vehicle types passenger cars have longest available sight distance because larger vehicle types have more obstruction from their vehicle bodies
2) Lean-Forward Position provides much longer available sight distance than other drving positions
3) except for passenger car types, for intersection angles less than 70 degree, available sight distances are less than stopping sight distance even with design speed of 20 km/h
4) at intersection angle 70 degree, available sight distances are increaing rapidly as intersection angle increases

Using those figures shown in Figure 6. to Figure 8., road designers can judge if the current geometric design of an skewed intersection provide sufficient available sight distance based on design speed, geometric design and design vehicle types. Also designers can check if design for a new intersection will satisfy a certain level of safety in terms of sight distance.

5. CONCLUSIONS

This paper has described a methodology for calculating sight distance available to drivers at skewed intersections non-signalized intersections of which minor roads are controlled by stop signs. The methodology considers the fact that the sight distance may be variable depending on driving positions of the drivers and different types of vehicles can give the drivers different lines of sight due to sight line obstruction by the vehicle bodies which are unique for vehicle types. Equations for calcluating available sight distance were derived which reflects factors affecting the sight distance available to drivers at skewed intersections such as geometry (intersection angle, lane width, shoulder width, position of stop line), vehicle's dimension and driver's field of view. Values of calculated available sight distance were compared with stopping sight distance and three nomographs are developed and shown in Figure 6 to Figure 8. for designers to make the comparison easy.
The methodology described in this paper considers only horizontal design factors. Further research is suggested on calculating sight distance incorporating vertical desi-ᄒ factors.

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