PROPOSED GUIDELINES FOR TRAFFIC ACTUATED WARNING SIGNS AT INTERSECTIONS WITH LIMITED SIGHT DISTANCE

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ABSTRACT

There are currently no formal guidelines for installing warning signs at existing intersections with limited sight distance. A speed differentials model was established to determine the minimum sight distance required for a vehicle to safely enter an intersection and complete a turning maneuver without being hit by an approaching vehicle. The minimum sight distance values resulting from the model were used to develop guidelines for installing traffic actuated warning signs at intersections with limited sight distance. Based on the guidelines being developed, traffic actuated warning signs were placed at eighteen intersections in Gwinnett County. Two types of traffic actuated warning signs are presented in this paper. The "Vehicle Entering Highway" warning sign is used to warn the approaching driver on the major road. The "Vehicle Approaching" warning sign is used to warn the entering driver on the minor road.

INTRODUCTION

Until the early 1980's, Gwinnett County was a predominately rural county northeast of metropolitan Atlanta. Many of its highways originated as farm-to-market roads which were eventually paved and further improved. From 1980 to 1997, the number of registered vehicles in Gwinnett County grew from 150,000 to 499,000, an increase of 330%. Consequently, many formerly low volume roads have become major arterials. The increase in traffic volume has accentuated the sight distance problems which exist at intersections on many of the County's winding, rolling roads.

As the volume of traffic on the County's roads increased, the number of potential intersection conflict situations also increased. This development was reflected by an increase in the number of complaints received by the Traffic and Transportation Planning Division within the Gwinnett County Department of Transportation (GCDOT). The GCDOT was faced with the task of developing a consistent method of evaluating those sight distance problems and responding to them in a responsible and cost effective manner. Guidelines were developed by the GCDOT staff to specifically address sight distance problems at existing intersections. This paper presents the guidelines which were designed for the placement of traffic actuated warning devices at intersections with limited sight distances.

LITERATURE REVIEW

There have been a considerable amount of disagreement among traffic engineers regarding intersection sight distance (ISD) criteria. State and local agencies are currently addressing existing sight distance problems with a variety of practices, including use of the American Association of State Highway and Transportation Officials (AASHTO) criteria, use of other guidelines such as their state manual, ITE Guidelines for Driveway Location and Design (ITE, 1987) and the Traffic and Transportation Engineering Handbook (Homburger, 1982), or reliance on local ordinance (Burke, 1990) and engineering judgement (Parsonson, 1992). Many of these procedures do not distinguish between new and existing intersections.

The body of available literature on the topic of remedying sight distance problems at existing intersections is very sparse. Research that studied intersection sight distance mostly focused on design for adequate sight distance at new intersections. There are few guidelines or standards that address the sight distance problems at existing intersections.

AASHTO published a definitive design standard in A Policy on Geometric Design of Highways and Streets (AASHTO, 1990 and 1994), i.e., the Green book. Its geometric design policy for sight distance at intersections with Stop control on the minor road considers three types of basic maneuvers that occur at the average intersection:

- Case IIIA - Crossing maneuver;
- Case IIIB - Left-turn maneuver;
- Case IIIC - Right-turn maneuver.

Among the three cases, Case IIIA (the crossing maneuver) always requires the least amount of clearance time. Case IIIB (the left-turn maneuver) and Case IIIC (the right-turn maneuver) control the minimum sight distance required to the right side and the left sides of the minor-road vehicle, respectively.

The current AASHTO policy states that the minor-road turning vehicle should be able to accelerate to a safe running speed by the time the major-road approaching vehicle closes to within a specified tailgate distance. The intersection sight distance criteria are based on the scenario that the major-road vehicle reduces speed from the design speed of the major road to 85% of the design speed and the minor-road vehicle, therefore, has to accelerate to the 85% of the design speed.

According to the AASHTO model, the required sight distance for right turns (Case IIIC) are 11 feet less that for left turns (Cases IIIB). Because this difference is so small, AASHTO policy chooses to ignore it and applies the Case IIIB criteria to Case IIIC as well. The ISD criteria are shown in Table 1. These values are based on passenger cars. Large trucks on either road require longer sight distances.

Since the AASHTO's ISD criteria are intended more to ensure desirable operations (a 15% speed reduction for the major-road vehicle) than to provide minimum values that are absolutely necessary to avoid crash, many feel that its sight distance criteria are overly conservative and require excessive sight distance values in practice. Even casual observation of intersections suggests that major-road vehicles often slow by more than 15% when a minor-road vehicle enters the roadway in front of them.

An alternative ISD model was proposed by Harwood in a 1996 study (Harwood, 1996). The current AASHTO model was modified using variable speed reduction. The results are shown in Table 2.

As shown in Table 2, the alternative model requires less sight distance than the current AASHTO model. The reductions in ISD are significant particularly for major-roads with high design speeds. The percentage of speed reduction for the major-road is based on the design engineer's judgement. However, no mention is made of how to apply the sight distance criteria to existing highways with limited sight distance at intersections. Consequently, no solutions are presented for those problems.

SCOPE OF THE STUDY

This study was conducted to:

1. determine the minimum sight distances required to allow a minor-road vehicle to safely enter or cross a two-lane major road;
2. to develop guidelines for installing traffic actuated warning signs when the sight distance is not adequate at an existing intersection of two two-lane roads;
3. to adjust the AASHTO's sight distance design values to practical operational values which the GCDOT staff would use in their sight distance studies for existing intersections.

There is a need in the traffic engineering field to establish uniform guidelines for remedy of sight distance problems at existing intersections. This study is an attempt to at least provide a foundation for the development of those guidelines. The guidelines presented in this paper are primarily based on the results of a speed differentials model which compared the distances traveled by both the entering and approaching vehicles in a given period of time. Other factors, such as the number of preventable accidents, were also considered.

Two types of traffic actuated warning signs are discussed in this paper. The "Vehicle Entering Highway" sign is used to warn traffic on the major road of an entering vehicle and the "Vehicle Approaching" sign is used to alert the entering vehicle on the minor road of approaching traffic.

The guidelines have been used to determine the placement of traffic actuated warning signs at 18 intersections in Gwinnett County. The 85th percentile speed, the existing sight distance, the required minimum sight distance, the accident history, and the type(s) of signs being placed at each location are presented in this paper.

SPEED DIFFERENTIALS STUDY

A speed differentials model was developed to study the dynamics between the approaching vehicle on the major road and the entering vehicle on the minor road. The model takes the form of:

$$S_A(t) - [\, V_B(0)\, J_A + S_B(t) - (ISD \pm \tfrac{1}{2}W_l)\,] = (V_B(t)\, t_g + L_v) \quad \text{when } t = t_e \text{ or } V_A(t) = V_B(t)$$

Where: t is the time from when the minor road vehicle begins to enter the major road;

$S_A(t)$ is the distance that the entering vehicle travels along the major road from time 0 to time t;

$V_B(0)$ is the initial speed of the approaching vehicle;

J_A is sum of the perception-reaction time and time to actuate the clutch or an automatic shift for the minor road driver, assumed to be 2 seconds;

$S_B(t)$ is the distance that the approaching vehicle travels along the major road from time 0 to time t;

ISD is the minimum sight distance required along the major road, measured from the centerline of the minor road;

W_l is the lane width of the minor road, assumed to be 12 ft. The term $\frac{1}{2}W_l$ represents the distance between the centerline of road and the center of the vehicle, plus for Case IIIC (right turn) and minus for Case IIIB (left turn);

$V_B(t)$ is the speed of the approaching vehicle at time t,

t_g is the minimum gap required, assumed to be 1.4 seconds, this is the 15th percentile value observated by a 1996 study (Harwood, 1996);

L_v is the length of the minor road vehicle, assumed to be 19 ft;

t_e is the time when both vehicles have the same speed, given that the entering vehicle continues to accelerate and the approaching vehicle continues to decelerate;

$V_A(t)$ is the speed of the entering vehicle at time t.

The above model is also graphically illustrated by Figure 1.

Acceleration and deceleration data from the Green Book was used to establish the speed profiles and the distance profiles for both the approaching and the entering vehicles.

Table IX-7 of the Green Book shows the speed, time, and distance relationships for normal acceleration from a stop by passenger cars. The data in the table was translated into the speed and distance profiles ($S_A(t)$ and $V_A(t)$) that are shown in Figures 2 through 4. A right angle intersection, a level two-lane major road, and 12 ft lanes were assumed. A 28-ft left-turning radius a 16-ft right-turning radius were used.

The speed and distance profiles of the approaching vehicle ($S_B(t)$ and $V_B(t)$) were derived from the deceleration distance and speed values in Figure II-17 of the Green Book. The results are shown in Figures 5 and 6. The perception-reaction time required by the major road driver, which is not explicit in the model, was assumed to be one second, that is, it took the driver one second to perceive the entering vehicle before beginning to brake.

In order to solve the speed differentials model for the minimum required sight distance, t_e and $V_A(t_e)$ were first determined by identifying the intersection of two speed profiles $V_A(t)$ and $V_B(t)$ (Figures 2 and 5). Then, $S_A(t_e)$ and $S_B(t_e)$ were determined using the known t_e and the distance profiles $S_A(t)$ and $S_B(t)$ (Figures 3, 4 and 6) as shown in Figure 7. Finally, the minimum required sight distance ISD was calculated as the following:

$$ISD = (V_A(0)J_A + S_B(t_e)) - S_A(t_e) + (V_A(t_e)\, t_g + L_v) - (\pm \tfrac{1}{2}W_l)$$

The results are shown in Table 3.

GUIDELINES FOR INSTALLING TRAFFIC ACTUATED WARNING SIGNS

The essential criterion for placement of a traffic actuated warning sign is that the sight distance at an intersection is less than the value given in Table 3. Both the existing sight distance and the 85th percentile speed are measured to determine if an intersection has adequate sight distance.

The existing sight distances can be measured using a rather simple method, which requires only one person and some inexpensive equipments. First, the person who is taking the measurement sets a 3.5 feet high pole in a traffic cone which is placed in the center of the minor road, 10 feet behind the edge-of-pavement line of the major road. The top of the pole is used to represent the height of the entering driver's eye at a reasonable location. The person then walks along the edge of the major road in the direction of the sight distance obstruction, sighting the pole at the intersection over the top of a 4.25 feet pole. The top of the longer pole represents the top of the approaching vehicle. Sighting from the edge of the major road conservatively represent the location of the approaching vehicle as well as ensure safety for the personnel. The existing sight distance is measured using a measuring wheel device from the point where the shorter pole is no longer visible back to the centerline of the minor road.

Speed data is collected for the vehicles traveling on the major road, approaching the intersection from the direction of the sight distance obstruction. The 85th percentile speed is used to determine the required sight distance value. If the sight distance measured is shorter than that required for the 85th percentile speed of traffic on the major road, the guidelines call for the installation of a traffic actuated warning sign.

An accident guideline was also established for placement of traffic actuated warning sign at intersections with somewhat limited sight distance and a significant number of accidents. The GCDOT staff studied each of the intersections which they received many complains about and found that three or more potentially preventable accidents in one year or one or more such accident a year for three consecutive years appeared to be the threshold that was rarely crossed. In other words, an intersection would be definitely considered to have a significant accident problem if it does cross that threshold. It was therefore decided that three or more potentially preventable accidents within a one year period or one or more such accident a year for three consecutive years would justify the installation of traffic actuated warning signs. Note that this criterion was not based on any statistical analysis because there is no sample large enough to validate such an analysis. The GCDOT uses this accident criterion to at least give its staff an opportunity to utilize traffic actuated warning signs at intersections with limited sight distance to reduce the number of accidents when it is necessary.

The proposed guidelines for traffic actuated warning signs are appropriate only for use at one- or two-way stop-controlled intersections of two two-lane roads. These guidelines are also applicable only to the intersections on arterials or collectors. Sight distance problems which exist on local, neighborhood streets should be addressed in another manner. For example, although the intersection may not be warranted for a four-way stop, installing the four-way stop may be a better solution to the problem than installing the traffic actuated warning sign.

Occasionally an intersection may meet the speed guidelines for a traffic actuated warning sign, and there may be no other solution to the problem, yet there have been no accidents at that location, and the volume on the side street is very low. In these instances the GCDOT will decide whether the cost of installing the sign (a measurable figure) is justified by the benefits (in this case, something hard to measure). The rule-of-thumb used by the GCDOT is that the average daily traffic on the minor road needs to be at least 75 vehicles per day for a traffic actuated warning sign to be considered.

VEHICLE ACTUATED WARNING SIGN INSTALLED AT INTERSECTIONS

Two types of traffic actuated warning signs are currently used by the GCDOT: the "Vehicle Entering Highway" and the "Vehicle Approaching" warning signs.

The "Vehicle Approaching" (VA) warning sign is actuated by the major road vehicle approaching the intersection. It is placed directly in front of the approach of the minor road to the intersection. Typically, it has two red beacons (See Figure 8). The upper beacon is on steady red at all times to let the minor road driver know the sign is operational. The lower beacon is on flash red when the sign is in the "resting" state and comes on steady red when the sign is actuated by an approaching vehicle on the major road. A warning sign is placed between the beacons indicating the direction from which the major road vehicle comes. An additional sign is placed below the lower beacon to alert the minor road driver that the sign is not operational if the upper beacon is not on. This sign is used to protect the liability interests of the County.

The "Vehicle Entering Highway" warning sign is actuated by the minor road vehicle about to enter the intersection. It is placed on the major road in the approach direction from the sight distance obstruction at a distance at least equal to the minimum required sight distance from the intersection. It consists of a warning sign and two yellow beacons (see Figure 9). When the sign is actuated by the vehicle stopped on the minor road, both yellow beacons flash to give the approaching driver notice that a vehicle may enter the highway from a "blind" side street. Both beacons go off once the minor road vehicle leaves the intersection. A speed limit sign is often posted with or near the "Vehicle Entering Highway" warning sign.

The "Vehicle Entering Highway" sign warns the approaching driver on the major road. The "Vehicle Approaching" sign warns the entering driver on the minor road. Warning either motorist will, in theory, prevent a collision. However, the "Vehicle

Approaching" sign may be more effective in preventing potential intersection conflict situations because:

(1) At a Stop Sign controlled intersection, only one of the major road and the minor road drivers needs to be made aware of a potential crash situation to take evasive action. Of the two, the entering driver is in more of a position to pay attention to a warning sign because of the Stop sign. With the "Vehicle Approaching" warning sign, the minor road driver knows when it is safe to enter the major road and when it is unsafe to do so. There will not be conflict situation if the minor road driver does not enter the intersection.

(2) Too often, the approaching driver on the major road is presented with numerous signs, and the signs begin to lose their effectiveness. The "Vehicle Entering Highway" warning sign will not eliminate the hazard situation if it is ignored by the approaching driver.

Because of the above reasons, the "Vehicle Approaching" sign is usually installed at the intersections where the available sight distance is significantly less than what is required or where there is a significantly number of accidents.

APPLICATION OF GUIDELINES TO INTERSECTIONS WITH

Over the years, the GCDOT used the established guidelines to justify the installation of the traffic actuated warning signs at eighteen intersections in Gwinnett County. Table 4 summarizes detailed intersection information including speed, sight distance, direction of sight obstruction, accident history, and type of warning signs being installed.

As shown in Table 4, two intersections, Lester Road at Cutler Drive and West Peachtree Street at Rock Tenn Company, had a sight distance significantly less than the required sight distance. In addition, the intersection of Lester Road and Cutler Drive had a significant number of preventable accidents. The "Vehicle Approaching" warning sign was installed at both intersections. The results show that the signs did effectively reduce the number of such accidents. The "Vehicle Entering Highway" warning sign was installed at all other sixteen intersections. There intersections did not have many accidents caused by inadequate sight distance although there were many complains about the sight distance problem. The effectiveness of the "Vehicle Entering Highway" warning sign on reducing accidents can not be decided.

OTHER POSSIBLE COUNTERMEASURES

The installation and maintenance of traffic actuated warning signs can be costly. It is therefore important to consider other less expensive countermeasures to sight distance problems before installing these warning signs. Sometimes it is possible to remove the sight distance obstruction by cutting down banks or removing trees, brush, or other types of vegetation. In some other situations, however, the installation of a traffic actuated warning sign may be the most cost effective solution to a sight distance problem, particularly when it is caused by vertical curves.

The traffic actuated warning signs at intersections may be removed once the intersections are re-configured/re-constructed up to the AASHTO design standard. As shown in Table 4, five warning signs were removed after the intersections were re-constructed as a part of new roadway or roadway improvement projects.

FUTURE STUDIES

The required sight distance values shown in Table 3 only apply to passenger vehicles on level roads. The proposed guidelines can be expanded to roads with different grades or trucks by applying appropriate vehicle performance data, i.e., vehicle acceleration and deceleration data.

The proposed guidelines for traffic actuated warning signs are appropriate only for intersections of two two-lane roads. If the guidelines would be used at intersections of a multi-lane major road and a two-lane minor road, the speed differentials model needs to be modified. In the case of a multi-lane major road, the approaching driver may be able to avoid overtaking the entering vehicle by weaving to another lane if the major road has a low traffic volume. The crossing maneuver (Case IIIA) will then become the most critical movement and control the minimum sight distance required. Future studies can be done to explore all these possible scenarios.

The GCDOT did not try to obtain the approval for experimentation from the Federal Highway Administration for the traffic actuated warning signs being used at intersections with limited sight distance because the County does not have a valid sample size to test and show the effectiveness of such signs. One purpose for publishing the results of this study is to promote presentation by other agencies who have these signs or the similar devices. Hopefully, studies on a large scale, maybe at national level, would be conducted on such devices in the future.

CONCLUSION

Traffic engineers have a responsibility to make intersections as safe as possible for motorists, and part of that responsibility involves consistent signing to meet driver expectation. Currently, traffic engineers have no uniform guidelines to address sight distance problems at existing intersections. This paper has attempted to provide some Guidelines for the placement of traffic actuated warning signs at such intersections.

The practice of using two types of traffic actuated warning signs may be most interested by the agencies whose jurisdictions have simillar characteristics to Gwinnet County, which has a rolling terrain with many roads that are not up to the ASSHTO design stardards.

Although the required minimum sight distances called for by the speed differentials model are as little as half of the sight distances called for by the current AASHTO policy, they are based on rather conservative vehicle performance data. For instance, using the acceleration data in Table 2, it takes the minor road vehicle over 25.4 seconds to accelerate from 0 to 60 mph. That is definitely not the maximum acceleration that today's vehicles are capable of achieving. (In a road test summary published by Road & Track magazine [July, 1991], the longest 0 to 60 mph time was given as 12.8 seconds for a Yugo.)

While these proposed guidelines will most likely be subject to revision based on more extensive traffic studies, they represent the beginning of a solution to the problem which is not based solely on the design-oriented AASHTO policy.

ACKNOWLEDGMENT

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Table 1. AASHTO Intersection Sight Distances

Major Road Design Speed (mph)	Sight Distance (ft)
25	290
30	380
35	470
40	580
45	700
50	840
55	990
60	1,160
65	1,360

Source: A Policy on Geometric Design of Highways and Streets, American Association of State Highway and Transportation Officials, Washington, D.C., 1990.

Table 2. Intersection Sight Distances (ft)

Major Road Design Speed (mph)	Speed Reduction for the Major-Road Vehicle					
	70%	60%	50%	40%	30%	15%
25	280	280	280	285	285	300
30	355	355	355	360	365	380
35	440	440	440	440	450	475
40	530	530	530	535	545	580
45	630	630	630	635	655	700
50	740	740	740	745	770	830
55	860	860	860	865	895	975
60	985	985	985	995	1,035	1,135
65	1,120	1,120	1,120	1,135	1,185	1,315

Source: Harwood, D.W., et al., "Intersection Sight Distance", National Cooperative Highway Research Program Report 383, Transportation Research Board, Washington, D.C., 1996.

Table 3. Minimum Required Sight Distance (ft)

85th Percentile Speed (mph)	Case IIIB (Left Turn) ISD to the Right (ft)	Case IIIC (Right Turn) ISD to the Left (ft)	Acceleration Time t_e (sec)	Final Speed $V_A(t_e)$ (mph)
25	231	213	3.9	13.1
30	280	261	4.5	15.0
35	334	315	5.1	16.8
40	388	369	5.6	18.4
45	446	427	6.1	19.9
50	505	486	6.5	21.4
55	565	546	6.9	23.0
60	626	607	7.3	23.2
65	689	670	7.6	25.2

Table 4. Intersections with Traffic Actuated Warning Signs

Intersection [1]	Posted Speed Limit (mph)	Available S. D. (ft)	85th Percentile Speed (mph)	ISD Case	Required Minimum S. D. (ft)	Preventable Accident [5] (Before/After)
Annistown Rd. / Bicentennial Dr.	45	375	60	IIIC (RT)	607	0 / 1
Arcado Rd. / Emily Dr. - North [4]	35	339	49	IIIB (LT)	493	0 / 0
Arcado Rd. / Emily Dr. - South [4]	35	376	49	IIIB (LT)	493	0 / 1
Bush Rd / Foxwood Rd.	35	274	44	IIIC (RT)	415	Unknown / 0 [6]
Camp Creek / Joy Ln.	35	312	46	IIIB (LT)	458	Unknown / 2
Davis Mill Rd. / La Mancha Dr. [4]	40	314	52	IIIC (RT)	510	1 / 0
Indian Trail Rd. / Tree Trail Pkwy.	45	411	54	IIIC (RT)	534	Unknown / 0
Killian Hill Rd. / Sarann Dr.	35	340	52	IIIB (LT)	529	0 / 0
Lester Rd. / Cutler Dr. [2]	35	255	43	IIIC (RT)	404	7 / 1
Lilburn Ind Way / Business Dr.	35	260	37	IIIC (RT)	337	0 / 0
Lilburn-Stone Mtn Rd. / Loma Ct.	40	302	53	IIIC (RT)	522	0 / 0
Old Norcross Rd. / Brass Key Ct. [4]	45	410	57	IIIC (RT)	570	0 / 0 [6]
Old Norcross Rd. / Wagon Trace	40	273	52	IIIC (RT)	510	0 / 0
Springdale Rd. / Greenvalley Rd.	35	221	50	IIIB (LT)	505	0 / 1
Stone Dr. / Stone Crossing Dr.	35	248	54	IIIC (RT)	534	0 / 0
Sycamore Rd. / Jimmy Dodd Rd.	40	340	51	IIIB (LT)	517	0 / 0
Sycamore Rd. / Old Sycamore Rd.	40	280	51	IIIB (RT)	498	0 / 0
W. P'tree St. / Rock Tenn Co. [3,4]	25	182	43	IIIC (RT)	404	Unknown / 0

1. "Vehicle Entering Highway" sign only unless stated otherwise.
2. "Vehicle Approaching" sign only.
3. Both "Vehicle Entering Highway" and "Vehicle Approaching" signs.
4. Traffic actuated warning signs were removed from these intersections after the intersections were reconstructed.
5. Three-year study periods were used in the before-after studies.
6. The number of accidents from 1992 to 1998 was used because no data was available for the three-year period immediately after the installation of the signs.

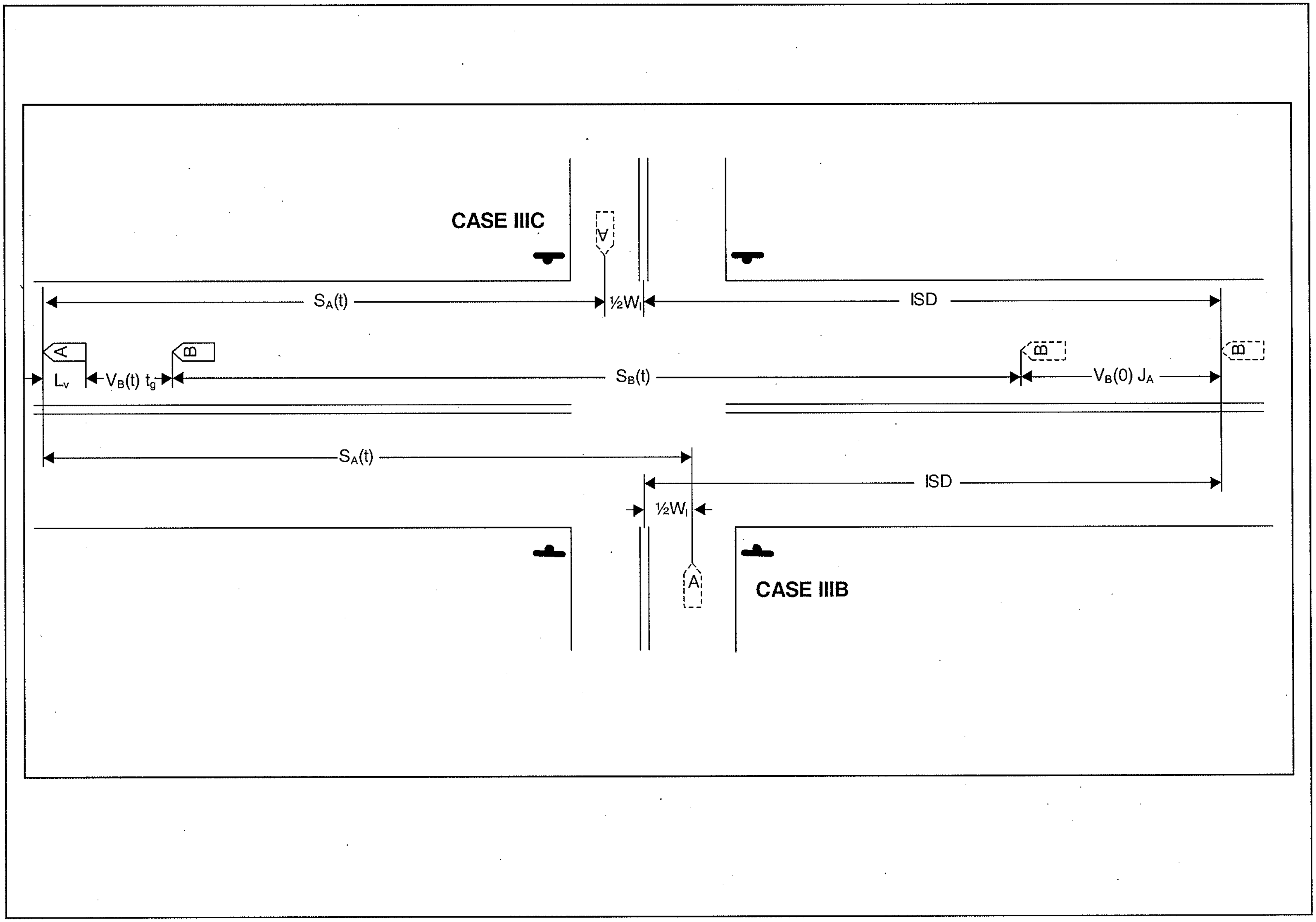

Figure 1. The Speed Differentials Model

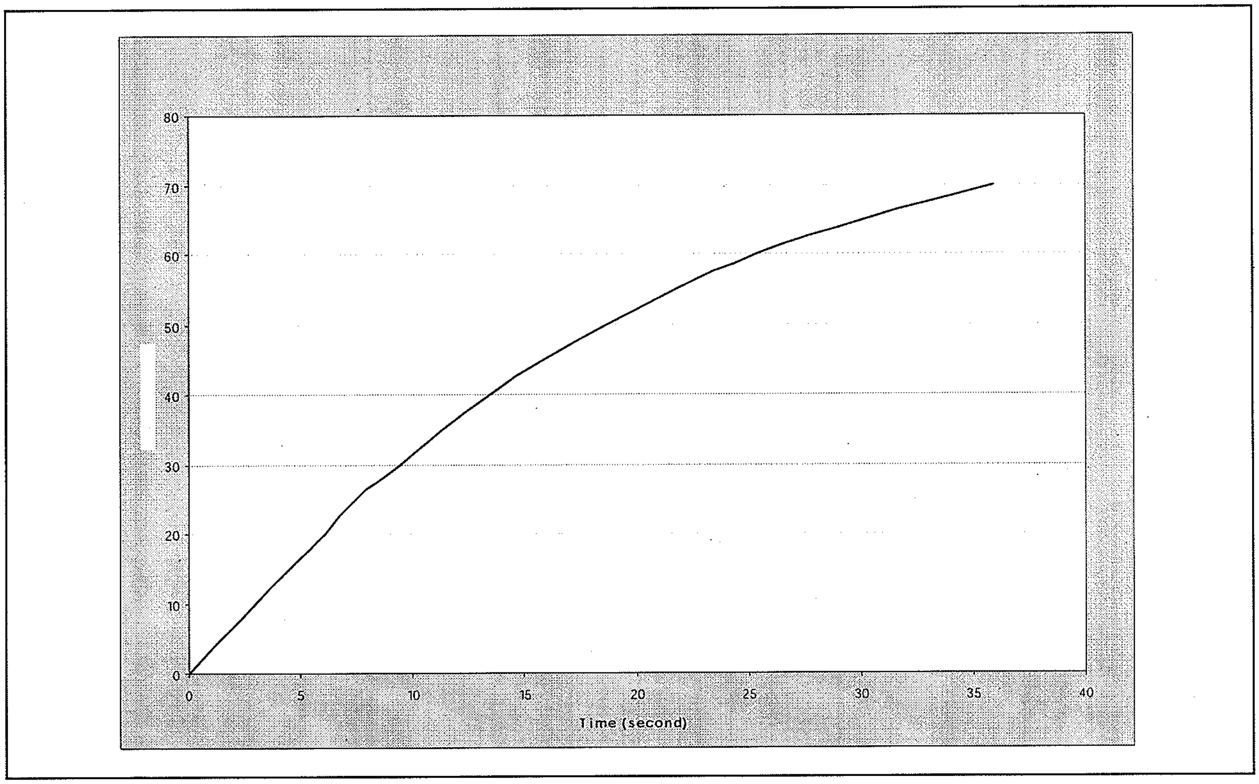

Figure 2. $V_A(t)$, **Speed Profile of the Entering Vehicle**

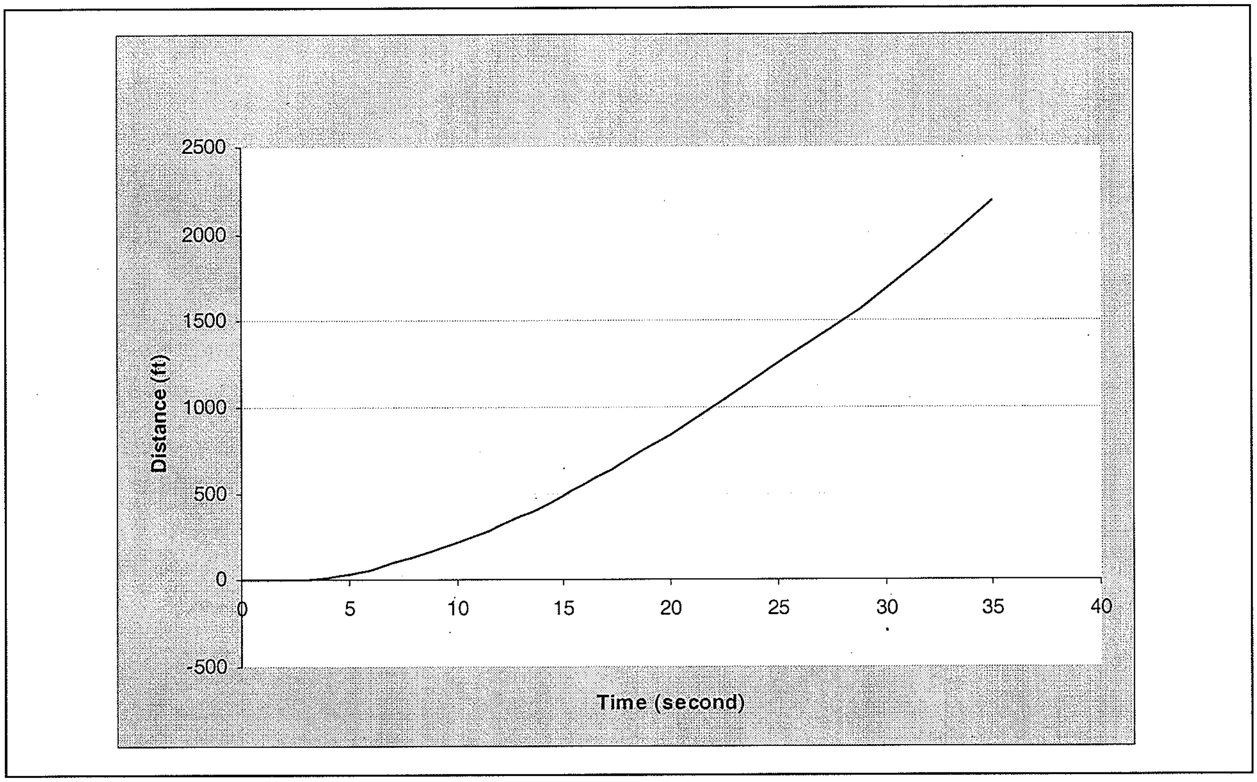

Figure 3. $S_A(t)$, Distance Profile of the Left Turning Vehicle (Case IIIB)

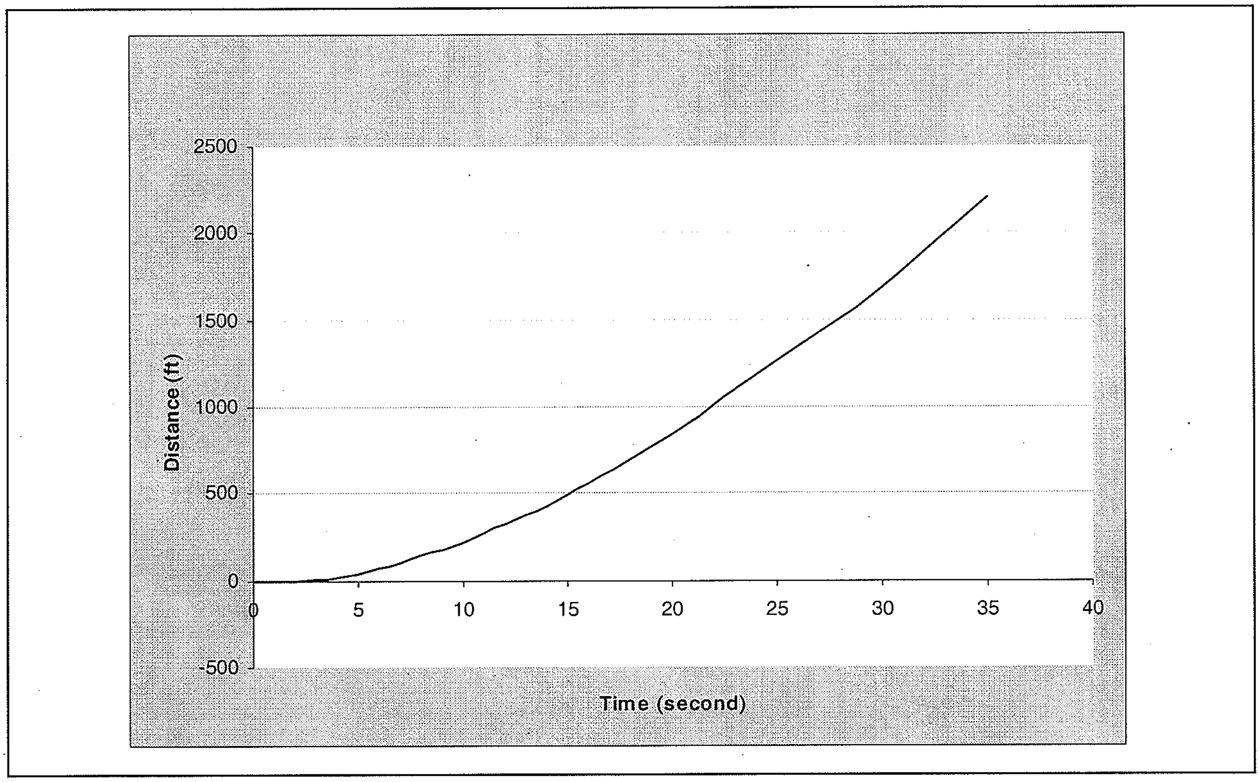

Figure 4. $S_A(t)$, Distance Profile for the Right Turning Vehicle (Case IIIC)

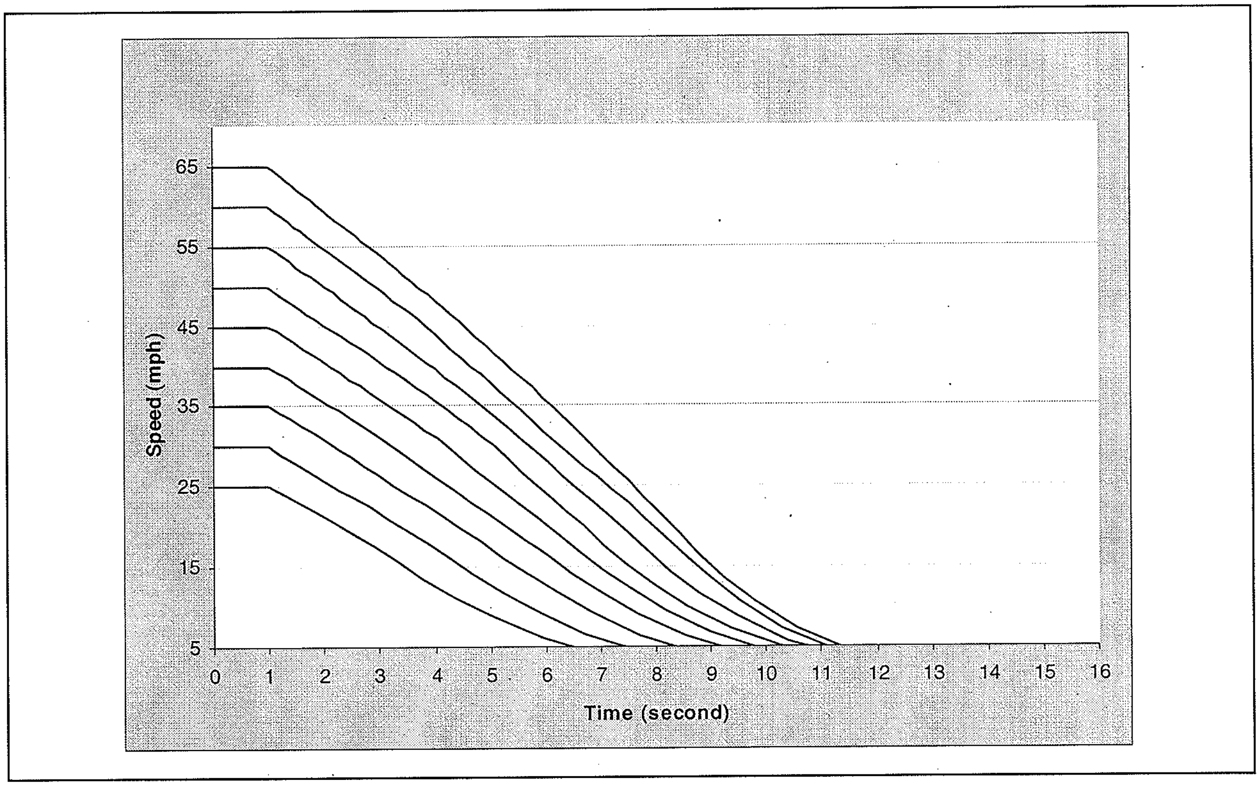

Figure 5. $V_B(t)$, **Speed Profile of the Approaching Vehicle**

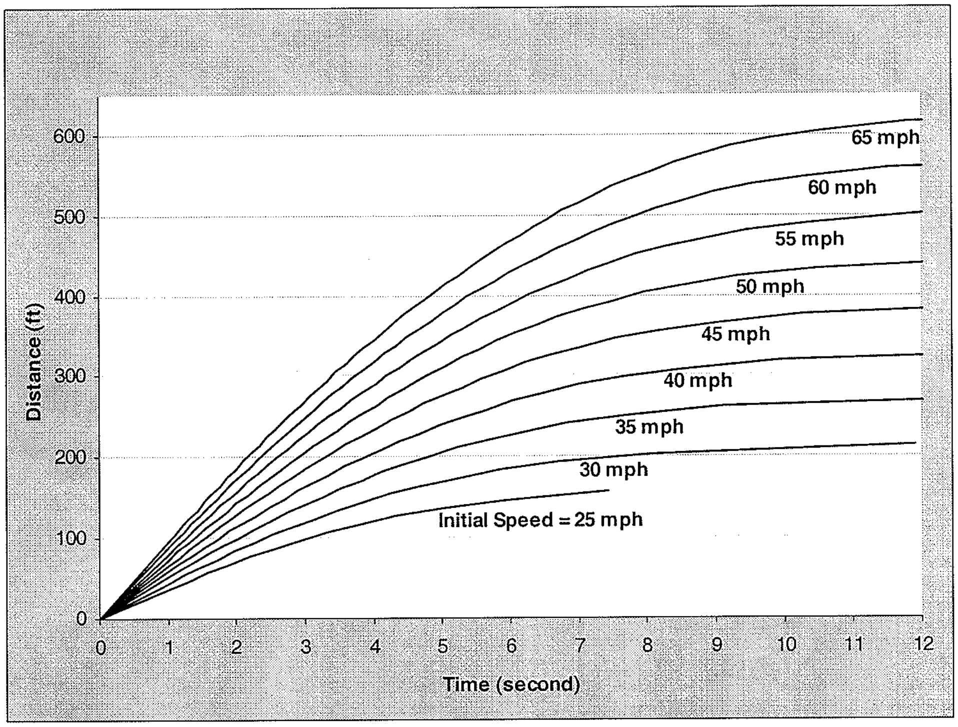

Figure 6. $S_B(t)$, **Distance Profile of the Approaching Vehicle**

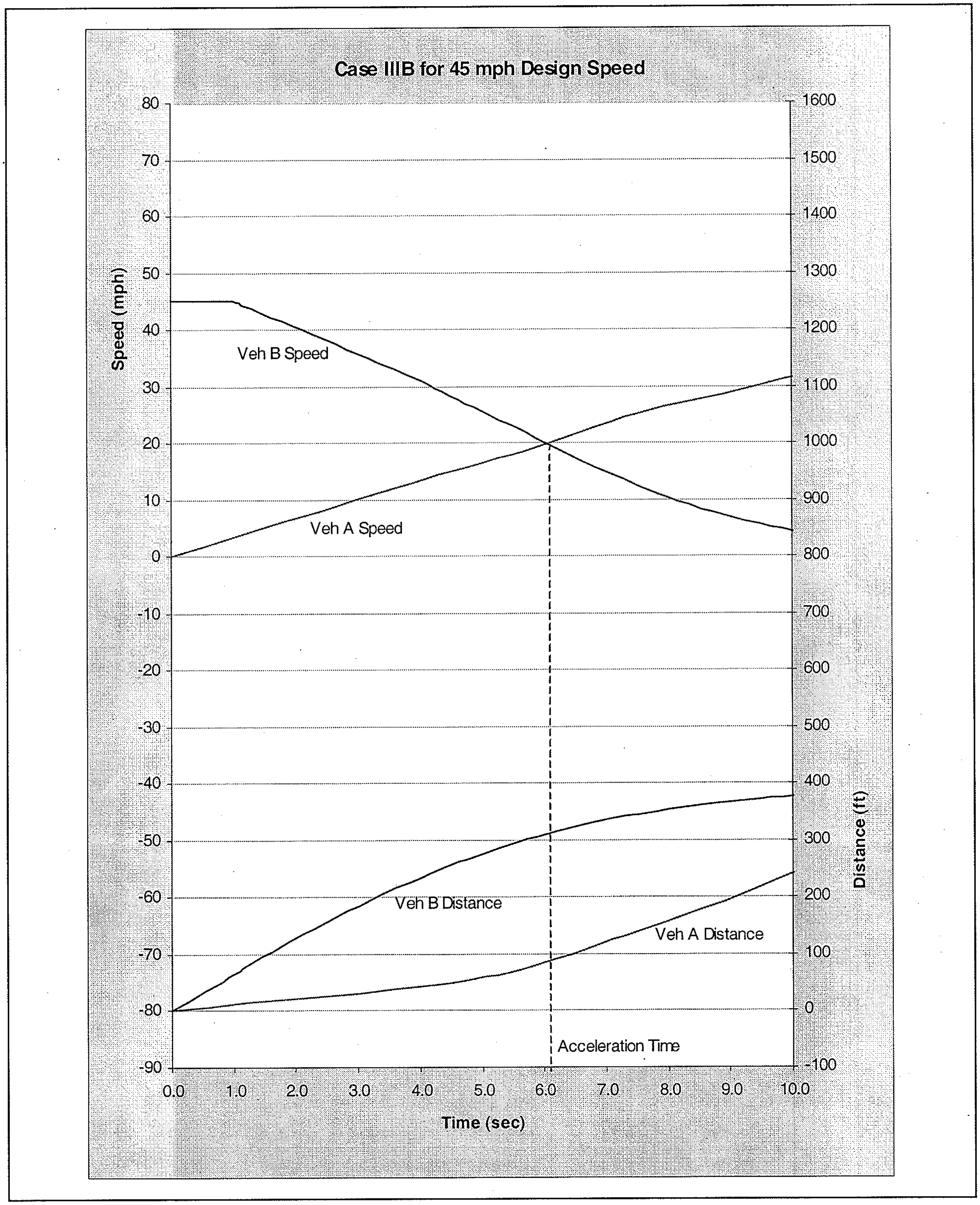

Figure 7. Solving for Minimum Required Sight Distance

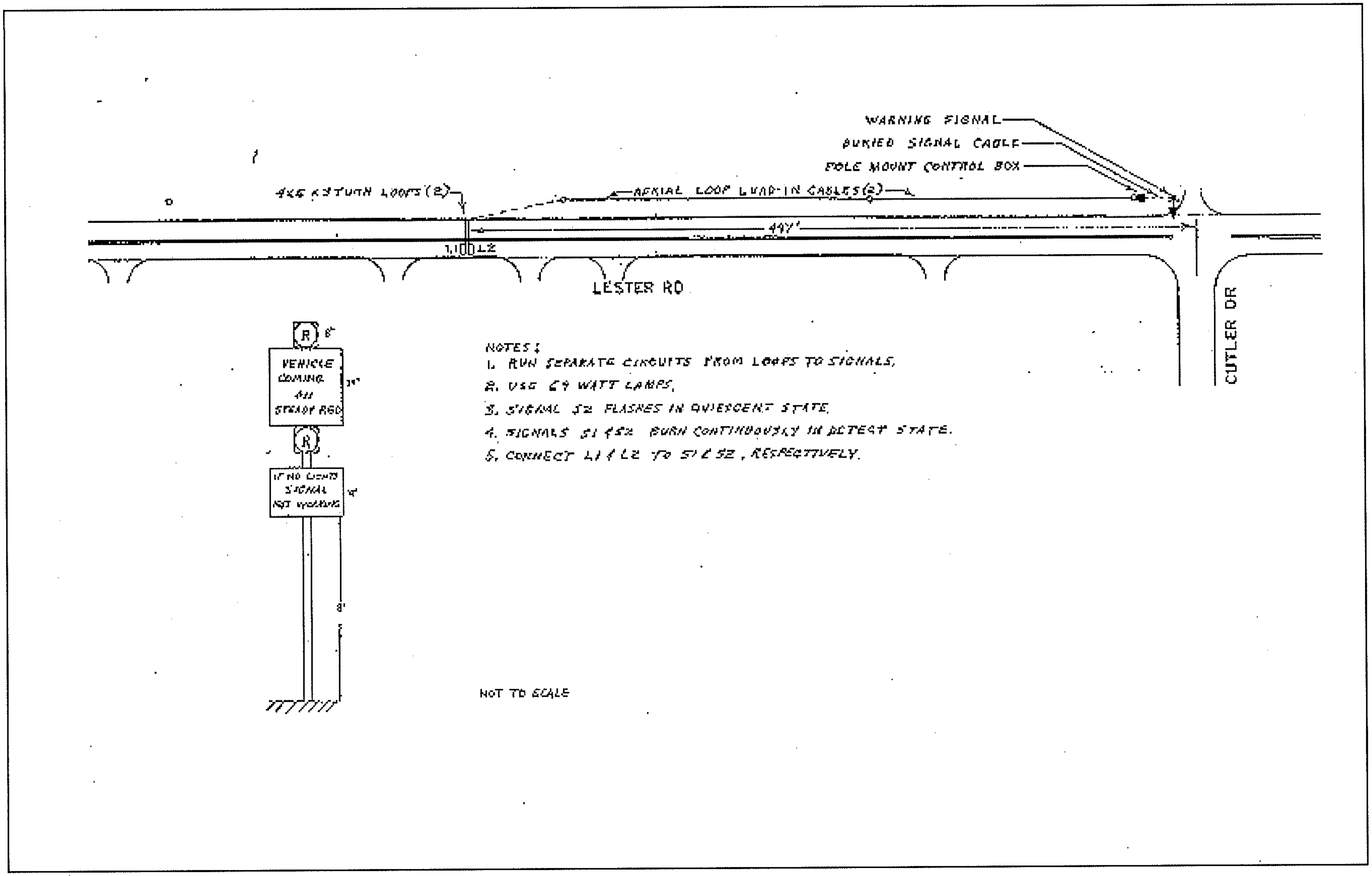

Figure 8. The "Vehicle Approaching" Traffic Actuated Warning Sign

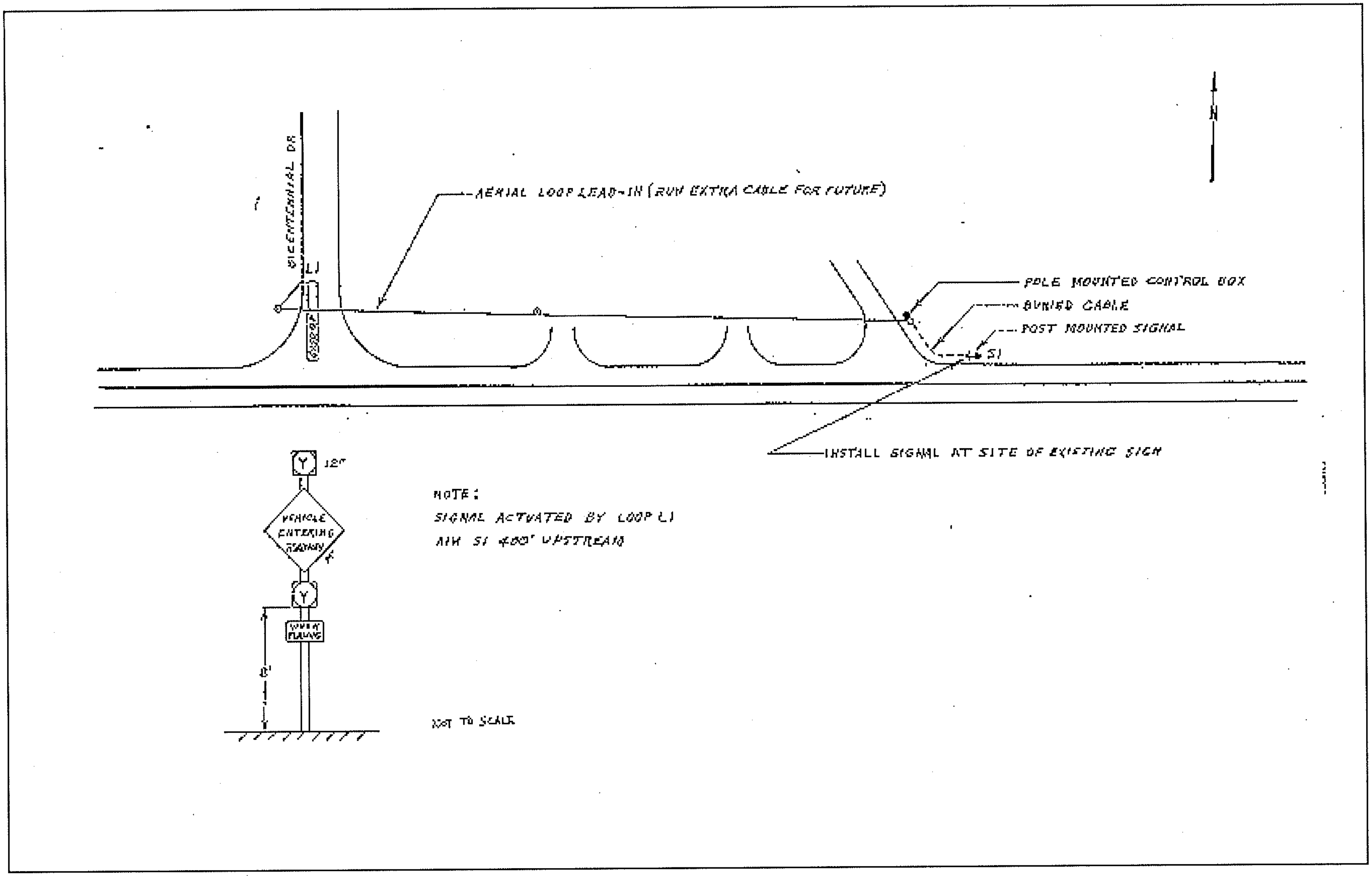

Figure 9. The "Vehicle Entering Highway " Traffic Actuated Warning Sign

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Figure 9. The "Vehicle Entering Highway" Traffic Actuated Warning Sign