Sign Visibility

Effects of Traffic Characteristics and Mounting Height

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A STUDY ON THE EFFECTS OF TRAFFIC VOLUME, TRAFFIC SPEED, MOUNTING HEIGHT, AND LATERAL OFFSET ON THE VISIBILITY OF ON-PREMISE COMMERCIAL SIGNS

A Research Project Of The
UNITED STATES SIGN COUNCIL FOUNDATION

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BACKGROUND

In recent years, there has been a movement in local government regulations (i.e., sign ordinances) toward restricting the mounting height of on-premise, commercial signing and other roadside oriented signs. These restrictions can dictate the maximum height to the bottom or top of a sign, or in some instances, they will only allow these signs to be mounted flush with the existing grade level (i.e., on the ground).

This has caused some concern among sign designers and fabricators in both the on-premise, commercial sign industry and the professional graphic design community that automobile drivers, for whom the messages on such signs are usually intended, will have difficulty in seeing and reading many of these low profile (or "ground mounted" or "monument") signs.

These potential visibility difficulties are caused by the presence of other vehicles; either those in front of the subject vehicle, those in the adjacent travel lane, or those traveling in the opposite direction; blocking the line of sight between the subject vehicle driver and any low-mounted, roadside sign. This visibility problem could be exacerbated by high volumes of traffic on the road or vehicle mixes that include a large number of oversize vehicles (i.e., trucks, buses, and recreational vehicles).

Recognition of this problem, as it relates to traffic signing, goes back several years. For example, in 1971 Abramson reported on the blockage of traffic signs by trucks. He undertook a mathematical analysis of this problem. Abramson considered the effect of a moving visual shadow (i.e., blockage) caused by a moving truck. If another driver's moving vehicle falls within that moving shadow, the driver cannot see the sign. Abramson considered the truck speed, truck size, the position and size of the sign along with lane widths and the speed of the "blocked" vehicle. His analysis showed that for many of the different scenarios tested, there was a significant amount of sign blockage.

Considering another aspect of "sign blockage," Roberts (1991) conducted a videotape "survey" from inside a moving passenger car to determine the frequency and cause of highway interchange sign blockage. Signs were considered to be blocked if, for some time while the sign was visible from inside the vehicle, the line of sight from the video camera (i.e., a surrogate for the driver's eye) to the sign was obscured by any type of obstacle (e.g., trees, bridge spans, bridge abutments, utility poles, etc.). Of the 1,012 interchange approaches surveyed, there were 583 instances (57 percent of the cases) of sign blockage "that left the observers with less than maximum viewability within their (the sign's) readable range."

Ullman and Dudek (2001) investigated the effect of large trucks on the readability of variable message signs (VMS) along freeways. They developed mathematical models to evaluate the influence of large truck volumes on the distance (i.e., reading time) available for a driver to view and read a VMS. They concluded that shorter reading times caused by the presence of large trucks in the traffic stream may require the sign designer to alter the placement, mounting height, orientation, or the operation of the VMS (e.g., message length, display rate). Their results for a sample case, using typical input values for traffic volumes and percentage of truck traffic, indicated "how significant the truck obstructions can become even when overall traffic demands are not excessive."

As part of Boston's Central Artery Tunnel project, a team of investigators (Carpenter, et al. 2001) used a full-scale, driving simulator to consider the effects of tunnel roadway geometry and the presence of trucks on the ability of drivers to detect and read signs in the tunnel. Several different signing configurations and traffic patterns were used to determine what designs would be most visible to tunnel drivers. While their work assessed a blockage problem specifically related to the geometric configuration of the tunnel and the anticipated truck traffic, it underscores the importance of understanding how moving traffic can influence the readability of traffic signs.

Another study using mathematical simulation to assess the effects of heavy vehicles on sign visibility was conducted by Al-Kaisy and Bhatt (2002). In their approach, they attempted to improve on the earlier work done by Abramson by considering other analysis factors, such as percentage of trucks in the traffic stream, lane utilization, and the average speeds of the passenger cars and trucks. Their model yields two measures of sign blockage. The first is the probability of a traffic sign being occluded by heavy vehicles under certain geometric and traffic conditions. The second is an estimate of the likelihood of a passenger car driver missing the sign based on the minimum time required for the driver to detect, recognize, and read the message.

While all of these studies demonstrate the importance of considering the influence of traffic and roadway geometry on the visibility of signs, none of this work examined this problem as it relates to on-premise, commercial signing or the potential effect of passenger cars.

RESEARCH OBJECTIVE

The objective of this research was to determine the probability of another automobile (i.e., object vehicle) blocking the line of sight between the driver of a subject vehicle and an on-premise, low-mounted, roadside sign. This probability would be a function of the position of the subject vehicle, the position(s) of one or more object vehicles, the volume of vehicles on the road, and the speed of the vehicles on the road.

RESEARCH APPROACH

METHOD

To achieve the stated research objective, an analytical study was initiated. Scale drawings of subject and object vehicles on various roadway configurations relative to varying sign positions were developed. Next, a set of traffic flow rates (i.e., the number of vehicles traveling past a fixed point adjacent to the roadway over a selected time period, usually one hour) was assumed. Once a series of roadway, traffic, and signing scenarios were produced, traffic flow simulation software was used to "position" the object vehicles relative to the location of the subject vehicle.

Initially, a series of experimental cases were developed. Scaled, computer-aided drafting (CAD) drawings were prepared to show the position of the subject and object vehicles for various roadway configurations. Additionally, the offset (i.e., the distance from the right edge of the roadway to the left edge of the sign for signs positioned to the right of the subject vehicle, or the inverse for signs positioned to the left of the subject vehicle) to the lateral mounting position of the sign was varied to develop an understanding of how object vehicles create visibility problems for subject vehicles. In such cases, the object vehicle can obstruct a sight line by traveling in front of the subject vehicle, adjacent to the subject vehicle, or in the opposite direction of the subject vehicle. In all instances, the commercial sign was assumed to be mounted at a height such that the line of sight, between the eye position of the driver of the subject vehicle and the sign, would be blocked by an automobile. (i.e., at 5 feet above grade or below).

Each experimental case was based on the four-lane, undivided highway shown in Figure 1. As shown, lanes 1 and 2 convey vehicle traffic in the opposite direction of lanes 3 and 4.

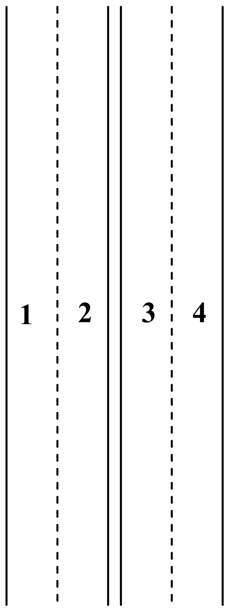

Figure 1. Lane numbering convention.

Both the subject and object vehicles were assumed to be 18 feet long and 6.5 feet wide. The driver eye location was assumed to be positioned 6 feet from the front of the subject vehicle and 2.17 feet from the left edge of each vehicle type (Figure 2). Additionally, the location of the on-premise sign was either 10 or 20 feet from the edge of the travel way – the sign was assumed to be 10 feet wide – on either the left or right-hand side of the roadway. The subject vehicle was assumed to travel at 35 or 45 miles per hour (mph) for each set of test cases.

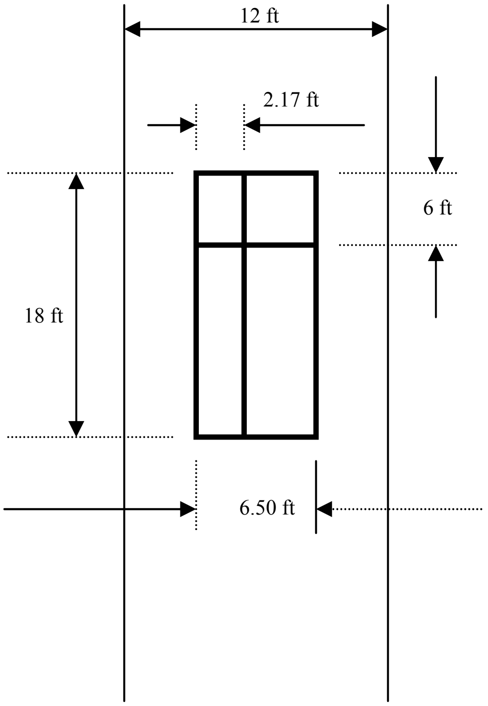

Figure 2. Dimensions of design vehicle and driver eye position.

In prior research, members of the project team determined analytically that the absolute minimum amount of time needed to perceive, react, and make an appropriate driving maneuver in response to an on-premise, commercial sign is 5.5 seconds (Garvey, Gates, and Pietrucha, 1995; and Kuhn, Garvey, and Pietrucha, 1996). It must be noted, however, that although this minimum reaction time value of 5.5 seconds is considered adequate by some highway engineers and human factors researchers, it is nonetheless lower than reaction time values suggested by other authorities in the field, (e.g., Garvey and Kuhn (in press); Mace 2002). Accordingly, in delineating the portion of the roadway where it would be critical for the driver to be able to see an on-premise, commercial sign, it was decided to provide a range of reaction time values. If the subject vehicle driver, traveling at 45 mph, requires at least 3.5 seconds to perceive, react, and make an appropriate turning maneuver when a commercial sign is clearly visible, then the subject vehicle would be positioned at a minimum of 230 feet from the commercial sign. At 500 feet from the on-premise sign, a subject vehicle driver would have 7.5 seconds to identify and react to the sign. Line of sight drawings were made at every 50 foot (nominally) increment beyond 230 feet to 500 feet from the sign. The object vehicle was positioned at the point of impending sign blockage for each test case shown in Table 1. The linear distance from the subject vehicle's driver eye location to the sign (d_1), the linear distance from the object vehicle's eye location to the sign (d_2), and the linear spacing between vehicles (d_3) were recorded. A sample test case scenario is shown in Figure 3 to illustrate vehicle position with respect to the sign.

Similar scenarios were constructed for the 35 mph travel speed case. The subject vehicle test cases were developed for each 50 foot increment between 180 and 380 feet (representing 3.5 and 7.5 seconds of perception and reaction time, respectively) from the sign. Again, the object vehicle was positioned at the point of impending blockage for each test case shown in Table 1. The linear distance from the subject vehicle's driver eye location to the sign (d_1), the linear distance from the object vehicle's eye location to the sign (d_2), and the linear spacing between vehicles (d_3) were recorded.

Table 1. Experimental cases.

Case	**Subject Vehicle Lane Position**	**Object Vehicle Position**				**Sign Location (Road Side)**
		Lane 1	**Lane 2**	**Lane 3**	**Lane 4**	
1	3	X				Left
2	3		X			Left
3	3			X		Left
4	3			X		Right
5	3				X	Right
6	4	X				Left
7	4		X			Left
8	4			X		Left
9	4				X	Left
10	4				X	Right

Instances where the object vehicle was positioned in front of the subject vehicle required the determination of only a single point of impending blockage. Instances where the object vehicle was positioned either adjacent to or traveling in the opposite direction of the subject vehicle required that two points of impending blockage be determined. Both scenarios are shown in Figure 3.

DETERMINATION OF SIGN BLOCKAGE

Once the physical dimensions of sign blockage were delineated, a means for determining how often (i.e., for the purposes of this research, a percentage of time) the line of sight between the subject driver and the sign had to be developed. As stated in the introduction, two approaches were used. One employed a generic time-space simulation software package to determine when the subject vehicle and the object vehicle were "aligned" so that the line of sight to the sign would be blocked. A second approach sought the same result using an analytically based algorithm.

Sign Blockage Simulation

The ARENA 6.0 simulation software, developed by the Rockwell Software Company, was used to create the sign blockage computer simulation. This software is widely used in industrial systems such as assembly lines, manufacturing plants, and warehouses, and it also has been applied to simulating traffic networks. The internal program algorithm was formulated for a general case so that it could be applied to any sign blockage scenario. A description of the procedure used to create the general simulation scenario follows:

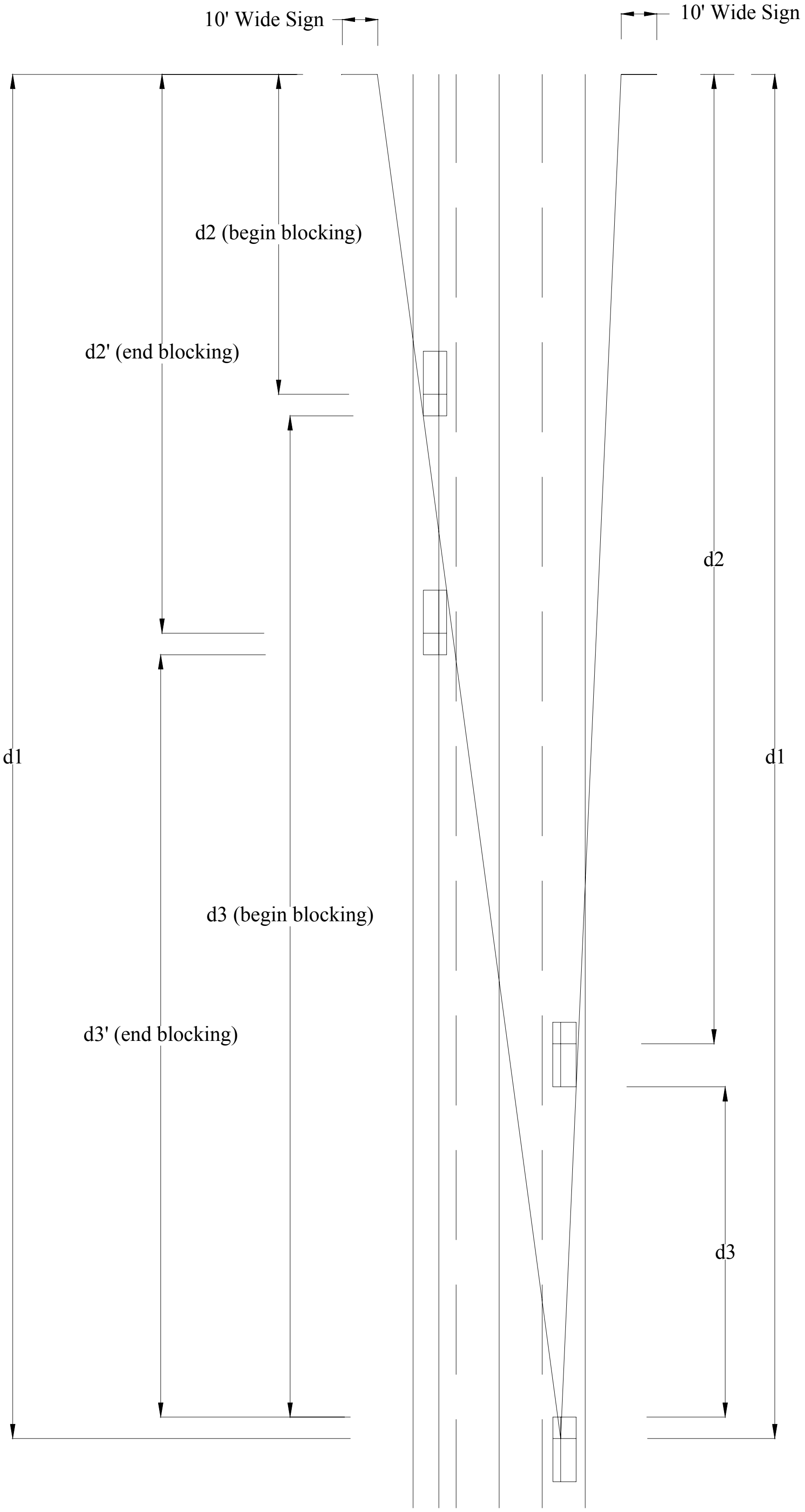

Figure 3. Impending blockage locations (right and left sign location).

1. Each lane of the roadway segments was divided into several cells. Each cell has a length of 50 feet. It should be pointed out that the smaller the cell size, the more accurate the results. However, this has to be balanced against the fact that as the cell size becomes smaller, the computational burden (i.e., processing time) for the model becomes greater. A numbering scheme was then applied to identify each of the cells on the roadway segment as shown in Figure 4.

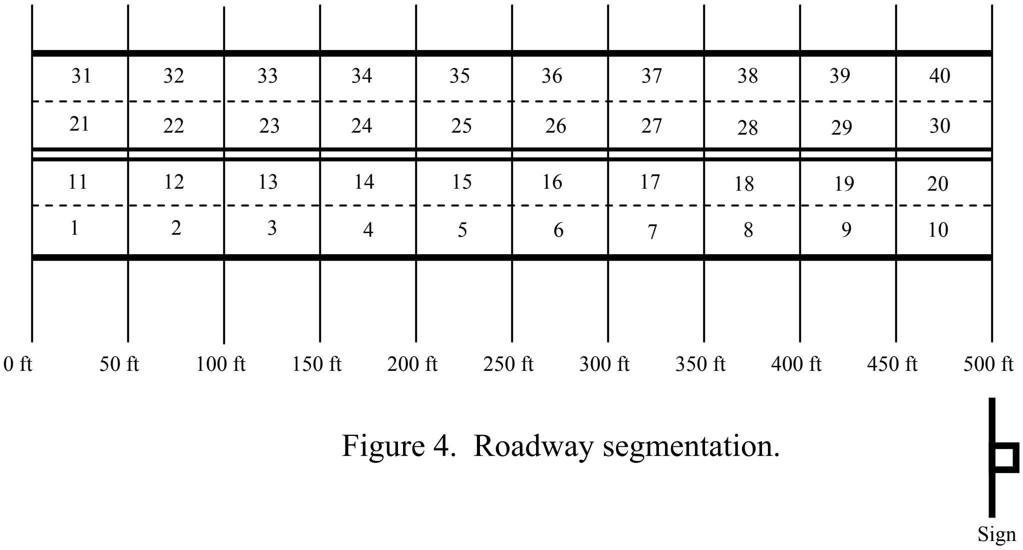

Figure 4. Roadway segmentation.

2. Using the sign blockage information based on the geometric configuration of the roadway, sign location, and the drawings of the different locations of the subject and object vehicles, the cells pairings that cause a blockage could be identified. For instance, if there are vehicles in cells 4 and 12, the object vehicle in cell 4 will block the line of sight of the subject vehicle in cell 12. Thus, the cell pair (4, 12) would constitute a blockage pair as shown in Figure 5. This process was repeated until all the sign blockage cell pairs were identified.

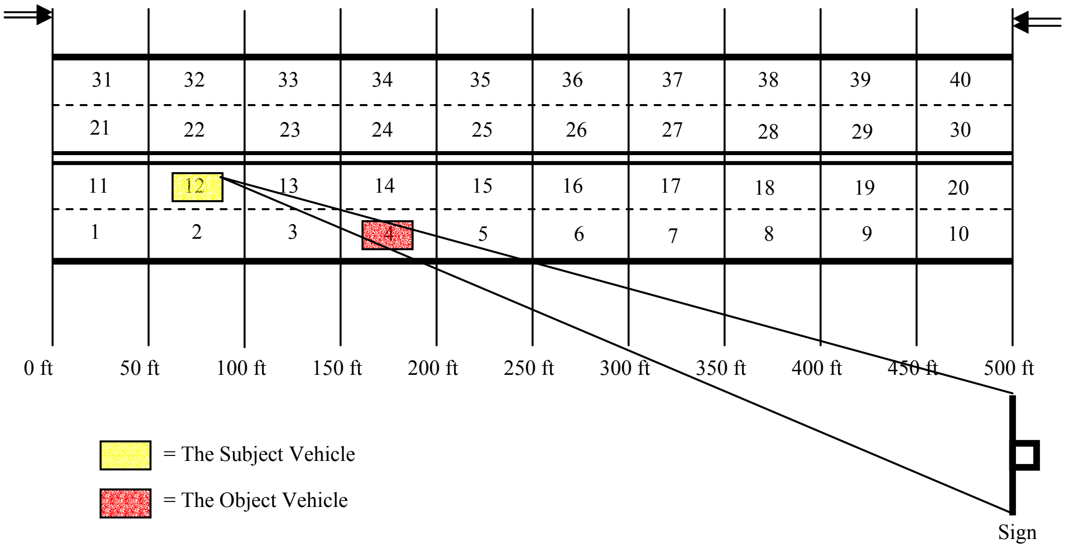

Figure 5. Sample sign blockage.

3. The software was then used to generate vehicles on each lane according to prescribed flow rates and concomitant time headway (i.e., the time between individual vehicles) distributions. For a given lane, the speed of the traffic stream (and the individual vehicles) was assumed to be constant along the entire length of the lane.
4. The number of sign blockages occurring within a specified time period was recorded. (Note that the simulation software did all the bookkeeping processes.)
5. The instances of sign blockage were then converted into a percentage of time of blockage using the following equation:

$$\text{Percentage Blockage} = \frac{\sum_{\forall i} (\text{Number of Blockages Observed}) * (\text{Time to travese one cell}) * 100}{\sum_{\forall i} (\text{Time to Traverse Roadway}) * (\text{Number of The Subject Vehicles Generated})}$$

Sign Blockage Simulation Results

Four scenarios of sign blockage were investigated by varying the speeds of the traffic streams and the lane occupied by the subject vehicle. Table 1 provides a summary of simulation scenarios. The individual results for each of the scenarios are provided in Appendix A. These results do not include the condition where the sign is offset 20 feet from the edge of the roadway. This condition is assessed using a different approach, which is explained in detail below.

Table 2. Simulation Scenarios.

Scenario Number	Location of Subject Vehicle	Speed of Traffic	Location of Sign
1	Lane 4	35	Right
2	Lane 4	45	Right
3	Lane 4	35	Left
4	Lane 4	45	Left
5	Lane 3	35	Right
6	Lane 3	45	Right
7	Lane 3	35	Left
8	Lane 3	45	Left

Analytical Method to Determine Sign Blockage

In the process of configuring the parameters for the simulation model, the research team suspected that the analysis might also be conducted using an analytical based stochastic approach. With that idea in mind, the study team began to formulate a series of equations that would also yield information about sign blockage time. This approach is detailed below.

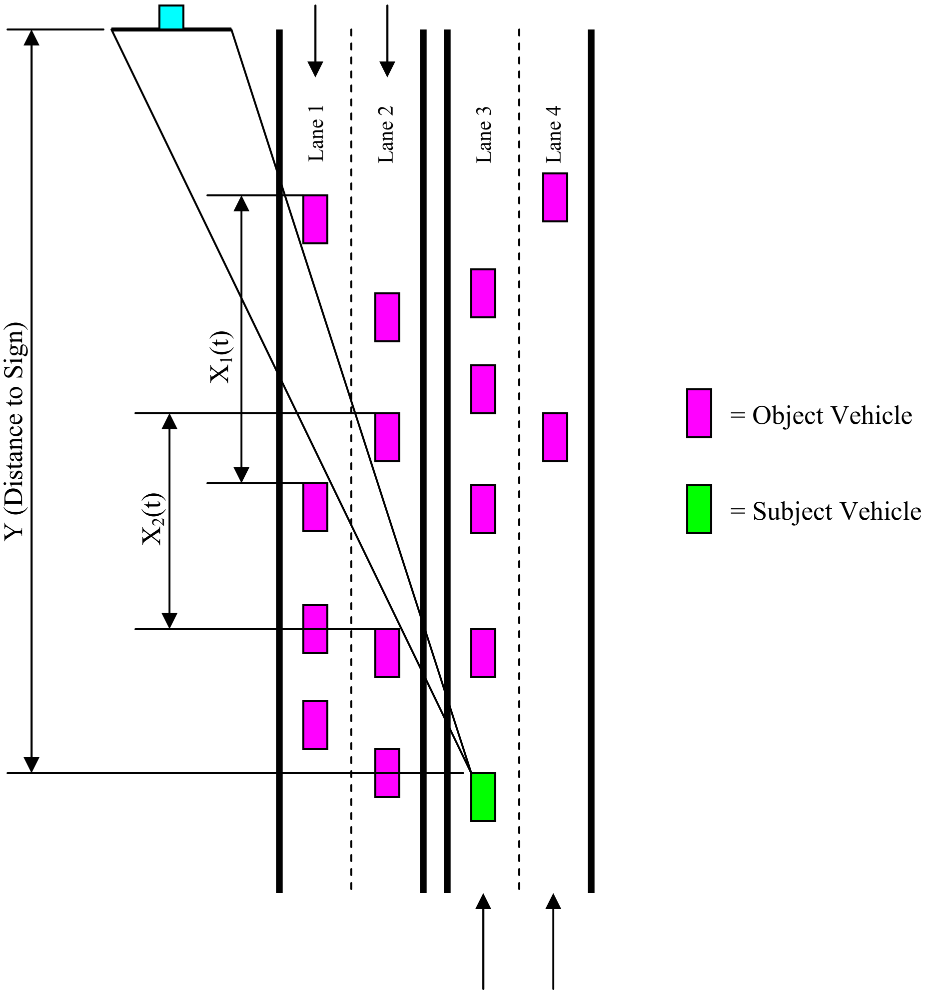

Figure 6. Sign on the left side.

The process began with a few basic assumptions. These were:

1. Time headway distributions of traffic streams on each lane are known.
2. Speeds (V) are constant over the roadway section.
3. Space windows ($X_1(t)$ and $X_2(t)$) are known at any given instance.

Using these assumptions, time headway distributions (T) of traffic streams on each lane were specified as follows:

Time Headway Distribution on lane 1: $P[T1 \le t] = FT_1(t)$
Time Headway Distribution on lane 2: $P[T2 \le t] = FT_2(t)$
Time Headway Distribution on lane 3: $P[T3 \le t] = FT_3(t)$
Time Headway Distribution on lane 4: $P[T4 \le t] = FT_4(t)$

From the simple equation of motion, the relationship among distance headway, speed, and time headway is specified as:

$$S = V*T$$

Where S = Distance headway
V = Speed
T = Time headway

The distance headway distribution of lane 1 could be written in terms of time headway distribution of lane 1 and speed as follows:

$$\begin{aligned} P[S1 \le s] &= P[V*T1 \le s] \\ &= \mathrm{P}[\mathrm{T}1 \le \frac{\mathrm{s}}{\mathrm{V}}] \\ &= \mathrm{FT}_1[\frac{s}{V}] \end{aligned}$$

Similarly, the distance headway distributions of lanes 2, 3, and 4 could be written in terms of time headway distributions using the same argument.

Considering the situation in Figure 6, blockage to the subject vehicle occurs when there is at least one vehicle in the X_1 and X_2 space windows at any given moment. Therefore, the problem could be reduced to a simple stochastic (i.e., probabilistic) problem. If the probability of no blockage at time t_i could be calculated as:

Probability of No Blockage = (Prob. of no vehicle in space X_1)*(Prob. of no vehicle in Space X_2)

= (Prob. of space headway > X_1)*(Prob. of space headway > X_2)

$$= P[S1 > x_1] \cdot P[S2 > x_2]$$

Then, the probability of blockage would be equal to:

$$\textit{Probability Blockage} = 1 - \textit{Probability of No Blockage}$$
$$= 1 - P[S1 \geq x_1] * P[S2 \geq x_2]$$

Then at time t_i:

$$\textit{Probability Blockage} = 1 - \textit{Probability of No Blockage}$$

$$= 1 - P[S1 \geq x_1(t_i)] * P[S2 \geq x_2(t_i)]$$
$$= 1 - \left\{ 1 - \mathrm{FT}_1[\frac{x_1(t_i)}{V}] \right\} \left\{ 1 - FT_2[\frac{x_2(t_i)}{V}] \right\}$$

At time $t_i + \Delta t_i$:

$$\textit{Probability Blockage} = 1 - \textit{Probability of No Blockage}$$

$$= 1 - P[S1 \geq x_1(t_i + \Delta t_i)] * P[S2 \geq x_2(t_i + \Delta t_i)]$$
$$= 1 - \left\{ 1 - \mathrm{FT}_1[\frac{x_1(t_i + \Delta t_i)}{V}] \right\} \left\{ 1 - FT_2[\frac{x_2(t_i + \Delta t_i)}{V}] \right\}$$

Since Δt_i is very small, probability of blockage can accurately be approximated as:

$$\textit{Probability of Blockage} = 1 - \left\{ 1 - \mathrm{FT}_1[\frac{x_1(t_i)}{V}] \right\} \left\{ 1 - FT_2[\frac{x_2(t_i)}{V}] \right\}$$

According to the definition above, the amount of blockage time out of the travel time (Δt_i), would be equal to:

$$\textit{Amount of Blockage Time} = \left\{ 1 - \left\{ 1 - \mathrm{FT}_1[\frac{x_1(t_i)}{V}] \right\} \left\{ 1 - FT_2[\frac{x_2(t_i)}{V}] \right\} \right\} * \Delta t_i$$

Therefore, the total amount of blockage time out of the total travel time could be approximated as:

$$TotalBlockageTime = \sum_{\forall i} \left\{ 1 - \left\{ 1 - FT_1[\frac{x_1(t_i)}{V}] \right\} \left\{ 1 - FT_2[\frac{x_2(t_i)}{V}] \right\} \right\} * \Delta t_i$$

Again, since Δt_i is very "small," the summation could be transformed to the integration as follows:

$$\begin{aligned} TotalBlockageTime &= \sum_{\forall i} \left\{ 1 - \left\{ 1 - FT_1[\frac{x_1(t_i)}{V}] \right\} \left\{ 1 - FT_2[\frac{x_2(t_i)}{V}] \right\} \right\} * \Delta t_i \\ &= \int_0^{TT} \left\{ 1 - \left\{ 1 - FT_1[\frac{x_1(t)}{V}] \right\} \left\{ 1 - FT_2[\frac{x_2(t)}{V}] \right\} \right\} dt \qquad (1) \end{aligned}$$

Similarly, when there are N obstructing traffic lanes, the total blockage time could then be expressed as:

$$Total\ Blockage\ Time = \int_0^{TT} 1 - \prod_{i=1}^{N} (1 - FT_i(\frac{x_i(t)}{V}))\ dt \qquad (2)$$

where TT = Total available time

N = Number of obstructing traffic lanes

$FT_i(t)$ = Cumulative density function of time headways on the i^{th} obstructing traffic lane

$x_i(t)$ = The required space window on the i^{th} obstructing traffic lane

V = Speed of traffic streams

The next step was to compute $x_i(t)$ in terms of speed and geometry of the facility of interest.

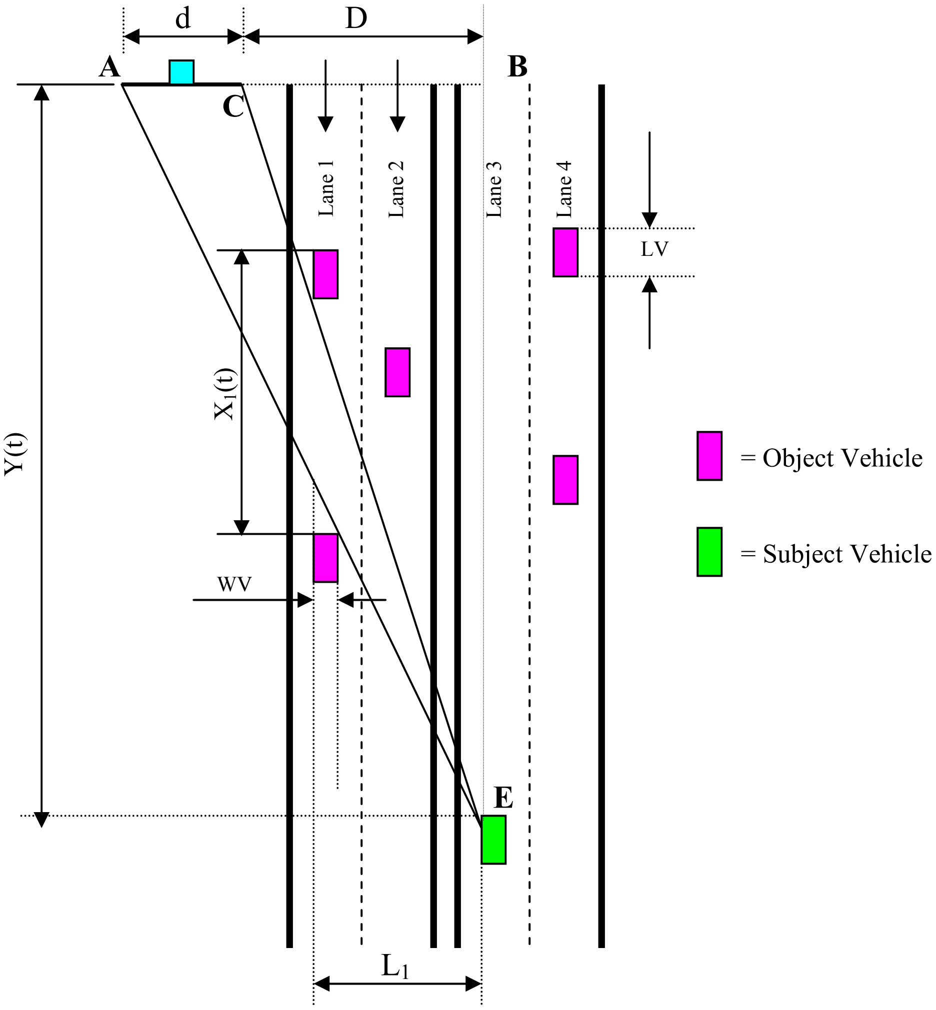

Figure 7. Space window on lane 1.

Considering Figure 7, which represents a situation when a sign is on the left side of the roadway, and using two similar triangles (Δ ABE and Δ CBE), the required space window on Lane 1 could be written as follows:

$$x_1(t) = \{\frac{L_1 \cdot d}{D(D+d)} + \frac{WV}{d+D}\} Y(t) + LV \tag{3}$$

where $x_1(t)$ = the required space window on Lane 1 at time t

Y(t) = the distance along the roadway from the subject eye to the sign at time t

L_1 = the transverse distance from the subject eye to the edge of the obtructing vehicle on Lane 1

D = the transverse distance from the subject eye to the near egde of the sign

d = the width of sign

LV = the length of vehicle

WV = the width of vehicle

If the object vehicles are on the same lane as the subject vehicle, then the required window space could be computed as follows.

$$x_i(t) = \frac{L_i}{D} Y(t) + LV \tag{4}$$

where $x_i(t)$ = the required space window when the object vehicles are on the same lane as the subject vehicle

L_i = the transverse distance from the subject eye to the edge of the obstructing vehicle on the same lane

D = the transverse distance from the subject eye to the near edge of the sign

LV= the length of vehicle

However, Y(t) could also be expressed in terms of the initial distance from the subject eye to the sign and speed of traffic stream using equations of motions as follows.

$$\frac{dY(t)}{dt} = -V$$

$$\int_{Y_I}^{Y} dY(t) = \int_0^t -V dt$$

$$Y(t) = Y_I - V \cdot t \tag{5}$$

Substituting Equation (5) into Equation (3), the required space window could be written as:

$$x_1(t) = \{\frac{L_1 \cdot d}{D(D+d)} + \frac{WV}{D+d}\} \cdot (Y_I \text{ - V} \cdot \text{t}) + \text{LV} \tag{6}$$

where $\text{x}_1(t)$ = the required space window on Lane 1 at time t

L_1 = the transverse distance from the subject eye to the edge of the obtructing vehicle on Lane 1

D = the transverse distance from the subject eye to the near egde of the sign

d = the width of sign

Y_I = the initial distance from the subject eye to the sign

V = the speed of the traffic streams

LV = the length of vehicle

WV = the width of vehicle

In this study, time headways on each lane were assumed to be exponentially distributed, which was expressed as follows.

$$FT_i(t) = 1 - e^{-\lambda_i \cdot t} \tag{7}$$

where $\text{FT}_\text{i}(t)$ = the CDF of time headways on the i^th lane

λ_i = the flow rate of the i^th lane

Using Equations (2), (6), and (7), the total blockage time could be calculated as follows:

$$
\begin{aligned}
\mathit{Total\ Blockage\ Time} &= \int_{0}^{\mathrm{TT}} 1 - \prod_{\mathrm{i}=1}^{\mathrm{N}} (1 - \mathrm{FT}_{\mathrm{i}}(\frac{x_i(t)}{V}))\ \mathrm{dt} \\
&= \int_{0}^{\mathrm{TT}} 1 - \mathrm{e}^{-[\frac{LV\cdot}{V}\sum_{\mathrm{i}=1}^{\mathrm{N}} \lambda_i + (\mathrm{Y_I} - V\cdot t)\sum_{i=1}^{N} k_i]}\ \mathrm{dt} \\
&= \mathrm{TT} - \mathrm{e}^{-\frac{\mathrm{LV}}{\mathrm{V}}\sum_{i=1}^{N}\lambda_i} \cdot \int_{0}^{\mathrm{TT}} \mathrm{e}^{-(\mathrm{Y_I} - V\cdot t)\sum_{i=1}^{N} k_i}\ dt \\
&= \mathrm{TT} - \mathrm{e}^{-\frac{\mathrm{LV}}{\mathrm{V}}\sum_{i=1}^{N}\lambda_{\mathrm{i}}} [\mathrm{e}^{\mathrm{V\cdot TT}\sum_{\mathrm{i}=1}^{\mathrm{N}} \mathrm{k_i}} - 1] \cdot \frac{e^{-Y_I\cdot\sum_{i=1}^{N} k_i}}{\mathrm{V}\sum_{\mathrm{i}=1}^{\mathrm{N}} \mathrm{k_i}}
\end{aligned} \tag{8}
$$

where $\mathrm{k_i} = \frac{L_i \cdot d \cdot \lambda_i}{D(D+d)V} + \frac{WV}{D+d} \cdot \frac{\lambda_i}{V}$ (Different lane from the subject vehicle)

$\mathrm{k_i} = \frac{L_i \lambda_i}{D \cdot V}$ (Same lane as the subject vehicle)

V = the speed of traffic streams

$\mathrm{L_i}$ = the transverse distance from the subject eye to the edge of the obstructing vehicle on Lane "i"

d = the width of sign

D = the transverse distance from the subject eye to the near edge of the sign

λ_{i} = the flow rate of traffic stream on the obstructing traffic on Lane "i"

TT = the total available time

$\mathrm{Y_I}$ = the initial distance along the roadway from the subject eye to the sign

LV = the length of vehicle

WV = the width of vehicle

Analytical Method Results

The results using the analytical method are provided in Appendixes B and C, covering the 10 foot sign offset and 20 foot sign offset respectively. When the analytical results were compared to the simulation results, they were found to be extremely close. As the analytical approach was much simpler to effect, the 20 foot offset condition was analyzed using the analytical approach.

DISCUSSION

For each of the scenarios tested there is a critical (nominal) 4 second period during which the likelihood of blockage of the line of sight between the subject vehicle and the roadside sign by another vehicle was assessed. This 4 second value roughly covers a period 2 seconds before the vehicle reaches a position where it is at, as previously stated, the critical perception reaction time value of 5.5 seconds and 2 seconds after this same location. As the simulations were run covering 50 foot sections of roadway and the entire lengths of the test sections were not evenly divisible by 50, there is a minor difference in the amount of time the vehicle, in an individual scenario, was is the test section. This time varied from 3.9 to 4.1 seconds.

In examining the results of the simulation (Appendix A) for each of the 4 cases tested, the percentage of time the line of sight from the subject vehicle to the sign was blocked, during the critical 4 second window described above, varied from slightly over 11 percent (11.22) to slightly over 90 percent (90.64). The dramatic increase is based primarily on increasing traffic flow rates. The flow rate reported in each of the tables of results represents the number of vehicles traveling in both lanes in one direction for a period of one hour. This consistent increase in “blockage time” would stand to reason since it is evident that as there are more object vehicles on roadway, there are more opportunities for the line of sight from the subject vehicle to the sign to be blocked. To gain a rough idea of how to interpret the flow rate values, one can assume an equal distribution of vehicles in each of the two lanes of travel and divide the 3600 seconds in one hour by half of the flow rate value (i.e., the approximate number of vehicles traveling in one lane) to quantify how often a vehicle would pass a roadside observer. For example, for the case where the blockage time was approximately 11 percent, if standing along the roadside, a vehicle would pass by the observer every 18 seconds. In the case where the blockage time was over 90 percent, a vehicle would pass the observer every 3 seconds. Another way of interpreting this information is to state that if the traffic flows are relatively low, the driver will have a clear line of sight to the roadside sign for approximately 3.5 seconds. This should provide adequate time to detect, read, and comprehend an individual sign (but not necessarily enough time for any appropriate driving maneuvers in response to the sign). However, when the traffic flows are high, the driver has less than 0.4 seconds to perform this same task. This time window is hardly adequate for detecting a sign and does not provide enough time for reading and comprehension, let alone any maneuvering requirement.

In considering the results of the analytical approach (Appendixes B and C), the outcomes are similar. When traffic volumes are relatively low, the amount of time available to detect, read, and comprehend the sign seems to be adequate (3.73 seconds). However, when the traffic flows rise, the percent of time the line of sight from the subject vehicle to the sign goes up and the corresponding amount of time available to the driver goes down (0.82 seconds).

The question now becomes how much time does the driver need to detect, read, and comprehend a roadside sign. This is very dependent on whether the vehicle operator is actively looking for the sign or passively scanning the roadway ahead. Based on the prior work done by the research team, a value of 1.5 seconds would be the absolute minimum amount of time that a driver would need to perform this task. However, it should be pointed out that this value is only valid in situations where the driver is actively engaged in looking for a specific sign containing a relatively short, simple, and easily recognizable message. In dealing with roadside-oriented, on-premise, commercial signs, particularly, on which text, graphics, and the length of the message are necessarily varied from sign to sign to suit individual business requirements in any given environment, a value of between 1.5 and 3 seconds for the performance of this specific task would be more likely to meet the time required for a driver to detect, read, and comprehend an individual sign in most driving situations. This general range is consistent with the recent work of Garvey and Kuhn (in press) documenting dynamic reading times equivalent to one word per half-second. Thus, even given optimum conditions of driver alertness, cognition, and roadway visibility, a message of six words is likely to require at least three seconds for detection, reading, and comprehension. Further, the 1.5 to 3 second value does not take into account visual scanning time, vehicle maneuvering, or deceleration time, which has generally been calculated to add a minimum of 4 additional seconds to the overall reaction time. As stated previously, the time required for detection, reading, comprehension, and reaction in the form of a maneuver – under relatively optimum conditions of driver awareness, reaction time, and road conditions - is a minimum of 5.5 seconds, but as indicated above – particularly with reference to roadside business identity or individual wayfinding signs - can be significantly higher.

CONCLUSIONS

In light of the research reported on herein, there are several conclusions that can be reached:

- The amount of time a driver or subject has to detect, read, and comprehend a low-mounted, roadside sign is dependent on the position of the subject's vehicle in the roadway cross section; the amount of traffic on the roadway, traveling both in the same and the opposite direction of the subject's vehicle; and the distance the sign is laterally offset from the edge of the roadway.

- The amount of time a driver has to detect, read, and comprehend a low-mounted, roadside sign decreases as the amount of "other" traffic on the roadway increases.

- The amount of time a driver has to detect, read, and comprehend a low-mounted, roadside sign decreases as the subject's vehicle's lane position is closer to the roadway centerline.

- The amount of time a driver has to detect, read, and comprehend a low-mounted, roadside sign increases as the distance that a roadside sign is laterally offset from the edge of the roadway increases.

- The amount of time provided to a driver to detect, read, and comprehend a roadside sign should be a minimum time of 1.5 seconds. It should be noted here that this value is "read-only" and does not include any time for maneuvers.

- Many of the scenarios tested as part of this study do not provide the driver with the minimum time necessary to detect, read, and comprehend a roadside sign.

- If a driver cannot be provided with at least a minimum of 1.5 seconds to detect, read, and comprehend a proposed or existing roadside sign, the design of the sign should be reconsidered or the sign should be redesigned (e.g., elevated) to allow the driver a clear line of sight to the sign for at least a minimum of 1.5 seconds.

Note: The issue of increasing the time available to the driver to detect, read, and comprehend a low-mounted, roadside sign by increasing the lateral offset should be tempered by another visual detection principle, and that is the absolute need to place signs or any object to be viewed by the driver within 10 degrees of the line of sight (Jenkins and Cole 1986) in front of the driver. Therefore, there is a practical limit that one should observe in attempting to ameliorate the driver detection, reading, and comprehension issue by increasing lateral offset. Increasing offset may in turn decrease detection, reading, and comprehension by placing the object outside the driver's field of view, or by otherwise rendering the message unreadable due to the perspective change in the copy presentation.

Note: For the sign blockage scenarios examined by this study, in which the minimum detection, reading, and perception times are adversely affected by existing traffic, the most direct solution is to elevate the sign to the point where copy presentation is above the blocking aspect caused by other vehicles on the road. Significantly, in this respect, the Manual on Uniform Traffic Control Devices (MUTCD) (2000) published for the guidance of highway engineers by the U.S. Department of Transportation, mandates at least 5 feet in rural areas and 7 feet in urban areas above grade for all types of traffic signing.

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APPENDIX A

SIMULATION RESULTS

Summary of Sign Visibility Results using Simulation

Case 1: Subject vehicle in Lane 4 and Sign on the right

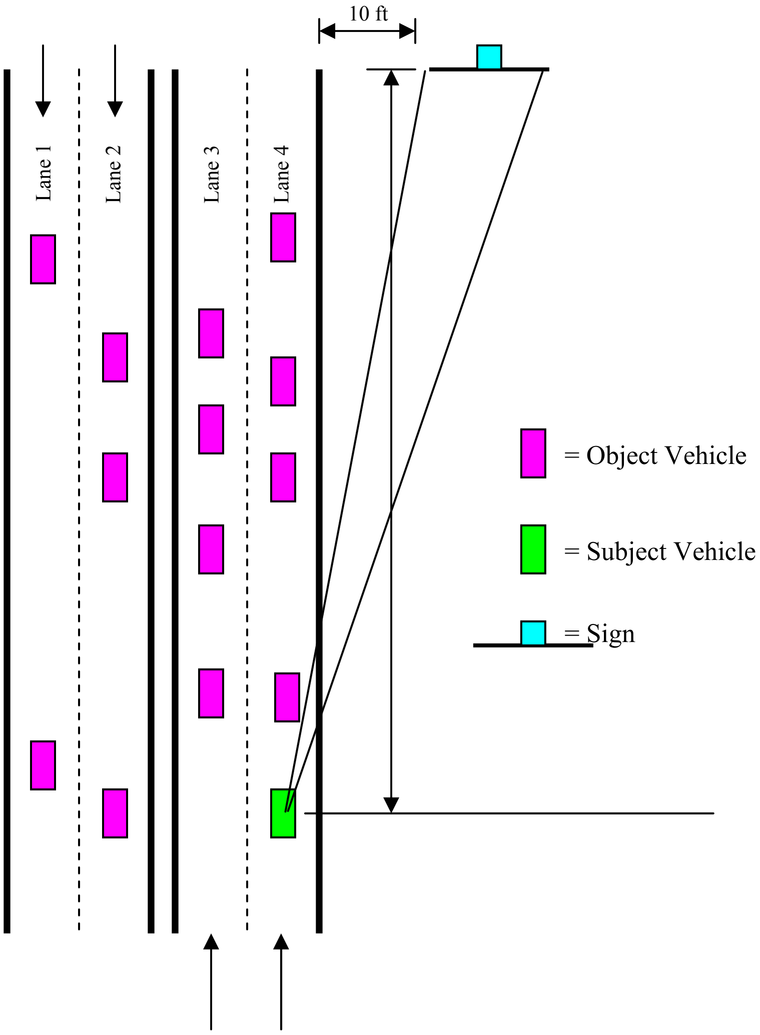

FIGURE 1: Case 1

TABLE 1: Blockage Time of Sign at 35 mph (Subject vehicle in Lane 4:Right sign)

Flow Rate (vehicles per hour)	Total Available Time (seconds)	Sign Blockage Time (seconds)	Sign Blockage Time (percent)
200	3.899 (380-180)/51.3	0.441	11.32
300	3.899	0.649	16.66
400	3.899	0.872	22.37
500	3.899	1.057	27.10
600	3.899	1.227	31.46
700	3.899	1.399	35.89
800	3.899	1.554	39.86
900	3.899	1.713	43.94
1000	3.899	1.861	47.73
1100	3.899	1.996	51.20
1200	3.899	2.133	54.70

TABLE 2: Blockage Time of Sign at 45 mph (Subject vehicle in Lane 4:Right sign)

Flow Rate (vehicles per hour)	Total Available Time (seconds)	Sign Blockage Time (seconds)	Sign Blockage Time (percent)
200	4.091 (500-230)/66	0.459	11.22
300	4.091	0.666	16.29
400	4.091	0.886	21.66
500	4.091	1.073	26.23
600	4.091	1.251	30.59
700	4.091	1.421	34.74
800	4.091	1.577	38.54
900	4.091	1.729	42.26
1000	4.091	1.879	45.92
1100	4.091	2.009	49.12
1200	4.091	2.135	52.18

Case 2: Subject vehicle in Lane 3 and Sign on the right

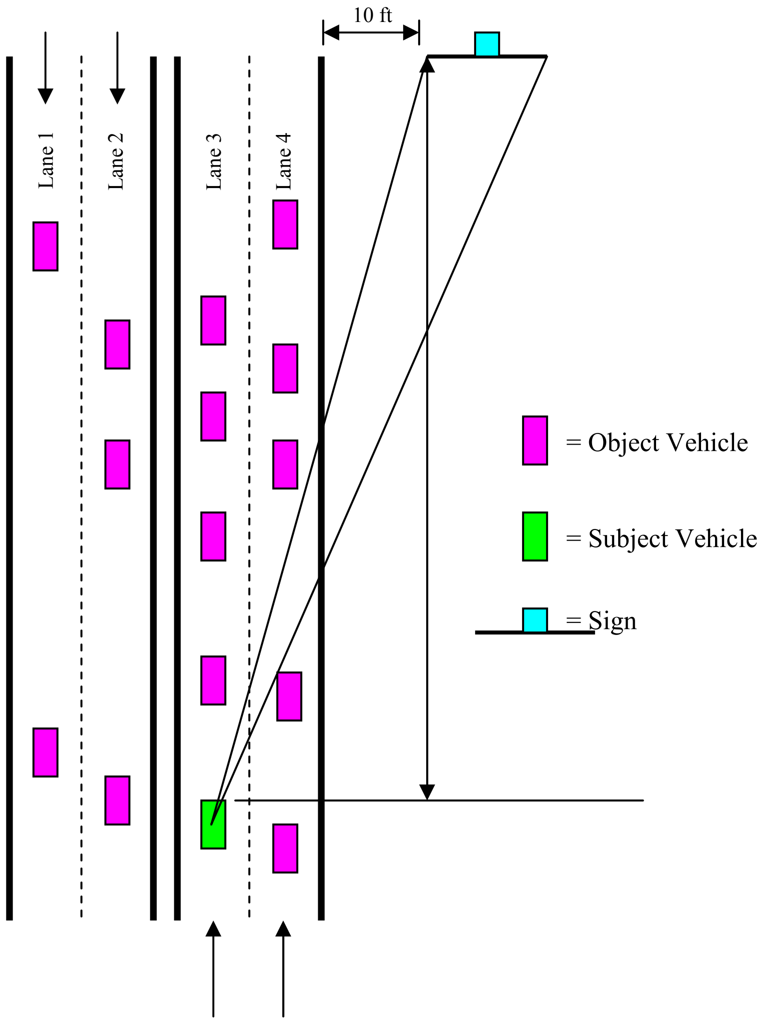

FIGURE 2: Case 2

TABLE 3: Blockage Time of Sign at 35 mph (Subject vehicle in Lane 3:Right Sign)

Flow Rate (vehicles per hour)	Total Available Time (seconds)	Sign Blockage Time (seconds)	Sign Blockage Time (percent)
200	3.899 (380-180)/51.3	0.855	21.93
300	3.899	1.204	30.88
400	3.899	1.528	39.19
500	3.899	1.813	46.50
600	3.899	2.062	52.89
700	3.899	2.292	58.78
800	3.899	2.500	64.12
900	3.899	2.681	68.76
1000	3.899	2.835	72.71
1100	3.899	2.973	76.25
1200	3.899	3.108	79.71

TABLE 4: Blockage Time of Sign at 45 mph (Subject vehicle in Lane 3:Right Sign)

Flow Rate (vehicles per hour)	Total Available Time (seconds)	Sign Blockage Time (seconds)	Sign Blockage Time (percent)
200	4.091 (500-230)/66	0.894	21.85
300	4.091	1.290	31.52
400	4.091	1.598	39.06
500	4.091	1.895	46.32
600	4.091	2.168	52.99
700	4.091	2.397	58.60
800	4.091	2.607	63.72
900	4.091	2.795	68.32
1000	4.091	2.949	72.07
1100	4.091	3.096	75.68
1200	4.091	3.226	78.84

Case 3: Subject vehicle in Lane 3 and Sign on the left

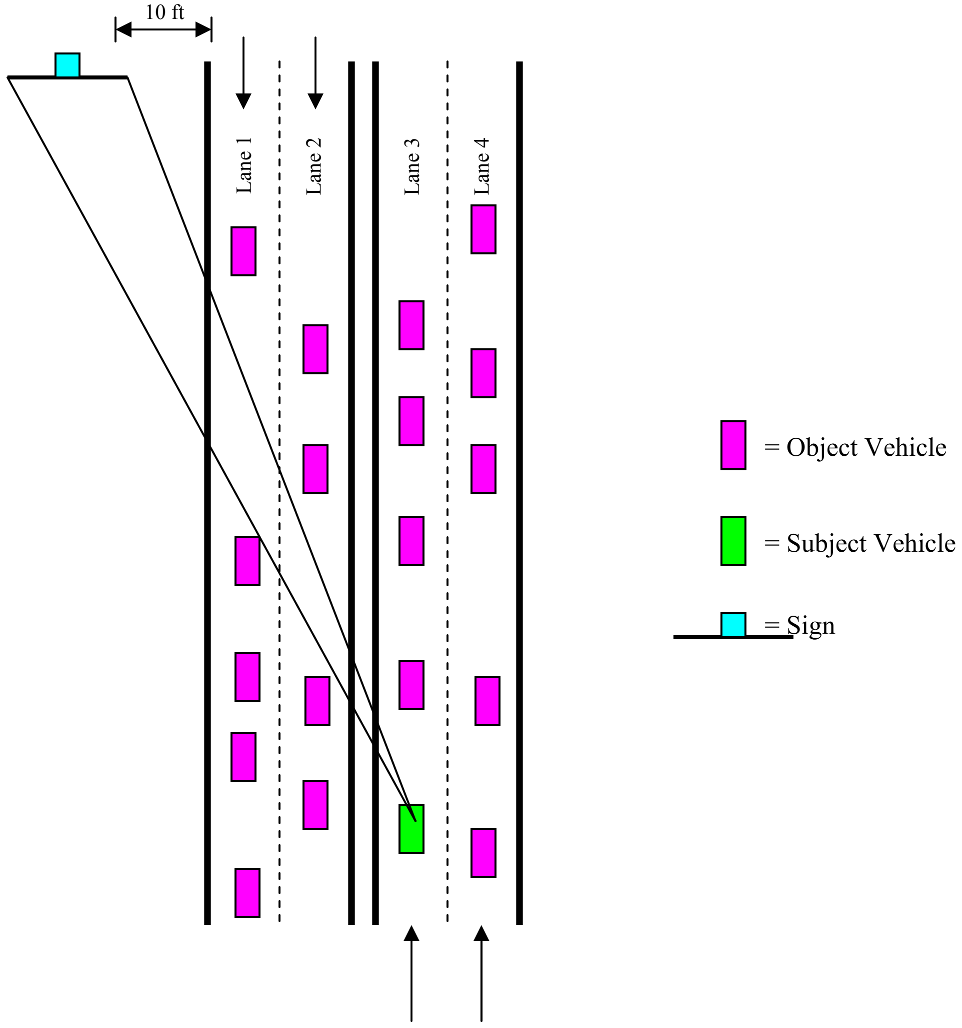

FIGURE 3: Case 3

TABLE 5: Blockage Time of Sign at 35 mph (Subject vehicle in Lane 3:Left Sign)

Flow Rate (vehicles per hour)	Total Available Time (seconds)	Sign Blockage Time (seconds)	Sign Blockage Time (percent)
200	3.899 (380-180)/51.3	0.96	24.56
300	3.899	1.41	36.22
400	3.899	1.76	45.17
500	3.899	2.08	53.31
600	3.899	2.34	60.09
700	3.899	2.57	65.87
800	3.899	2.76	70.75
900	3.899	2.93	75.18
1000	3.899	3.07	78.78
1100	3.899	3.18	81.68
1200	3.899	3.30	84.59

TABLE 6: Blockage Time of Sign at 45 mph (Subject vehicle in Lane 3:Left Sign)

Flow Rate (vehicles per hour)	Total Available Time (seconds)	Sign Blockage Time (seconds)	Sign Blockage Time (percent)
200	4.091 (500-230)/66	1.19	29.05
300	4.091	1.67	40.82
400	4.091	2.06	50.29
500	4.091	2.40	58.63
600	4.091	2.68	65.57
700	4.091	2.91	71.20
800	4.091	3.10	75.85
900	4.091	3.26	79.80
1000	4.091	3.39	82.88
1100	4.091	3.50	85.62
1200	4.091	3.60	87.95

Case 4: Subject vehicle in Lane 4 and Sign on the left

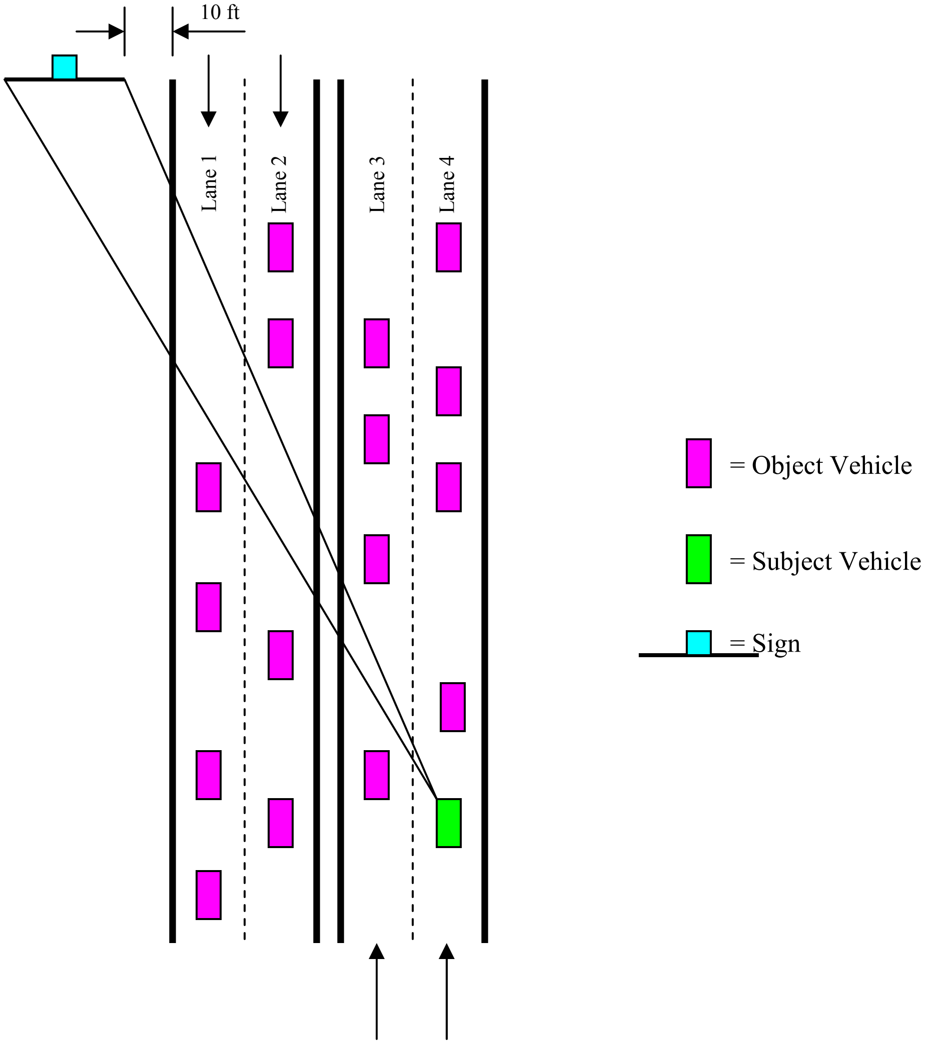

FIGURE 4: Case 4

TABLE 7: Blockage Time of Sign at 35 mph (Subject vehicle in Lane 4:Left Sign)

Flow Rate (vehicles per hour)	Total Available Time (seconds)	Sign Blockage Time (seconds)	Sign Blockage Time (percent)
200	3.899 (380-180)/51.3	1.12	28.64
300	3.899	1.59	40.82
400	3.899	1.95	50.08
500	3.899	2.28	58.57
600	3.899	2.58	66.26
700	3.899	2.80	71.87
800	3.899	2.98	76.34
900	3.899	3.14	80.58
1000	3.899	3.27	83.84
1100	3.899	3.38	86.78
1200	3.899	3.48	89.21

TABLE 8: Blockage Time of Sign at 45 mph (Subject vehicle in Lane 4:Left Sign)

Flow Rate (vehicles per hour)	Total Available Time (seconds)	Sign Blockage Time (seconds)	Sign Blockage Time (percent)
200	4.091 (500-230)/66	1.31	31.92
300	4.091	1.80	43.95
400	4.091	2.22	54.31
500	4.091	2.56	62.47
600	4.091	2.85	69.76
700	4.091	3.08	75.30
800	4.091	3.25	79.36
900	4.091	3.40	83.14
1000	4.091	3.52	86.03
1100	4.091	3.61	88.31
1200	4.091	3.71	90.64

APPENDIX B

ANALYTIC RESULTS

10 FOOT SIGN OFFSET

Summary of Sign Visibility Results using Analytical Approach with 10 ft Sign Offset

Case 1: Subject vehicle in Lane 4 and Sign on the right

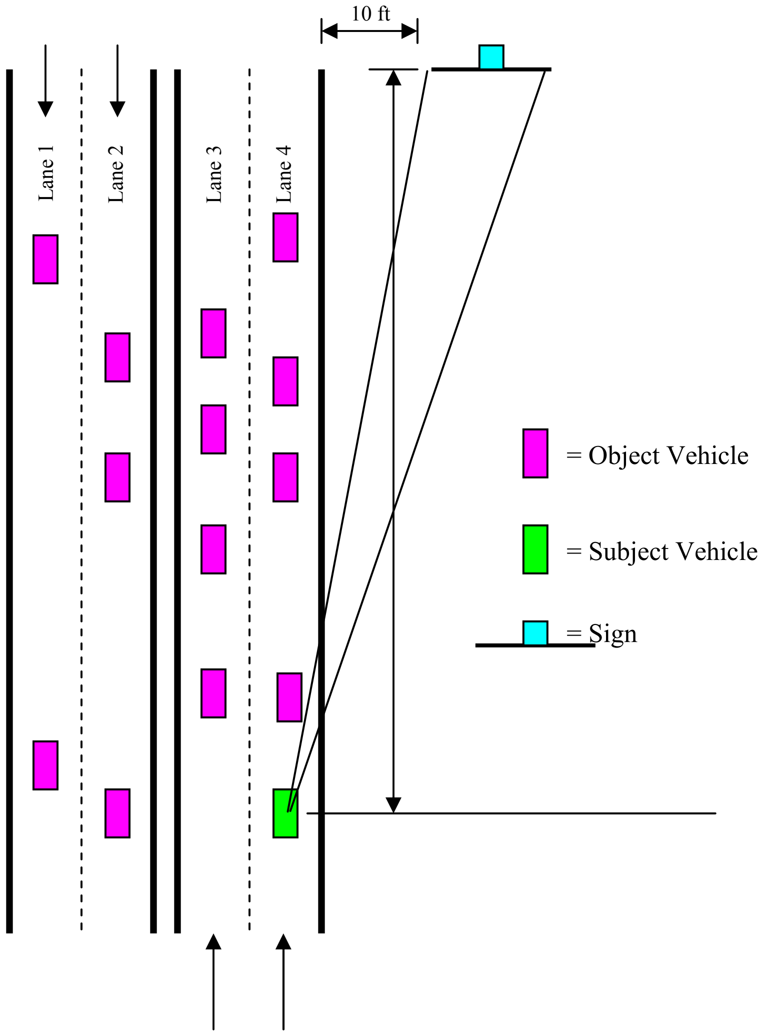

FIGURE 1: Case 1

TABLE 1: Blockage Time of Sign at 35 mph (Subject vehicle in Lane 4:Right sign)

Flow Rate (vehicles per hour)	Total Available Time (seconds)	Sign Blockage Time (seconds)	Sign Blockage Time (percent)
200	3.899 (380-180)/51.3	0.357	9.170
300	3.899	0.523	13.426
400	3.899	0.681	17.478
500	3.899	0.831	21.335
600	3.899	0.974	25.007
700	3.899	1.111	28.504
800	3.899	1.240	31.833
900	3.899	1.364	35.033
1000	3.899	1.481	38.021
1100	3.899	1.593	40.896
1200	3.899	1.700	43.634

TABLE 2: Blockage Time of Sign at 45 mph (Subject vehicle in Lane 4:Right sign)

Flow Rate (vehicles per hour)	Total Available Time (seconds)	Sign Blockage Time (seconds)	Sign Blockage Time (percent)
200	4.091 (500-230)/66	0.363	8.872
300	4.091	0.532	12.999
400	4.091	0.693	16.933
500	4.091	0.846	20.685
600	4.091	0.992	24.261
700	4.091	1.132	27.671
800	4.091	1.265	30.923
900	4.091	1.392	34.024
1000	4.091	1.513	36.982
1100	4.091	1.628	39.803
1200	4.091	1.738	42.493

Case 2: Subject vehicle in Lane 3 and Sign on the right

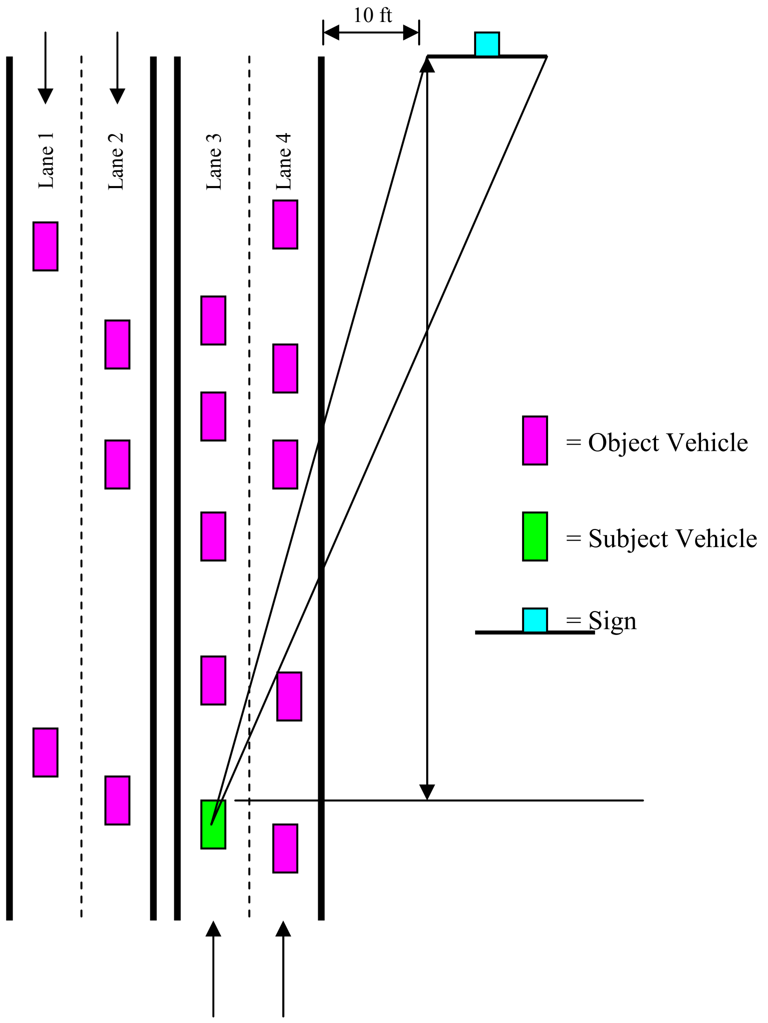

FIGURE 2: Case 2

TABLE 3: Blockage Time of Sign at 35 mph (Subject vehicle in Lane 3:Right Sign)

Flow Rate (vehicles per hour)	Total Available Time (seconds)	Sign Blockage Time (seconds)	Sign Blockage Time (percent)
200	3.899 (380-180)/51.3	0.634	16.274
300	3.899	0.910	23.365
400	3.899	1.163	29.841
500	3.899	1.393	35.757
600	3.899	1.604	41.162
700	3.899	1.796	46.101
800	3.899	1.972	50.616
900	3.899	2.133	54.743
1000	3.899	2.280	58.517
1100	3.899	2.414	61.968
1200	3.899	2.537	65.125

TABLE 4: Blockage Time of Sign at 45 mph (Subject vehicle in Lane 3:Right Sign)

Flow Rate (vehicles per hour)	Total Available Time (seconds)	Sign Blockage Time (seconds)	Sign Blockage Time (percent)
200	4.091 (500-230)/66	0.642	15.705
300	4.091	0.924	22.580
400	4.091	1.181	28.879
500	4.091	1.418	34.651
600	4.091	1.634	39.940
700	4.091	1.832	44.789
800	4.091	2.014	49.235
900	4.091	2.181	53.312
1000	4.091	2.334	57.053
1100	4.091	2.474	60.458
1200	4.091	2.603	63.634

Case 3: Subject vehicle in Lane 3 and Sign on the left

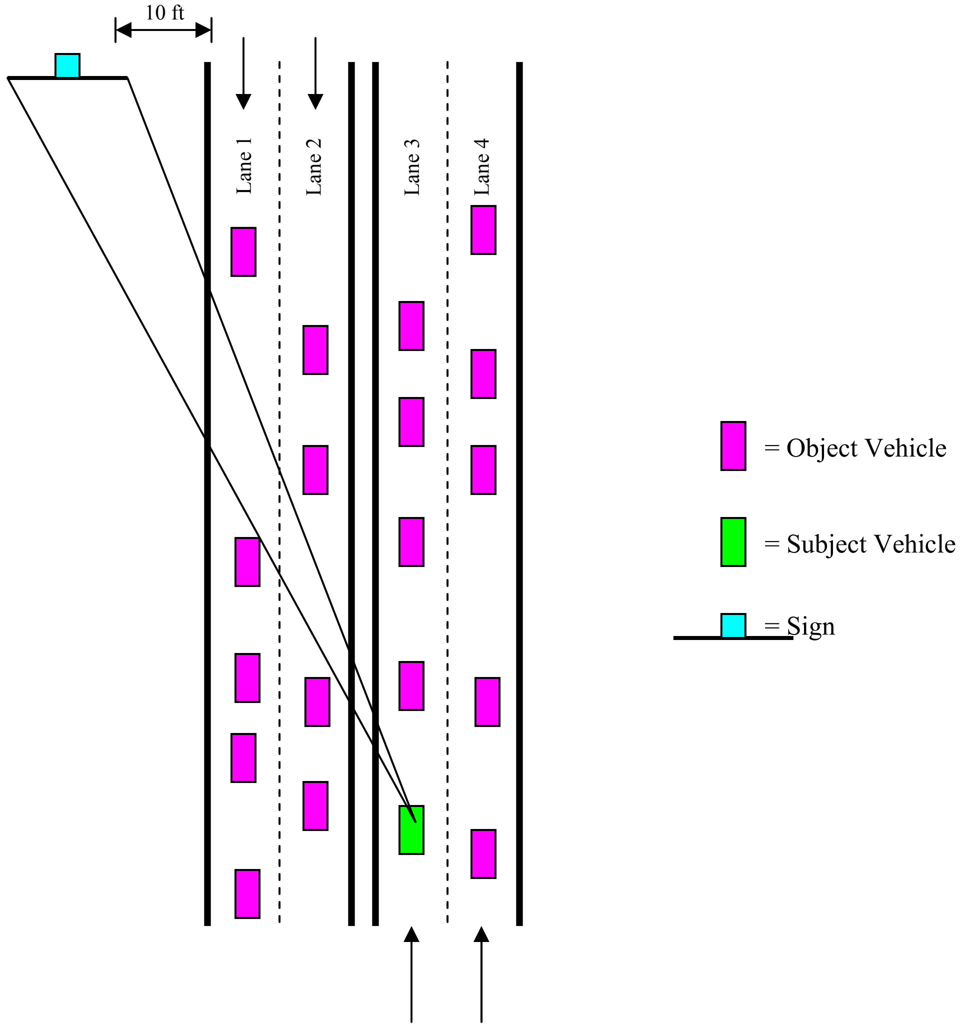

FIGURE 3: Case 3

TABLE 5: Blockage Time of Sign at 35 mph (Subject vehicle in Lane 3:Left Sign)

Flow Rate (vehicles per hour)	Total Available Time (seconds)	Sign Blockage Time (seconds)	Sign Blockage Time (percent)
200	3.899 (380-180)/51.3	0.768	19.709
300	3.899	1.092	28.025
400	3.899	1.382	35.462
500	3.899	1.641	42.114
600	3.899	1.873	48.067
700	3.899	2.080	53.394
800	3.899	2.266	58.164
900	3.899	2.433	62.435
1000	3.899	2.582	66.260
1100	3.899	2.715	69.688
1200	3.899	2.835	72.760

TABLE 6: Blockage Time of Sign at 45 mph (Subject vehicle in Lane 3:Left Sign)

Flow Rate (vehicles per hour)	Total Available Time (seconds)	Sign Blockage Time (seconds)	Sign Blockage Time (percent)
200	4.091 (500-230)/66	0.771	18.837
300	4.091	1.098	26.847
400	4.091	1.393	34.045
500	4.091	1.658	40.518
600	4.091	1.896	46.339
700	4.091	2.110	51.575
800	4.091	2.303	56.287
900	4.091	2.476	60.529
1000	4.091	2.632	64.348
1100	4.091	2.773	67.788
1200	4.091	2.900	70.888

Case 4: Subject vehicle in Lane 4 and Sign on the left

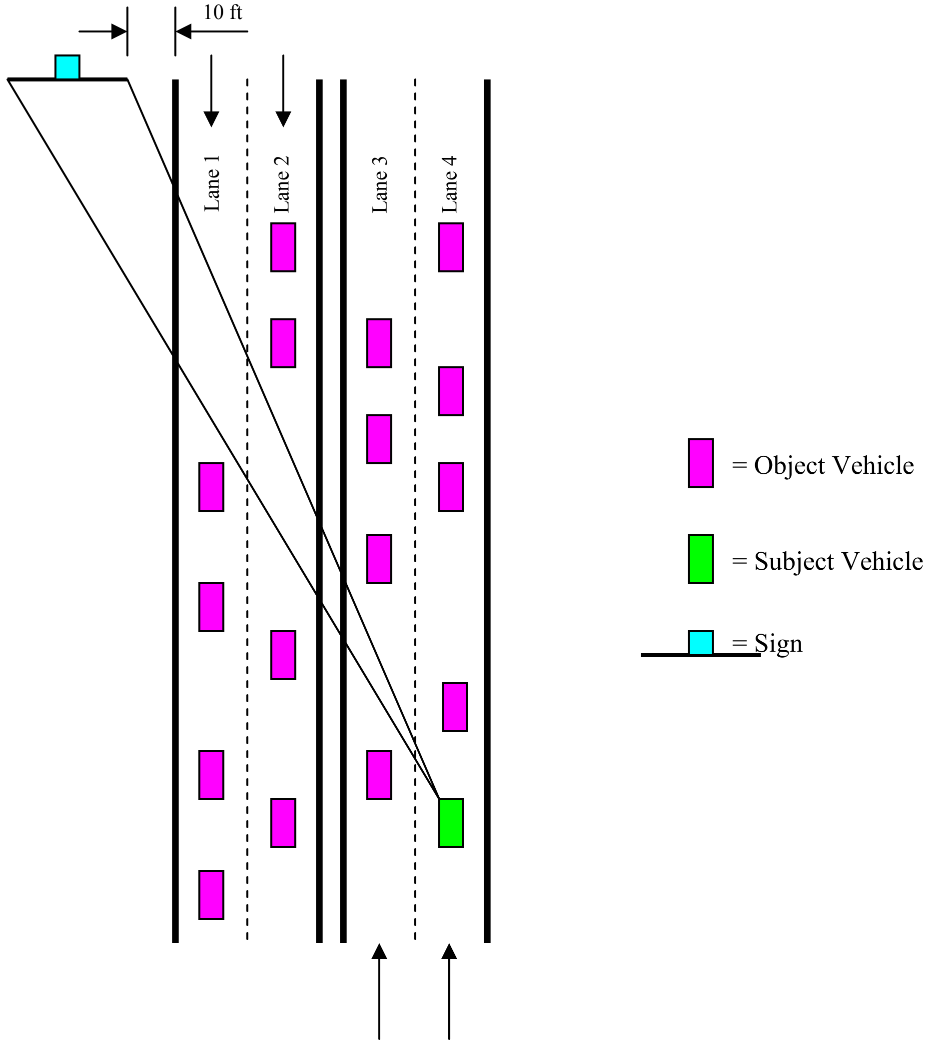

FIGURE 4: Case 4

TABLE 7: Blockage Time of Sign at 35 mph (Subject vehicle in Lane 4:Left Sign)

Flow Rate (vehicles per hour)	Total Available Time (seconds)	Sign Blockage Time (seconds)	Sign Blockage Time (percent)
200	3.899 (380-180)/51.3	0.903	23.186
300	3.899	1.272	32.641
400	3.899	1.594	40.909
500	3.899	1.876	48.144
600	3.899	2.122	54.476
700	3.899	2.338	60.020
800	3.899	2.528	64.876
900	3.899	2.693	69.131
1000	3.899	2.839	72.861
1100	3.899	2.966	76.131
1200	3.899	3.078	79.000

TABLE 8: Blockage Time of Sign at 45 mph (Subject vehicle in Lane 4:Left Sign)

Flow Rate (vehicles per hour)	Total Available Time (seconds)	Sign Blockage Time (seconds)	Sign Blockage Time (percent)
200	4.091 (500-230)/66	0.902	22.041
300	4.091	1.273	31.124
400	4.091	1.601	39.125
500	4.091	1.889	46.174
600	4.091	2.143	52.388
700	4.091	2.367	57.867
800	4.091	2.565	62.700
900	4.091	2.740	66.966
1000	4.091	2.894	70.733
1100	4.091	3.030	74.059
1200	4.091	3.150	77.000

APPENDIX C

ANALYTIC RESULTS

20 FOOT SIGN OFFSET

Summary of Sign Visibility Results using Analytical Approach with 20 ft Sign Offset

Case 1: Subject vehicle in Lane 4 and Sign on the right

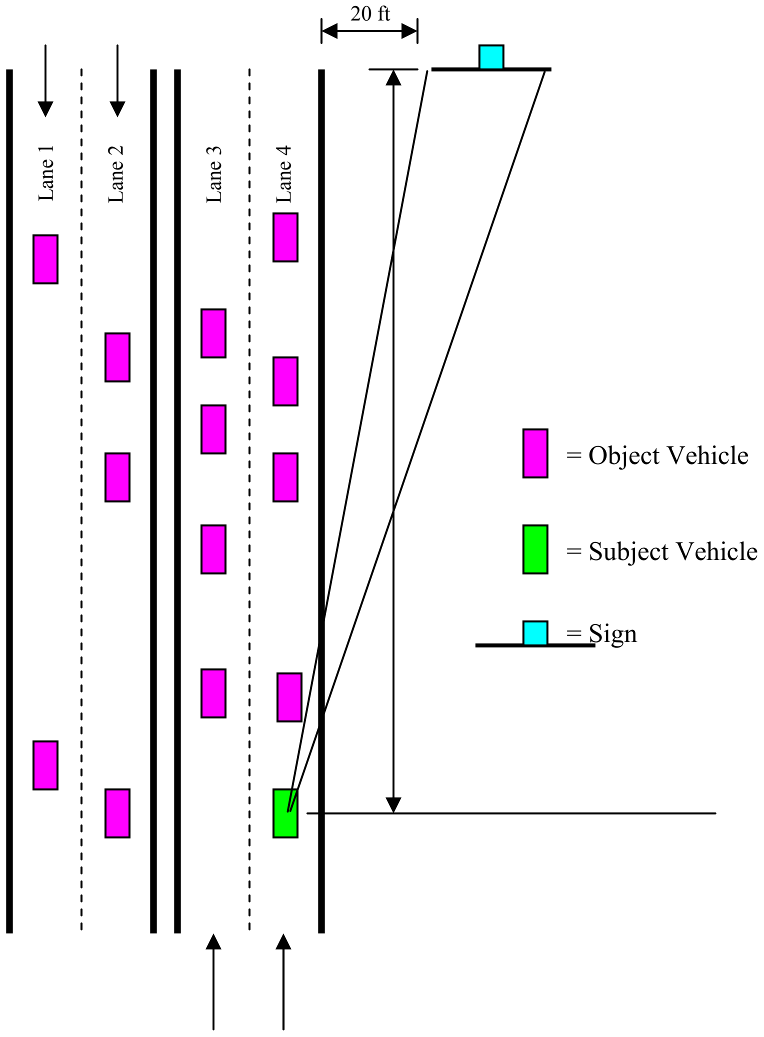

FIGURE 1: Case 1

TABLE 1: Blockage Time of Sign at 35 mph (Subject vehicle in Lane 4:Right sign)

Flow Rate (vehicles per hour)	Total Available Time (seconds)	Sign Blockage Time (seconds)	Sign Blockage Time (percent)
200	3.899 (380-180)/51.3	0.256	6.563
300	3.899	0.377	9.678
400	3.899	0.494	12.687
500	3.899	0.608	15.593
600	3.899	0.717	18.401
700	3.899	0.823	21.113
800	3.899	0.925	23.734
900	3.899	1.023	26.265
1000	3.899	1.119	28.711
1100	3.899	1.211	31.073
1200	3.899	1.300	33.356

TABLE 2: Blockage Time of Sign at 45 mph (Subject vehicle in Lane 4:Right sign)

Flow Rate (vehicles per hour)	Total Available Time (seconds)	Sign Blockage Time (seconds)	Sign Blockage Time (percent)
200	4.091 (500-230)/66	0.254	6.220
300	4.091	0.376	9.180
400	4.091	0.493	12.044
500	4.091	0.606	14.816
600	4.091	0.716	17.497
700	4.091	0.822	20.092
800	4.091	0.925	22.604
900	4.091	1.024	25.034
1000	4.091	1.120	27.386
1100	4.091	1.213	29.662
1200	4.091	1.304	31.866

Case 2: Subject vehicle in Lane 3 and Sign on the right

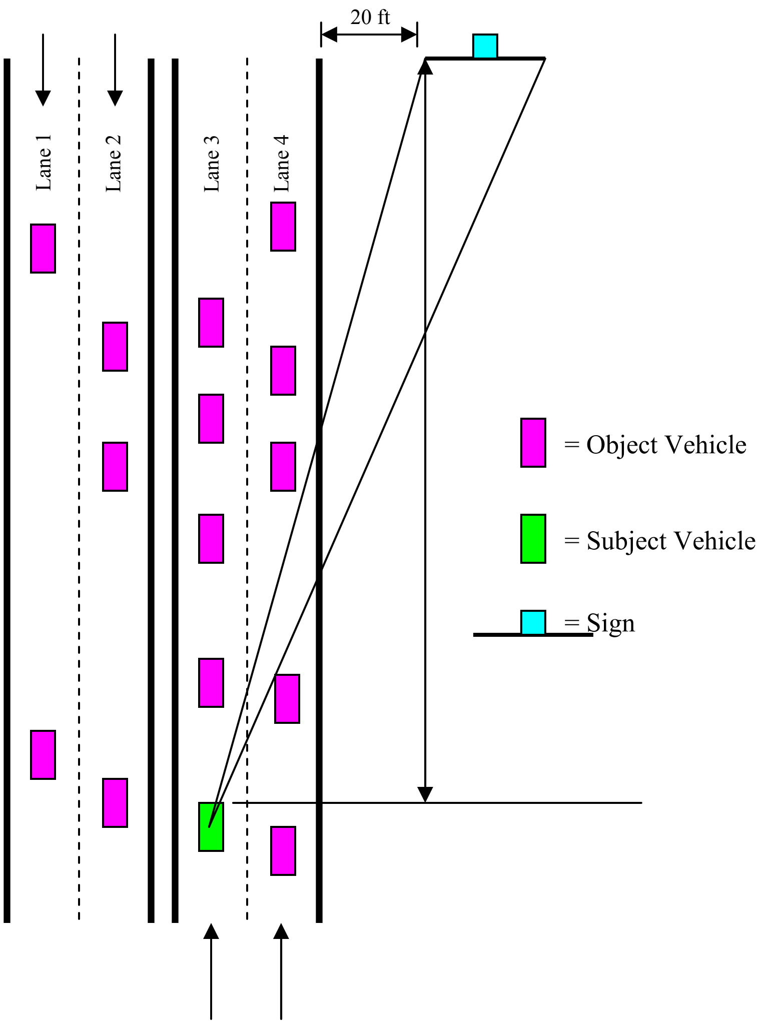

FIGURE 2: Case 2

TABLE 3: Blockage Time of Sign at 35 mph (Subject vehicle in Lane 3:Right Sign)

Flow Rate (vehicles per hour)	Total Available Time (seconds)	Sign Blockage Time (seconds)	Sign Blockage Time (percent)
200	3.899 (380-180)/51.3	0.503	12.913
300	3.899	0.729	18.717
400	3.899	0.940	24.126
500	3.899	1.136	29.168
600	3.899	1.320	33.868
700	3.899	1.490	38.249
800	3.899	1.649	42.334
900	3.899	1.798	46.144
1000	3.899	1.936	49.696
1100	3.899	2.065	53.009
1200	3.899	2.186	56.099

TABLE 4: Blockage Time of Sign at 45 mph (Subject vehicle in Lane 3:Right Sign)

Flow Rate (vehicles per hour)	Total Available Time (seconds)	Sign Blockage Time (seconds)	Sign Blockage Time (percent)
200	4.091 (500-230)/66	0.502	12.275
300	4.091	0.729	17.821
400	4.091	0.941	23.007
500	4.091	1.140	27.858
600	4.091	1.325	32.395
700	4.091	1.499	36.640
800	4.091	1.661	40.611
900	4.091	1.813	44.327
1000	4.091	1.956	47.804
1100	4.091	2.089	51.059
1200	4.091	2.213	54.105

Case 3: Subject vehicle in Lane 3 and Sign on the left

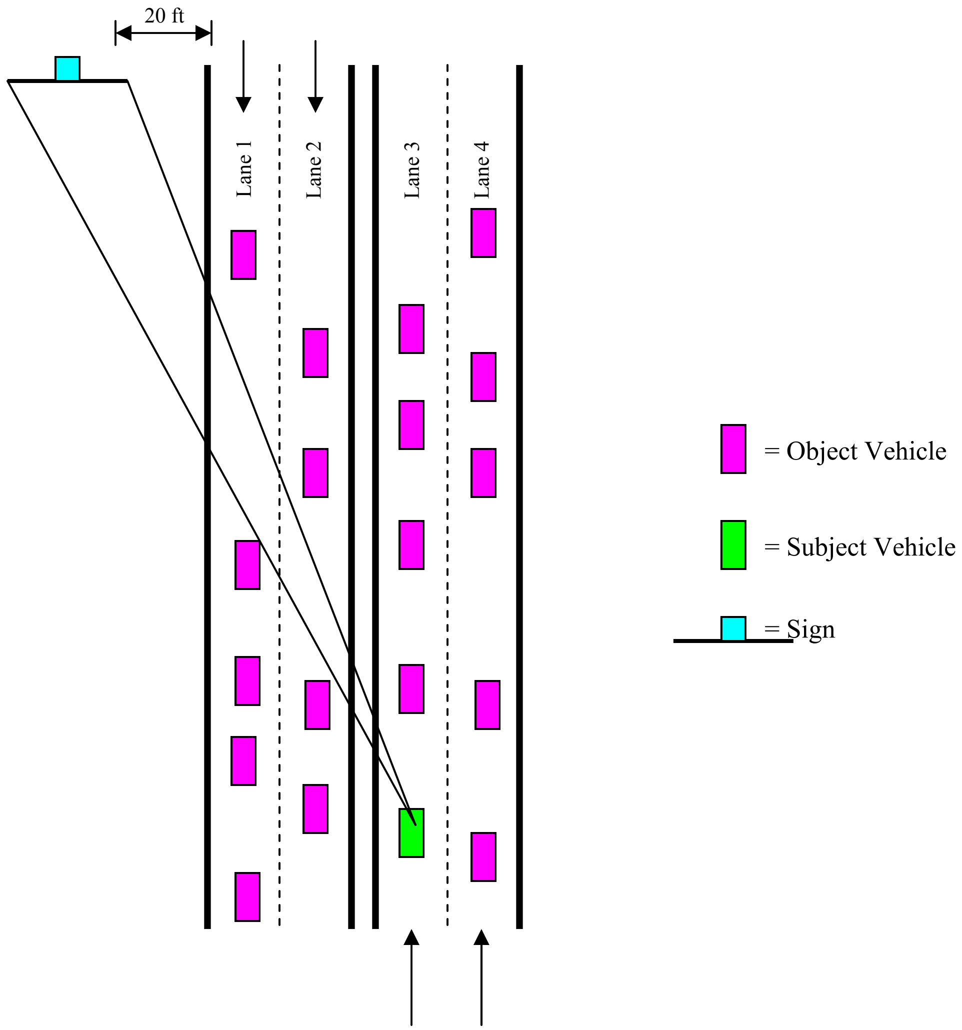

FIGURE 3: Case 3

TABLE 5: Blockage Time of Sign at 35 mph (Subject vehicle in Lane 3:Left Sign)

Flow Rate (vehicles per hour)	Total Available Time (seconds)	Sign Blockage Time (seconds)	Sign Blockage Time (percent)
200	3.899 (380-180)/51.3	0.645	16.543
300	3.899	0.925	23.739
400	3.899	1.181	30.304
500	3.899	1.414	36.294
600	3.899	1.627	41.759
700	3.899	1.821	46.747
800	3.899	1.999	51.300
900	3.899	2.161	55.457
1000	3.899	2.309	59.253
1100	3.899	2.444	62.719
1200	3.899	2.567	65.885

TABLE 6: Blockage Time of Sign at 45 mph (Subject vehicle in Lane 3:Left Sign)

Flow Rate (vehicles per hour)	Total Available Time (seconds)	Sign Blockage Time (seconds)	Sign Blockage Time (percent)
200	4.091 (500-230)/66	0.638	15.593
300	4.091	0.918	22.432
400	4.091	1.174	28.704
500	4.091	1.410	34.458
600	4.091	1.626	39.736
700	4.091	1.824	44.580
800	4.091	2.006	49.025
900	4.091	2.173	53.106
1000	4.091	2.326	56.853
1100	4.091	2.467	60.293
1200	4.091	2.596	63.452

Case 4: Subject vehicle in Lane 4 and Sign on the left

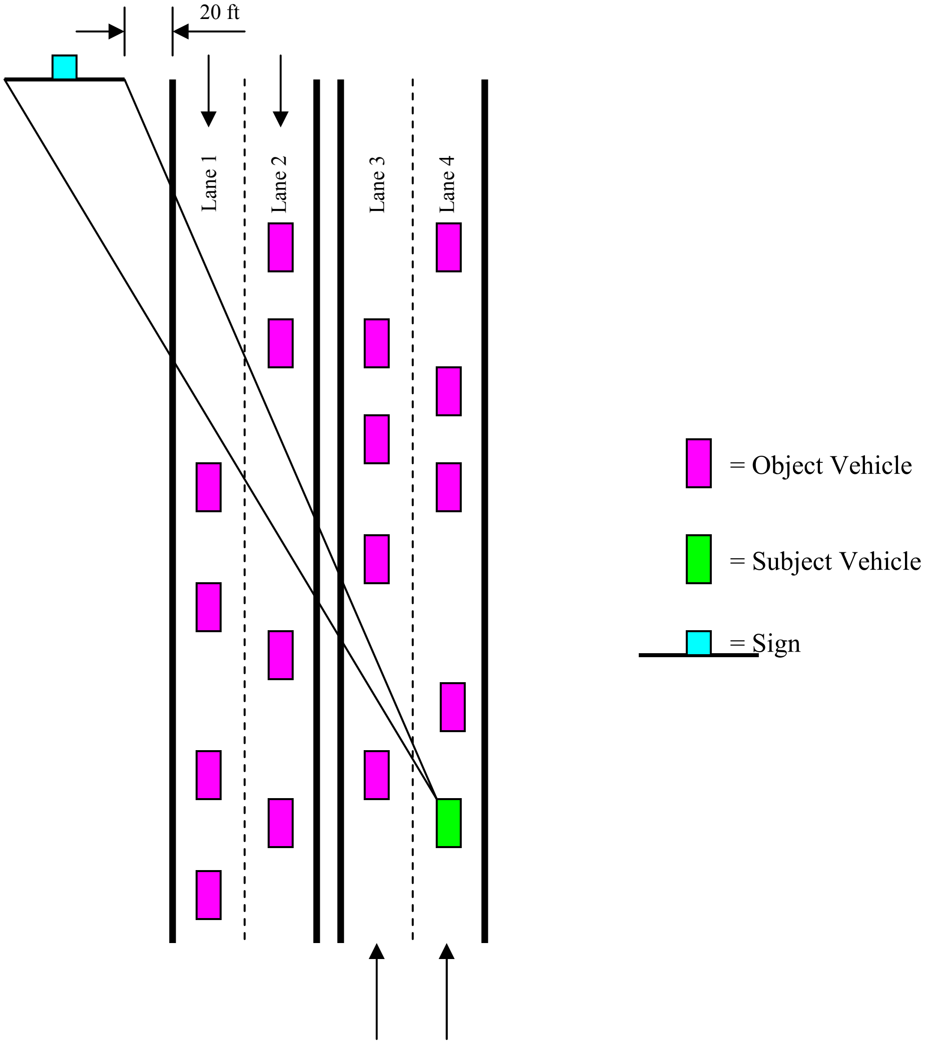

FIGURE 4: Case 4

TABLE 7: Blockage Time of Sign at 35 mph (Subject vehicle in Lane 4:Left Sign)

Flow Rate (vehicles per hour)	Total Available Time (seconds)	Sign Blockage Time (seconds)	Sign Blockage Time (percent)
200	3.899 (380-180)/51.3	0.790	20.278
300	3.899	1.122	28.794
400	3.899	1.418	36.385
500	3.899	1.681	43.153
600	3.899	1.916	49.189
700	3.899	2.126	54.573
800	3.899	2.313	59.378
900	3.899	2.480	63.665
1000	3.899	2.630	67.493
1100	3.899	2.763	70.911
1200	3.899	2.882	73.963

TABLE 8: Blockage Time of Sign at 45 mph (Subject vehicle in Lane 4:Left Sign)

Flow Rate (vehicles per hour)	Total Available Time (seconds)	Sign Blockage Time (seconds)	Sign Blockage Time (percent)
200	4.091 (500-230)/66	0.779	19.050
300	4.091	1.110	27.139
400	4.091	1.407	34.402
500	4.091	1.674	40.927
600	4.091	1.914	46.788
700	4.091	2.130	52.055
800	4.091	2.323	56.790
900	4.091	2.497	61.047
1000	4.091	2.654	64.876
1100	4.091	2.795	68.320
1200	4.091	2.922	71.419