

Modeling the Effect of Heavy Vehicles on Sign Visibility at Multilane Highways

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ABSTRACT

The research presented in this paper is concerned with modeling the occlusion of ground-mounted traffic signs by heavy vehicles on multilane highways. It is part of a more extensive research effort to examine the different factors that determine the effect of heavy vehicles on the visibility of traffic signs. An analytical tool was developed where road geometry, traffic sign, and moving entities are simulated over space at any point in time. This tool dynamically models the movement and location of passenger cars and trucks on the facility upstream of the subject traffic sign and verifies the continuity of sightline between the subject driver and traffic sign. Besides roadway and sign geometry, the model accounts for other traffic conditions such as traffic level, percentage of trucks, lane utilization, and average speeds of passenger cars and trucks. The occlusion of ground-mounted traffic signs by heavy vehicles is estimated using two measures. The first measure is the probability of a traffic sign being occluded by heavy vehicles under certain traffic and geometric conditions. The second measure estimates 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.

Keywords: ground-mounted signs, visibility, occlusion, heavy vehicles, simulation

1. INTRODUCTION

Despite their smaller proportion of vehicular traffic, heavy vehicles are known for their impacts on the traffic stream. One important impact on traffic safety is the occlusion of ground-mounted traffic signs by heavy vehicles due to their large dimensions and occupation of the rightmost lane(s). This negative impact of heavy vehicles is believed to be only minimal for signs that are installed using overhead or cantilever structures. Therefore, the Manual on Uniform Traffic Control Devices (MUTCD), the national guide for the design, use, and placement of traffic signs, refers to the percentage of trucks as one of the conditions where the use of overhead signs should be considered. However, it also states: “the factors to be considered for the installation of overhead sign displays are not definable in specific numerical terms” (1) and leaves much of this decision to engineering judgment. There is no guidance in the current practice as to when ground-mounted traffic signs become inadequate due to the impact of larger vehicles on sign visibility, thus justifying the use of overhead or cantilever signs. Logically, the first step in developing such guidance would be to assess the effect of heavy vehicles on sign visibility under different traffic, geometric, and sign design variables.

The ultimate objective of this research is to explore and assess the effect of the different traffic, geometric, and sign design variables on the occlusion of ground-mounted signs by heavy vehicles. However, this paper is mainly concerned with developing a simulation model to assess this effect. While the model was developed primarily to investigate the effect of heavy vehicles on sign visibility, it is equally applicable to other situations where driver’s sightline is obstructed by any other object.

2. PREVIOUS RESEARCH

The literature search revealed that there is very little information in the literature that addresses the issue of sign visibility as related to the presence of heavy vehicles in the traffic stream.

Abramson (2) developed a mathematical formulation of the problem that addressed the occlusion of signs when a passenger car and a heavy vehicle happen to exist within the area of legibility upstream of the traffic sign. The study modeled the geometry of the problem based on the shadow created by heavy vehicle(s) and derived probabilities for the passenger car being in the shadow, outside the shadow, or both. While this formulation focused on the geometry of the problem, it gave minimal consideration to different traffic conditions and their effects on sign occlusion.

Another study by Ullman and Dudek (3) provided an analytical approach to assess the potential impacts of vertical curves, horizontal curves, and heavy vehicles on Variable Message Sign (VMS) readability. The analyses were mainly based on the premise that each of these factors can significantly limit the distance at which a VMS can be read. This in turn translates into shorter available reading times and the need to display a shorter message with fewer units of information.

The literature survey found no other studies that investigated the effect of larger vehicles on sign visibility, however, several other studies were identified that are related, in one way or another, to this investigation and therefore are briefly discussed in this section.

A study sponsored by the Ohio Department of Transportation (ODOT) investigated the occlusion effect of vehicles on the accuracy of a low cost, non-intrusive, lane-monitoring system called “Off Road Axle Detector Sensor (ORADS)” (4). This system is used to measure and classify vehicular traffic over multiple lane roadways. The source of occlusion was that, in using a single laser beam directed across a multiple lane highway, the vehicle in the lane closest to the laser source may mask or occlude the axle(s) of the vehicle(s) in the subsequent lane(s). The study found that the occlusion effect, while impacts the accuracy of the system, was still within acceptable limits.

Another study by Yung et al. (5) examined a vehicle occlusion detection algorithm that can be used with Visual Traffic Surveillance (VTS) technology typically used to identify and track the

movement of vehicles. The study confirmed that the proposed algorithm was effective in detecting vehicle occlusion thus increasing the accuracy of these traffic surveillance techniques.

3. OCCLUSION OF SIGNS BY HEAVY VEHICLES: IMPORTANT VARIABLES

Many variables are believed to affect the occlusion of ground-mounted traffic signs by heavy vehicles, and therefore should be accounted for in modeling this effect. These variables are either related to traffic conditions or variables that define the geometry of the problem and they include:

- Legibility distance: this is the maximum distance along the driver's sightline from the subject traffic sign where the driver is able to read the sign. It is mainly a function of sign design (e.g. letter size, font, color contrast, etc) and human vision characteristics particularly vision acuity.
- Divergence angle θ : this is the angle between the driver's sightline and the centerline of the lane where the passenger car travels.
- Legibility zone: this is an imaginary zone upstream of the subject traffic sign where the passenger car driver is able to read the sign. This zone is delineated by the legibility distance along the driver's sightline (upstream) and the line that represents the maximum divergence angle θ (downstream). This zone is represented by the shaded area in Figure 1.
- Speed of passenger car: this variable determines the time spent by the passenger car within the legibility zone described in (3) above.
- Relative speed between passenger car and truck(s) in the adjacent lane: this variable affects the time during which driver's sightline is obstructed by the heavy vehicle(s).
- Location of truck(s) relative to the passenger car driver when the latter arrives at the legibility zone: this variable also affects the time during which driver's sightline is obstructed by the heavy vehicle(s).
- Lateral offset: this is the distance between the subject traffic sign and the outer edge of the traveled lanes
- Length of heavy vehicle(s)
- Hourly traffic volume that represents vehicle count during the hour of interest.
- Percentage of trucks in the traffic mix
- Lane utilization factors that represent the distribution of trucks over the traveled lanes.

4. MODEL DEVELOPMENT

4.1. Model Requirements

The proposed model should fulfill certain requirements in order to be able to assess the occlusion of ground-mounted signs by heavy vehicles. These requirements are:

1. Ability to dynamically model the movement and location of passenger cars and trucks on the facility upstream of the subject traffic sign and the continuity of sightline between the passenger car driver and the sign
2. Ability to model traffic variables that are relevant to the occlusion of signs by trucks such as; traffic volume, the percentage of heavy vehicles in a traffic mix, and the distribution of heavy vehicles on the traveled lanes

3. Ability to model variables that define the geometry of the problem such as lateral distance of sign placement, legibility distance, relative location of truck(s) with respect to the passenger car, etc.

4.2. Proposed Model: Main Assumptions

To simplify complex real-world phenomena, assumptions are often made in almost all theoretical models. The most important assumptions that underlie the proposed occlusion model involve:

1. The driver of passenger car is fully attentive, i.e. no distraction of any kind within the legibility zone
2. Passenger cars and trucks travel at constant speeds, i.e. no acceleration or deceleration within the legibility zone
3. No lane changing occurring within the legibility zone
4. Tangent highway segment

4.3. Model Description

The proposed model assesses the occlusion of ground-mounted traffic signs by heavy vehicles traveling in any of the adjacent right lane(s). Specifically, the model estimates two measures in assessing the amount of occlusion under certain traffic, geometric, and sign design variables. The first is the absolute probability of the subject traffic sign being occluded by heavy vehicle(s) while the second is the probability of a passenger car driver missing the subject traffic sign.

The proposed model consists of the following three components:

1. Sub-model I: this sub-model is concerned with modeling the amount of occlusion caused by one or more heavy vehicles that happen to be in the legibility zone upstream of the subject traffic sign
2. Sub-model II: this sub-model is concerned with modeling the probability of having one or more heavy vehicles within the legibility zone of the subject traffic sign
3. Sub-model III: this sub-model estimates the two measures of occlusion mentioned above using results from sub-models I & II

Each component (sub-model) is discussed in detail in the following sections. In those discussions, trucks and heavy vehicles are used interchangeably to refer to vehicles with larger dimensions.

4.3.1. Sub-Model I

This sub-model estimates the probability of a sign being occluded by heavy vehicle(s) and the probability of a passenger car driver missing the subject traffic sign during the time when there is one or more heavy vehicles within the legibility zone. The flow chart shown in Figure 2 explains the main processes performed in this sub-model.

As shown in this flow chart, sub-model 1 updates the location of passenger car and heavy vehicle(s) on the traveled lanes within the legibility zone and evaluates the continuity of sightline between the passenger car driver and the sign every deci-second. This is done by determining the points of intersection of the driver's sightline with the two planes that represent the left and right sides of the heavy vehicle(s), and comparing these points with points that represent the area occupied by heavy vehicle(s) at any time t . The model utilizes a binary variable that represents the status of the continuity of sightline at any time t . The model then calculates the amount of time when occlusion is in effect during the total

duration when the passenger car traverses the legibility zone. Finally, by estimating the minimum time required to read the sign, this sub-model determines the probability of a passenger car driver missing the subject traffic sign when the legibility zone is occupied by one or more heavy vehicles.

From the geometry of Figure 3 and assuming that the passenger car driver position is at a distance of two thirds lane width from the right side of the lane

$$Y = \left(\frac{W_s}{2} + W_{lo} + \frac{5}{3}W_l \right)$$

$$Y_1 = Y - \left(\frac{W_s}{2} + W_{lo} + \left(\frac{W_l}{2} + \frac{W_{hv}}{2} \right) \right)$$

$$Y_{11} = Y - \left(\frac{W_s}{2} + W_{lo} + \left(\frac{W_l}{2} - \frac{W_{hv}}{2} \right) \right)$$

Where:

- W_s = Sign width
- W_{lo} = Lateral offset
- W_l = Lane width
- W_{hv} = Width of heavy vehicle

Assuming S_{pc} as the average speed of the passenger car, T_{lz} as the time required for the passenger car to traverse the legibility zone, and D_{leg} as the legibility distance, then

$$D_1 = T_{lz} \times S_{pc} \dots\dots\dots(1)$$

$$D_2 = Y \cot \theta \dots\dots\dots(2)$$

$$X = D_1 + D_2 = \sqrt{(D_{leg})^2 - (Y)^2} \dots\dots\dots(3)$$

Substituting equations 1 and 2 into 3 and solving for T_{lz}

$$T_{lz} = \frac{\sqrt{(D_{leg})^2 - (Y)^2} - Y \cot \theta}{S_{pc}}$$

To find the coordinates $X_{1(t)}$ and $X_{11(t)}$, the distance traveled by passenger car at time t upon entering the legibility zone ($D_{pc(t)}$) can be expressed as

$$D_{pc(t)} = S_{pc} \times t$$

Distance between points J and C (D_{JC}) at any time t can be expressed as

$$D_{JC} = X - S_{pc} \times t$$

From the similar triangles $\triangle JCM$ and $\triangle KDM$

$$X_{1(t)} = X - \left[\left(\frac{D_{JC}}{Y} \right) (Y - Y_1) \right] = X - \left[\left(\frac{X - S_{pc} \times t}{Y} \right) (Y - Y_1) \right]$$

Also, from the similar triangles $\triangle JCM$ and $\triangle LEM$

$$X_{11(t)} = X - \left[\left(\frac{X - S_{pc} \times t}{Y} \right) (Y - Y_{11}) \right]$$

From the similarity of $\triangle BCM$ and $\triangle FEM$ shown in Figure 3, X_2 can be expressed as

$$X_2 = \left(\frac{D_2}{Y} \right) (Y - Y_{11}) \dots\dots\dots(4)$$

Also, from the similarity of $\triangle ACM$ and $\triangle GDM$, D_3 can be expressed as

$$D_3 = \left[\left(\frac{D_1 + D_2}{Y} \right) (Y - Y_1) \right] - X_2 \dots\dots\dots(5)$$

Substituting X_2 from equation 4 into equation 5

$$D_3 = \left[\left(\frac{D_1 + D_2}{Y} \right) (Y - Y_1) \right] - \left(\frac{D_2}{Y} \right) (Y - Y_{11})$$

To find the distances D_4 and D_5

$$D_4 = D_3 + L_{hv}$$

$$D_5 = D_1 + D_2 - D_3 - X_2$$

The distance traveled by the heavy vehicle at time t after entering the legibility zone ($D_{hv(t)}$) is

$$D_{hv(t)} = S_{hv} \times t$$

If the position of the heavy vehicle at the moment the passenger car arrives at the legibility zone is at a distance equivalent to $n\%$ of D_4 , $X_{f(t)}$ and $X_{b(t)}$ at time t can be expressed as:

$$X_{f(t)} = D_5 + \frac{n}{100} D_4 + S_{hv} \times t$$

$$X_{b(t)} = X_{f(t)} - L_{hv} = D_4 + \frac{n}{100} D_5 + S_{hv} \times t - L_{hv}$$

IF $X_{b(t)} < X_{1(t)} < X_{f(t)}$ OR $X_{b(t)} < X_{11(t)} < X_{f(t)}$, Then occlusion is in effect, i.e. the driver's sightline is obstructed by the heavy vehicle. Otherwise, the sightline is clear and not obstructed.

The continuity of the sightline is checked every deci-second until the passenger car leaves the legibility zone. The time during which occlusion was in effect (T_{occ}) is then determined by adding the time during which the sightline is obstructed.

Time available to read the sign T_a is

$$T_a = T_{lz} - T_{occ}$$

The percentage of time when occlusion is in effect (one form of probability) for a specific position of heavy vehicle (i) is

$$P_{occ(i)} = \frac{T_{occ(i)}}{T_{lz}} \times 100$$

The average speed of the passenger car, the relative speed of heavy vehicle(s) with respect to the passenger car, and the legibility distance (mainly a function of legend size) are user-specified. These variables can reasonably be estimated for the situation at hand. However, the location of heavy vehicle(s) relative to the passenger car at the moment when the passenger car arrives at the legibility zone was treated differently by the model. While this variable is a major determinant of the amount of occlusion for a particular scenario, it has no meaning nor typical values in current practice. The variable is fully random and therefore cannot be estimated by users.

It is logical to believe that the probability of a heavy vehicle being located at any point within the legibility zone (at the moment when passenger car arrives at the zone) is equal. The main reason behind this logic is that the passenger car and the heavy vehicle(s) travel on two separate lanes. Consequently, a heavy vehicle could be present at any point within the legibility zone when the passenger car arrives at the zone. Therefore, the model estimates the occlusion for a particular situation by considering many values of this variable within the legibility zone and averaging the amount of occlusion. Specifically, the model divides a range equivalent to the distance within the legibility zone along the centerline of the heavy-vehicle lane plus one heavy vehicle length into small equal increments (divisions) and evaluates occlusion when the position of truck front end is located at any of these increments. The amount of occlusion for that particular situation is then estimated by determining the mean value of occlusion from all these different scenarios.

$$P_{occ} = \frac{\sum_{i=1}^n P_{occ(i)}}{n}$$

The increment used in this model is equivalent to one hundredth of the distance mentioned earlier (n=100). This means that for a particular situation at hand, the program runs 100 different scenarios and finds the average occlusion. Figure 4 shows a schematic diagram that explains the treatment of this variable in sub-model I.

Also, the probability of a passenger car driver missing the sign P_m is found by estimating the minimum time required to read the sign (T_{min}). T_{min} is mainly a function of the number of words and symbols in a particular sign and can be estimated using several theoretical models.

For each relative position of truck, the model determines whether the passenger car driver is able to read the sign by comparing T_a to T_{min} . If T_a is less than T_{min} , then the passenger car driver will miss the sign ($P_{m(i)}=1$), otherwise, he will be able to read the sign ($P_{m(i)}=0$). The model used a binary variable ($P_{m(i)}$) to represent the two possibilities. The model then estimates the probability of a passenger car driver missing the sign by dividing the number of scenarios when $P_{m(i)}=1$ by the total number of scenarios (n).

$$P_m = \frac{\sum_{i=1}^n P_{m(i)}}{n}$$

Similar logic is used to check the continuity of sightline when multiple trucks happen to occupy the legibility zone. The model updates the location of the trucks every deci-second and compare the coordinates of the points of intersection ($X_{1(t)}$ & $X_{11(t)}$) with the coordinates that represent the location of each truck within the legibility zone.

Although, in theory, a passenger car could interact with three or more trucks within the legibility zone, experiments showed that such an interaction is not likely given the typical values for legibility distance and speeds of passenger cars and trucks. Specifically, experiments showed that the amount of occlusion when two trucks occupied the legibility zone did not change when a third truck was introduced after the first two trucks. Furthermore, it was found that when the speed differential between passenger car and trucks was relatively small, the effect of the second truck was generally insignificant. This means that, as far as the occlusion is concerned, a passenger car can have interaction with up to two trucks that happen to occupy the legibility zone.

In the scenario of two trucks occupying the legibility zone, the model establishes a range of distance headway between the two trucks. This range is defined by the minimum distance headway and the distance D_4 described earlier. The minimum headway is estimated using the Forbe's car-following theory (12) which has the following formula:

$$d_{min} = 1.5 \left[S_l \dot{(t)} \right] + L_n$$

Where,

d_{min} = Minimum distance headway

$S_1(t)$ = Speed of lead vehicle (ft/sec) at any time t
 L_n = Length of lead vehicle (ft)

The model then divides the range into 25-ft distance intervals, evaluates occlusion for each interval, and calculates the average occlusion. The two measures P_{occ} and P_m are estimated for this scenario by this sub-model.

4.3.2 Sub-model II

Having estimated the amount of occlusion when one or more heavy vehicles occupy the legibility zone, it is important to know the likelihood of this event taking place for a particular sign under certain traffic and geometric conditions. This likelihood is mainly a function of traffic demand, the proportion of heavy vehicles in the traffic mix, and its distribution over the traveled lanes. Using these variables, the number of heavy vehicles on a particular lane expressed as hourly volume can be determined using the following formula:

$$N_{hv(lanei)} = V \times P_{hv} \times LaneUtilizationFactor$$

Where V is total traffic volume measured in vph and P_{hv} is the proportion of heavy vehicles in the traffic mix.

The probability of legibility zone being occupied by one or more heavy vehicles can be determined from the amount of time this zone is occupied by one or more heavy vehicles and the total amount of time elapsed (3600 seconds for hourly volume).

Theoretically, each truck occupies the legibility zone for an amount of time determined by its speed, distance along the lane centerline within the legibility zone, and its length. If each truck would occupy the zone individually, then the total time the legibility zone is occupied can be estimated from the number of heavy vehicles on that particular lane and the time it takes a heavy vehicle to traverse and completely clear the legibility zone. However, in real life, the legibility zone may be occupied by more than one truck and this possibility should be accounted for in determining the total time the legibility zone is occupied by heavy vehicles.

The logic used in this model classifies the event of truck(s) occupying the legibility zone into two types; individual events and overlapped events. Individual events refer to situations where only one truck occupies the zone at a time. On the other hand, overlapped events refer to situations where two or more trucks occupy the zone at the same time, i.e. when there is time overlap between two successive events. The space-time diagram in Figure 5 illustrates the two types of events. The model estimates the percentage of time the legibility zone is occupied by individual events and overlapped events individually.

Individual events occur when the headway between two successive trucks is equal to or greater than the time required to traverse a distance within the legibility zone along the path of the truck plus one truck length (t_{D4}). In these events, the leading truck clears the legibility zone before the following truck enters the zone. Similarly, overlapped events occur when the headway between two successive trucks is smaller than t_{D4} . In these events, the following truck enters the legibility zone before the leading truck clears the zone. The time overlap between two successive trucks is equivalent to $t_{D4}-h$, and hence the time duration of that overlapped event (two-truck scenario) is $t_{D4}+h$, which is equivalent to $2t_{D4}-(t_{D4}-h)$. Similarly, for multiple successive trucks with short headways, the time duration for the overlapped event becomes $t_{D4}+\Sigma h$.

The shifted negative exponential distribution was utilized to model headways between successive heavy vehicles assuming that arrivals are fully random. The shift in the negative exponential distribution represents the minimum headway between two successive heavy vehicles.

$$P(h \geq t) = e^{-\lambda(t-\alpha)}$$

Where

$$\alpha = h_{\min} \quad (\text{minimum headway})$$

$$\lambda = \frac{1}{h_{ave} - \alpha}$$

Therefore, the frequency of headways that are equal or greater than t is:

$$F(h \geq t) = N_{hv(lanei)} \times P(h \geq t) \dots\dots\dots(6)$$

Figure 6 shows a flow chart that illustrates the processes involved in sub-model II. As shown in this figure, this sub-model estimates the probability of a headway being greater or equal to t_{D4} . Based on this probability, and by using the total number of heavy vehicles on a particular lane $N_{hv(lanei)}$, the model calculates the number of individual events and overlapped events.

Using equation 6, the number of individual events can be determined as follows:

$$F(h \geq t_{D4}) = N_{hv(lanei)} \times P(h \geq t_{D4})$$

Similarly, the total number of overlapped events can be determined:

$$F(h < t_{D4}) = N_{hv(lanei)} \times P(h < t_{D4})$$

Where:

$$P(h < t_{D4}) = 1 - P(h \geq t_{D4})$$

The model then calculates the percentage of time the legibility zone is occupied by heavy vehicles on that particular lane both for individual as well as overlapped events. For individual events, the model determines the amount of time using the following formula

$$T_{hv(i)} = [F(h \geq t_{D4}) - F_{hv(lead)}] \times t_{D4}$$

Where $F_{hv(lead)}$ is the number of lead trucks that precedes one or more short headways (overlapped events). In the equation above, $F_{hv(lead)}$ was deducted from the number of individual events as the leading truck in an overlapped event was modeled jointly with the following truck as described in sub-model I (multiple truck scenario). This number is dependent on the succession of headways that are

smaller than t_{D4} . Using a Monte Carlo type of simulation, the model generates random headways based on the shifted negative exponential distribution and finds the value of $F_{hv(lead)}$. To account for random fluctuation, the model repeats this process ten times and determines the average value for $F_{hv(lead)}$ to be used in the previous equation.

The percentage of time legibility zone is occupied by individual events is then calculated

$$T_{per(i)} = \frac{T_{hv(i)}}{3600} \times 100$$

For overlapped events, the time for a single event is variable as it is a function of the headway between the leading and the following trucks. The model establishes a range between the minimum and maximum headways for overlapped events. As in sub-model I, the minimum headway is estimated using Forbe's car-following theory (12). The maximum headway is represented by t_{D4} . If the headway falls within this range, then an overlapped event will take place. This range is then divided into one deci-second intervals where the probability of a headway being in each interval is calculated using the following formula:

$$P(t_1 \leq h < t_2) = P(h \geq t_1) - P(h \geq t_2)$$

The frequency of headways in each interval becomes equal to

$$F(t_1 \leq h < t_2) = N_{hv(lanei)} \times [P(t_1 \leq h < t_2)]$$

The model then calculates the amount of time the legibility zone is occupied by overlapped events $T_{hv(o)}$ using the following formula

$$T_{hv(o)} = \left[\sum_{i=1}^n F_i \times h_i \right] + F_{hv(lead)} \times t_{D4}$$

Where:

- $T_{hv(o)}$ = Total time for overlapped events (seconds)
- F_i = Frequency of headways for interval i
- h_i = Average headway for interval i (seconds)
- $F_{hv(lead)}$ = Number of lead trucks in overlapped events

Finally, the percentage of time the legibility zone is occupied by overlapped events is

$$T_{per(o)} = \frac{T_{hv(o)}}{3600}$$

4.3.3. Sub-model III

This is the last step in the analysis where the outputs from sub-models I & II are used to estimate two measures: the first is the absolute probability of a traffic sign being occluded by heavy vehicles while the

second is the likelihood of a passenger car driver missing the sign. Figure 7 illustrates the main processes involved in this sub-model.

To find the first measure, the percentage of time for individual events ($T_{per(i)}$) and the percentage of time for overlapped events ($T_{per(o)}$) are multiplied by the amount of occlusion found from sub-model I. This probability is expressed as

$$P_1 = T_{per(i)} \times P_{occ(i)} + T_{per(o)} \times P_{occ(o)}$$

Also, the absolute probability of a passenger car driver missing the sign is estimated by this sub-model as

$$P_2 = T_{per(i)} \times P_{m(i)} + T_{per(o)} \times P_{m(o)}$$

5. SIGNIFICANCE OF THE PROPOSED MODEL

The model presented in this paper was originally developed to assess the effect of heavy vehicles on the visibility of ground-mounted traffic signs. This assessment is essential to:

- Identify the factors that significantly affect the occlusion of ground-mounted traffic signs by heavy vehicles
- Develop design guidelines for selecting the type of sign installation as related to the effect of heavy vehicles on sign visibility. These guidelines are particularly important for facilities where the use of overhead signs due to geometric considerations is not very likely (such as four- and six-lane freeways).
- Test different strategies that are intended to improve the visibility of ground mounted traffic signs by minimizing the occlusion effect of heavy vehicles

While the model was developed primarily to investigate the effect of heavy vehicles on sign visibility, it is equally applicable to other situations where driver's sightline is obstructed by any other object.

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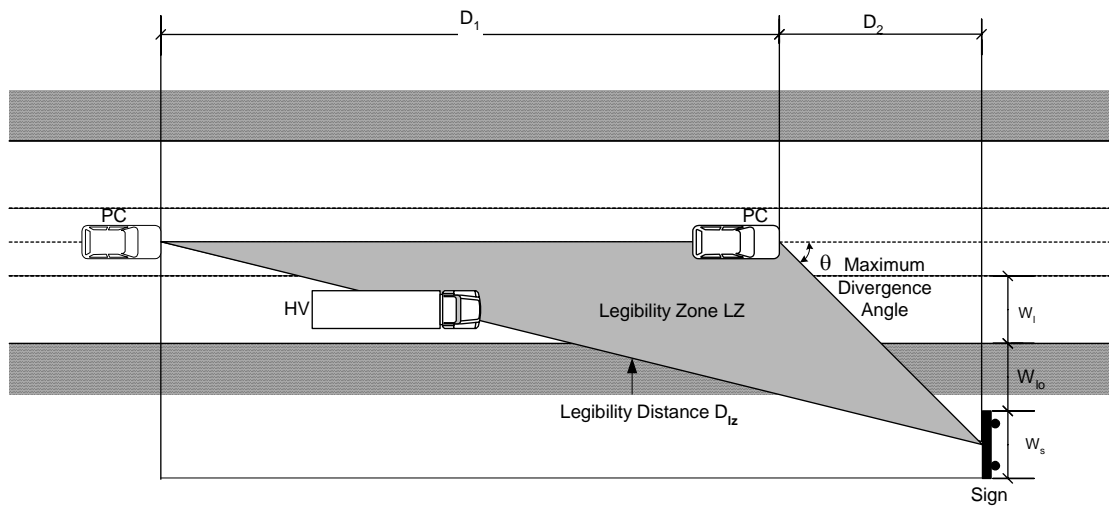


FIGURE 1 Legibility distance and legibility zone.

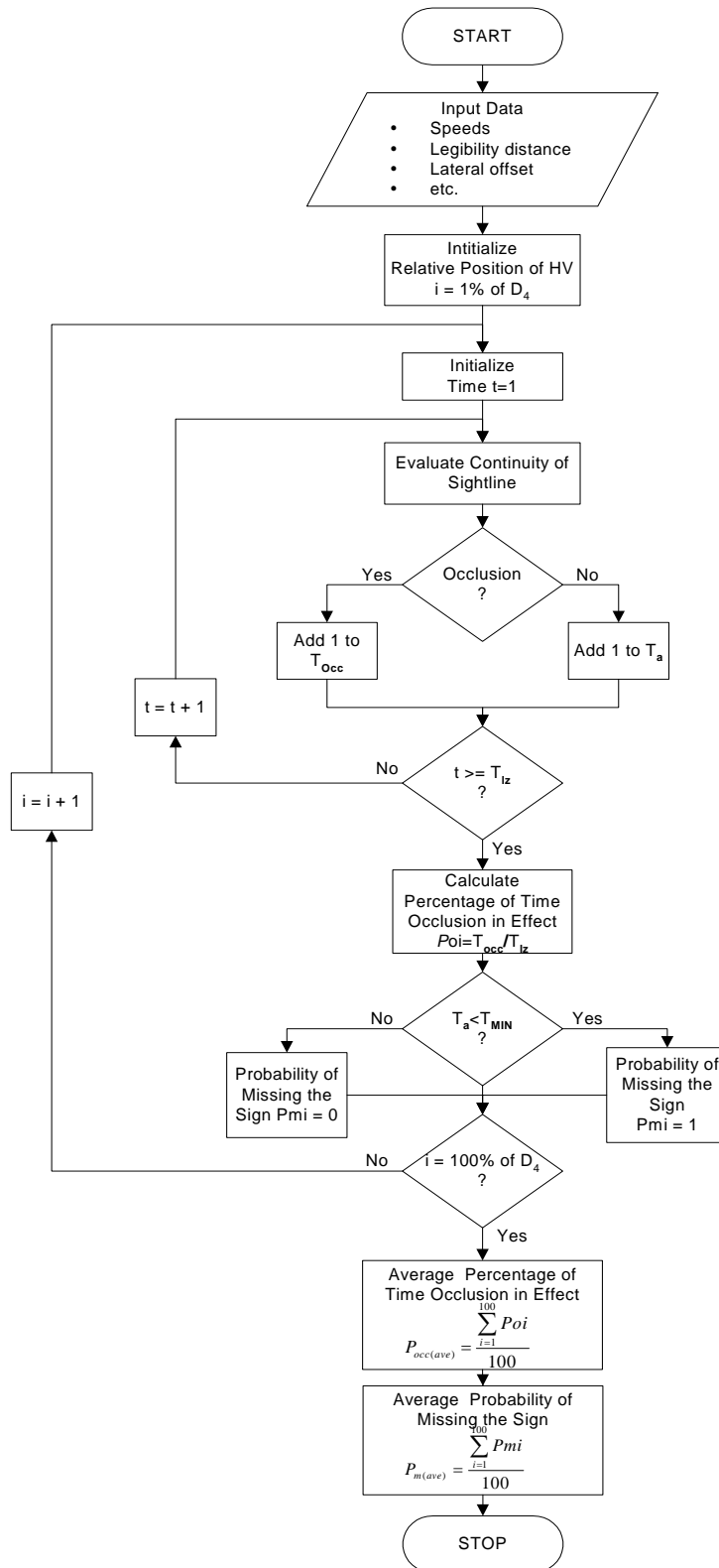


FIGURE 2 Flow chart for the main processes involved in sub-model I.

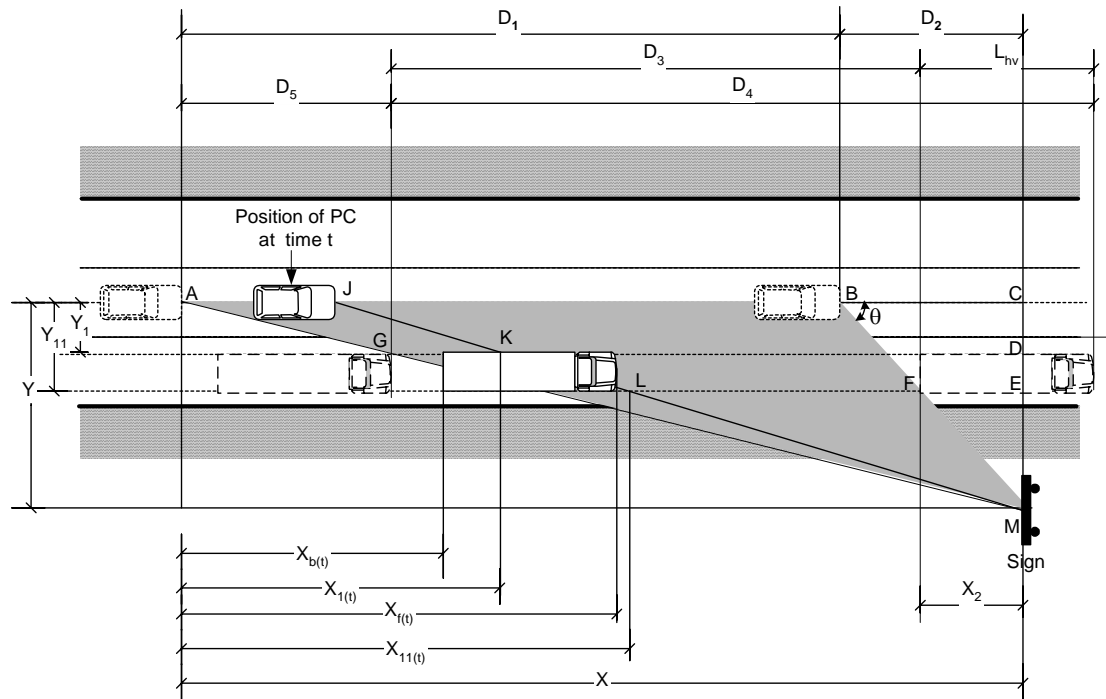


FIGURE 3 Static layout for the occlusion problem and the main geometric variables.

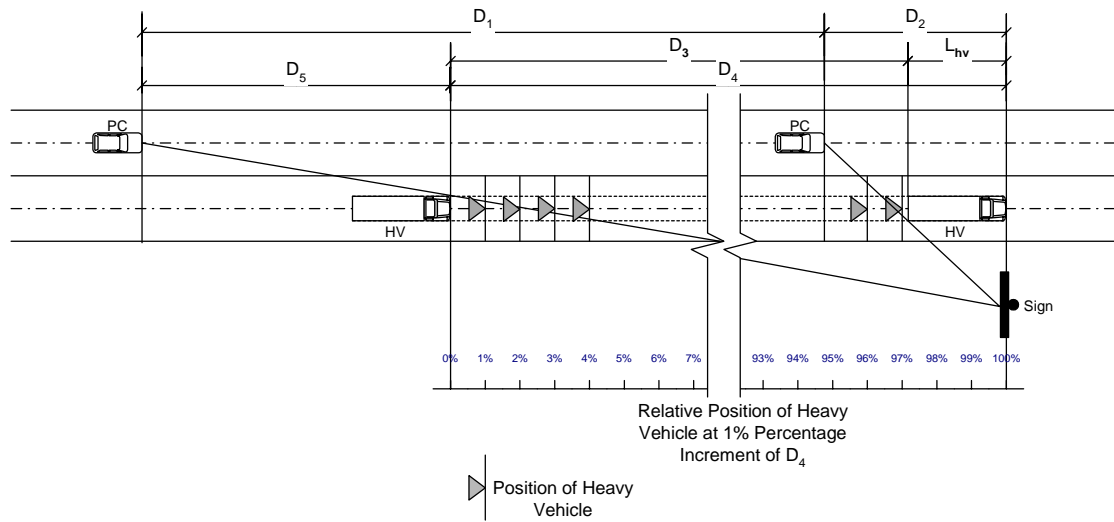


FIGURE 4 Treatment of relative position of truck in sub-model I.

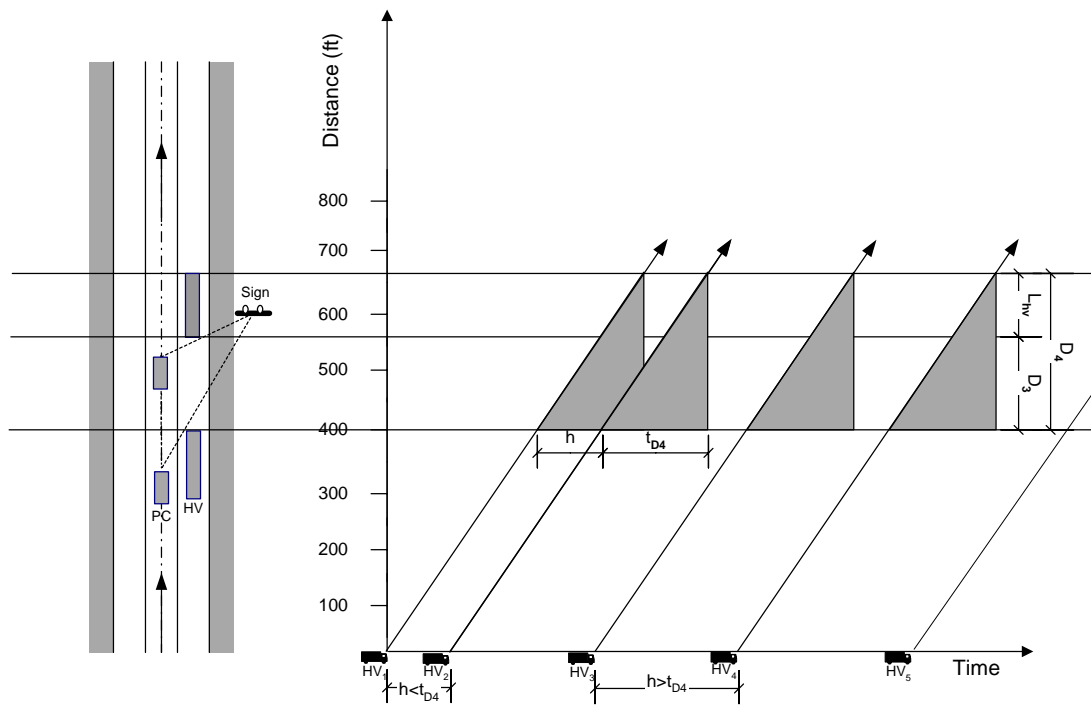


FIGURE 5 Individual and overlapped events.

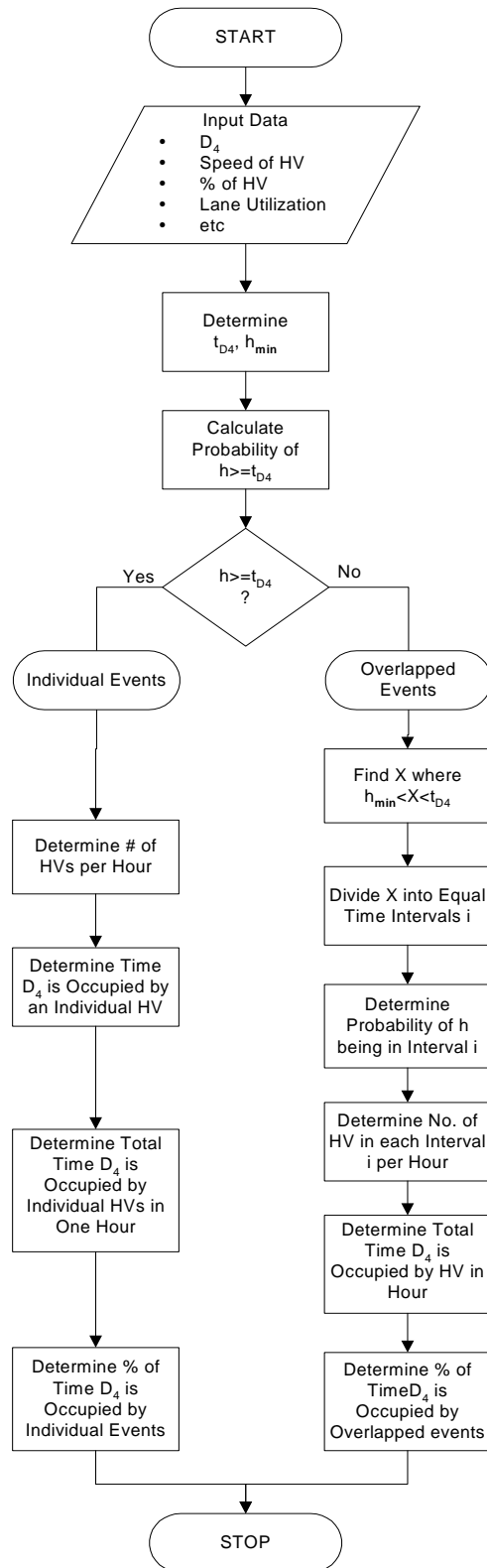


FIGURE 6 Flow chart for the main processes involved in sub-model II.

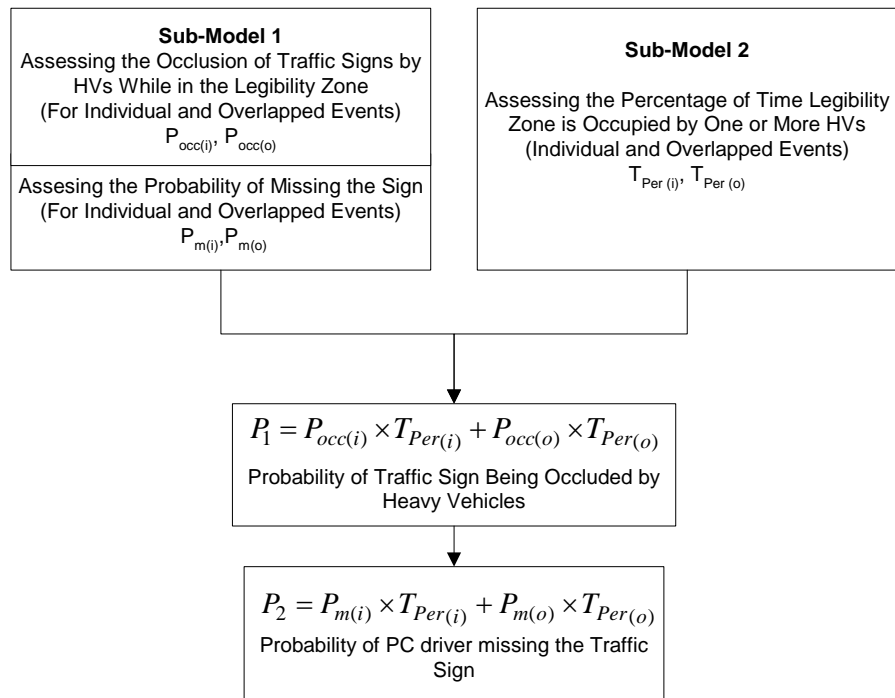


FIGURE 7 Flow chart for the main processes involved in sub-model III.