Intersection Sight Distance Requirements for Large Trucks

JOHN M. MASON, JR., KAY FITZPATRICK, AND DOUGLAS W. HARWOOD

An analysis has been conducted to determine the sight distance requirements of large trucks at intersections. AASHTO policy is briefly reviewed and related vehicle characteristics are identified. Truck characteristics are updated based on permitted 1982 Surface Transportation Assistance Act design vehicles and published truck acceleration models. The results of sensitivity analyses are compared with current policy and are summarized for each of the intersection sight distance cases considered by AASHTO. The findings imply that current intersection sight distance criteria may not be adequate for trucks when the current AASHTO models are exercised for the representative truck characteristics. Nevertheless, the findings, particularly for Case III intersection sight distance, result in impractically long sight distance requirements. Therefore, the development of alternative approaches for establishing realistic sight distance values is advocated. In particular, a truck driver gap-acceptance concept is proposed for further study. The gap lengths that truck drivers safely accept would be determined through field studies, and sight distance criteria would then be established to ensure that truck drivers on a side road approach would have sight distance at least equal to acceptable gap length.

The 1984 AASHTO Green Book (*1*) classifies intersection sight distance as adequate when a driver has an unobstructed view of the entire intersection and sufficient lengths of the intersecting highway to avoid collisions. The AASHTO policy makes various assumptions of physical conditions and driver behavior, including vehicle speed, vehicle performance capabilities, and distances traveled during perception-reaction time and locked-wheel braking.

The current intersection sight distance policy is based primarily on consideration of the passenger car as the design vehicle. Highway design and operational criteria, however, should consider the characteristics of all vehicles using a facility with reasonable frequency. To address the need for additional information an analysis has been conducted to determine the sight distance requirements of large trucks at intersections. This paper focuses on the types of trucks that have been permitted since the 1982 Surface Transportation Assistance Act (STAA) but are excluded from the AASHTO Green Book. The analysis is a simple extension of the existing AASHTO intersection sight distance models to reflect the characteristics and performance of trucks as well as passenger cars. No specific changes in the AASHTO intersection sight distance policies are suggested on the basis of this analysis. Instead, the results of extending these models to trucks point to deficiencies in the AASHTO models themselves and the need for further research to develop new concepts for use in determining intersection sight distance policy.

J. M. Mason and K. Fitzpatrick, Pennsylvania Transportation Institute, Pennsylvania State University, University Park, Pa. 16802. D. W. Harwood, Midwest Research Institute, Kansas City, Mo. 64110.

INTERSECTION SIGHT DISTANCE POLICIES

The sight distance to be provided at intersections is determined by calculating the unobstructed sight distance for vehicles approaching simultaneously on two crossing roadways or for vehicles accelerating from a stop at an intersection approach. Figure 1 illustrates the current design considerations for these two general situations. The simultaneous approach of vehicles on intersecting approaches is considered at "uncontrolled" intersections or where the minor approach has a posted Yield sign. The consideration of acceleration from a stop assumes that a Stop sign is present on the minor roadway or traffic signalization is provided for all approaches.

AASHTO considers four general cases for establishing minimum intersection sight distance dimensions. The four conditions represent various levels of control applied to at-grade intersections:

- *Case I.* No control, but allowing vehicles to adjust speed.
- *Case II.* Yield control where vehicles on the minor intersecting roadway must yield to vehicles on the major intersecting roadway.
- *Case III.* Stop control where traffic on the minor roadway must stop prior to entering the major roadway.
- *Case IV.* Signal control where all legs of the intersecting roadways are required to stop by a Stop sign, or where the intersection is controlled by traffic signals.

Case I—No Control

The operator of a vehicle must be able to perceive a hazard in sufficient time to alter the vehicle's speed as necessary before reaching an intersection that is not controlled by Yield signs, Stop signs, or traffic signals. The sight distance required is a function of the speed of the vehicles and the time to perceive and react by accelerating or decelerating.

The following equation represents AASHTO's method of determining the minimum sight distance along each approach:

$$ISD = 1.47 * V * t \quad (1)$$

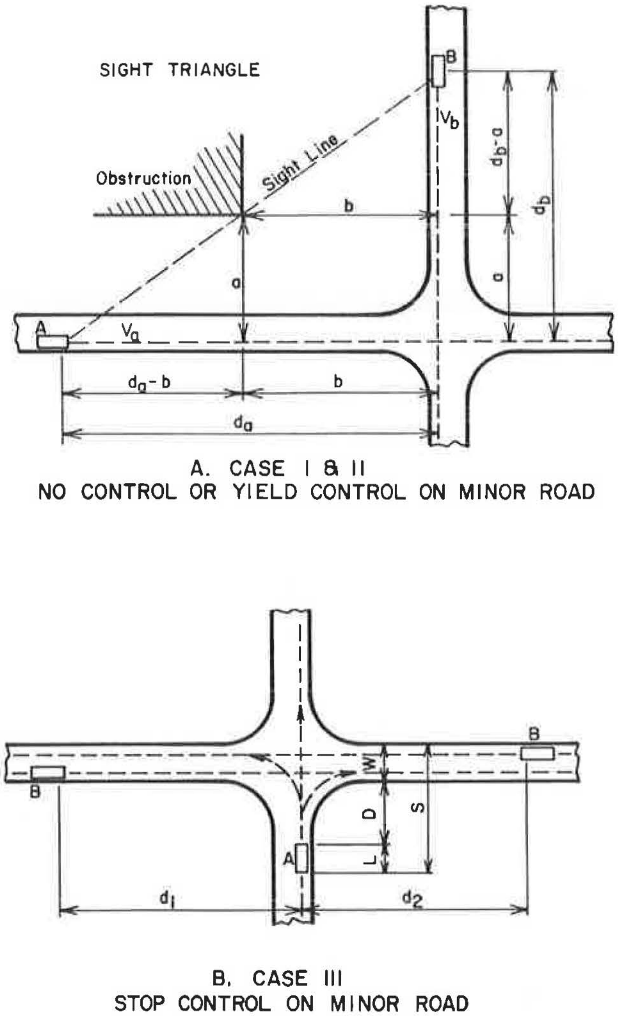

FIGURE 1 Design considerations for intersection sight distance (*1*).

where

ISD = d_a or d_b, minimum intersection sight distance (ft) (see Figure 1A),
V = speed of vehicle (mph),
t = $t_{pr} + t_r$ (sec) (assumed: t = 3.0 sec),
t_{pr} = perception-reaction time (sec) (assumed: t_{pr} = 2.0 sec), and
t_r = time required to regulate speed (sec) (assumed: t_r = 1.0 sec).

An earlier analysis of Case I intersection sight distance by McGee et al. (*2*) focused on its sensitivity to changes in the time needed to regulate speed (assumed by AASHTO as 1 sec). Since deceleration, the vehicle characteristic, is inherent in the 1 sec, a change in the time needed to regulate speed was used as a surrogate for a change in the deceleration rate. Modifying t by ½ sec results in a 17 percent change in the required sight distance. When using this method of testing changes in deceleration rate, it is important to remember that change in the time to regulate speed can represent three different things: a change in the final speed reached, a change in the distance traveled while decelerating, or a change in the deceleration rate. Since the current design standard does not include an explicit term incorporating vehicle deceleration characteristics, the determination of the standard's sensitivity to this characteristic is limited. Because of these limitations, a new formula that incorporates consideration of deceleration rate (d) was proposed by McGee:

$$ISD_A = 1.47\, V_A t_{pr} + \frac{WV_A}{V_B} - \frac{d_A W^2}{2.93 V_B^2} \quad (2)$$

where

ISD_A = d_a, minimum intersection sight distance for Vehicle A (ft) (see Figure 1A),
V_A = design speed for Vehicle A (mph),
t_{pr} = perception-reaction time (sec) (assumed: t_{pr} = 2.0 sec),
W = width of roadway on which Vehicle A is traveling (ft),
V_B = design speed of Vehicle B (mph), and
d_A = deceleration rate of Vehicle A (mph/sec) (note that if the vehicle accelerates, d_A has a negative value).

Equation 2 explicitly considers deceleration rate, but it does not incorporate vehicle length and is highly dependent on perception-reaction time. Vehicle length consideration is presented later in the sensitivity analysis section of this paper.

Case II—Yield Control

The sight distance for the vehicle operator on the minor road must be sufficient to allow him to observe a vehicle on the major roadway approaching from either the left or the right and to bring the vehicle to a stop before he reaches the intersecting roadway. This maneuver requires sight distance equal to stopping sight distance, which is a function of perception-reaction time and braking time.

Case III — Stop Control

The AASHTO Green Book states: "Where traffic on the minor road of an intersection is controlled by Stop signs, the driver of the vehicle on the minor road must have sufficient sight distance for a safe departure from the stopped position, even though the approaching vehicle comes in view as the stopped vehicle begins its departure movements" (Figure 1B). Three basic maneuvers occur at the average intersection:

1. Traveling across the intersecting roadway by clearing traffic on both the left and the right of the crossing vehicle,
2. Turning left into the crossing roadway by first clearing traffic on the left and then entering the traffic stream with vehicles from the right, and
3. Turning right into the intersecting roadway by entering the traffic stream with vehicles from the left.

Consequently, there are three separate sight distance criteria for a vehicle stopped at an intersection. (These conditions are referred to as Cases A, B, and C in Figure IX-23 of the AASHTO Green Book.)

Case III-A—Crossing Maneuver

As stated in the AASHTO Green Book "the sight distance for a crossing maneuver is based on the time it takes for the stopped vehicle to clear the intersection and the distance that a vehicle will travel along the major road at its design speed in that amount of time." Case B in Figure 1 illustrates this condition. The sight distance may be calculated from the following equation:

$$ISD = 1.47 * V * (J + t_a) \qquad (3)$$

where

- ISD = d_1 or d_2, sight distance along the major highway from the intersection (ft),
- V = design speed on the major highway (mph),
- J = sum of the perception time and the time required to actuate the clutch or an automatic shift (sec) (assumed: J = 2.0 sec),
- t_a = time required to accelerate and traverse the distance (S) to clear the major highway pavement (sec) (values of t_a can be read directly from AASHTO Figure IX-21 for nearly level conditions for a given distance S),
- S = $D + W + L$, the distance that the crossing vehicle must travel to clear the major highway (ft) (see Figure 1B),
- D = distance from the near edge of pavement to the front of a stopped vehicle (ft) (assumed: D = 10 ft),
- W = pavement width along path of crossing vehicle (ft), and
- L = overall length of vehicle (ft) (AASHTO Green Book values are 19, 30, 50, 55, and 65 ft for the P, SU, WB-40, WB-50, and WB-60 vehicles, respectively).

McGee et al. (*2*) found Case III-A to be generally insensitive to changes in vehicle characteristic values used in current AASHTO criteria. The current criteria are based on a truck with a length of 55 ft. Increasing the truck length to between 60 and 70 ft increased the required intersection sight distance by approximately 10 percent. An important concern noted by McGee et al. (*2*) is that the AASHTO curves for t_a (time to accelerate) were established from empirical data observed prior to 1954.

Case III-B—Turning Left into a Crossroad

A vehicle turning left into a crossroad should have, as a minimum, sight distance to a vehicle approaching from the right at the design speed. The turning vehicle should be able to accelerate to the average running speed by the time the approaching vehicle gets within a certain tailgate distance after reducing its speed to the average running speed, or the turning vehicle should be able to accelerate to the design speed by the time the approaching vehicle gets within a certain tailgate distance while maintaining the design speed. Figure IX-24 in the AASHTO Green Book describes the details of this case.

AASHTO states that the required sight distances for trucks turning left onto a crossroad will be substantially longer than those for passenger cars. AASHTO further indicates that the sight distance for trucks can be determined using appropriate assumptions for vehicle acceleration rates and turning paths. The specific assumptions, however, are not detailed in AASHTO policy. As presented, the case for this standard lacks sufficient information to derive the design curves for determining required sight distance dimensions.

Case III-C—Turning Right into a Crossroad

A right-turning vehicle must have sufficient sight distance to vehicles approaching from the left to complete its right turn and to accelerate to the running speed before being overtaken by traffic approaching from the left and traveling at the same running speed. The Case III-C policy is described in Figure IX-25 in the AASHTO Green Book. The sight distance requirement for a right-turn maneuver is only a few feet less than that required for a left-turn maneuver. As in Case III-B, AASHTO indicates that sight distances for trucks need to be considerably longer than for passenger vehicles, but sufficient information is lacking to derive the design curves for determining required sight distance dimensions.

Case IV—Signal Control

Because of the increased workload present at an intersection, the AASHTO Green Book recommends that drivers accelerating at a signalized intersection should have sight distances available based on the Case III procedures. Hazards associated with vehicles turning at or crossing an intersection strengthen the argument for providing the Case III sight distance. The AASHTO rationale for this provision is that motorists should have sufficient sight distance to see the traffic signal in sufficient time to perform the action it indicates; have a view of the intersecting approaches in case a crossing vehicle violates the signal indication or the signal malfunctions; and have a sufficient departure sight line for a right-turn-on-red maneuver.

SENSITIVITY ANALYSIS

Table 1 contains a summary of the intersection sight distance parameters used in the AASHTO Green Book and the values of the vehicle-related parameters that were varied in the subsequent sensitivity analyses. The values in the AASHTO column are those used in the current criteria. They include driver characteristics (perception-reaction time) and vehicle characteristics (deceleration or acceleration time, stopping distance, and vehicle length). "Modifications for Truck Characteristics" in Table 1 represent updated truck characteristics data, including truck lengths, based on permitted STAA design vehicles and stopping sight distances for trucks. The sources of the truck characteristics data are documented below. The application of these data to derive sight distances for trucks for each intersection case is presented in the following sections.

The revised passenger car and truck acceleration rates for Case I are based on the work of McGee et al. (*2*). The stopping

TABLE 1 SUMMARY OF TRUCK CHARACTERISTICS FOR INTERSECTION SIGHT DISTANCES (ISD)

	AASHTO (1)			Modifications for Truck Characteristics	
Case	Perception-Reaction Time (sec)	Deceleration/ Acceleration Time or Distance	Length of Vehicle	Deceleration/ Acceleration Time or Distance	Length of Vehicle
CASE I ISD = 1.47Vt $t = t_{pr} + t_r$	$t_{pr} = 2.0$	$t_r = 1.0$ seconds	NA	New Equation $d_A = 5.5$ mphps for pc $d_A = 3.63$ mphps for tractor-trailer combinations	70' tractor semi-trailer truck 75' tractor semi-trailer-full trailer truck (double bottom)
CASE II ISD = SSD = $1.47Vt_{pr} + \frac{V^2}{30(f+g)}$	$t_{pr} = 2.5$	AASHTO's SSD Values Speed SSD 20 mph 125' 30 mph 200' 40 mph 325' 50 mph 475' 60 mph 650' 70 mph 850'	NA	SSD for truck with worst and best performing drivers Driver Performance Speed Worst Best 20 mph 150' 125' 30 mph 300' 250' 40 mph 500' 375' 50 mph 725' 525' 60 mph 975' 700' 70 mph 1275' 900'	NA
CASE III-A $ISD = 1.47V(J+t_a)$ t_a = function(D+W+L)	J = 2.0	t_a from AASHTO Figure IX-21	19' PC 30' SU 55' WB-50	t_c from Gillespie's equation (5)	70' tractor semi-trailer truck 75' tractor semi-trailer-full trailer truck (double bottom)
CASE III-B & III-C	From AASHTO Figure IX-27			See Table 5	70' tractor semi-trailer truck 75' tractor semi-trailer-full trailer truck (double bottom)

sight distances used for Case II are those derived by Harwood, Glauz, and Mason (in this Record), based on estimates of truck braking distances developed by Fancher (*3*). These distances represent controlled braking by an empty truck on a poor, wet road with relatively good radial tires (at least 12⁄32 in of tread depth). The truck braking performance of drivers varies widely as a result of driver experience and expertise: many truck drivers lack experience in emergency braking, and different drivers accept varying amounts of "risk" in what is potentially a hazardous operation that could lead to truck jackknifing. Fancher (*3*) found that the worst-performing driver has a braking efficiency of approximately 62 percent of the vehicle capability, while the best-performing drivers can achieve nearly 100 percent of vehicle capability. A range of stopping sight distances appropriate for both the worst and best drivers (62 to 100 percent driver control efficiency) is considered in this paper.

Clearance times for trucks crossing intersections in Case III-A are based on a relationship developed by Gillespie (*4*), presented later in this paper. Truck acceleration performance for Cases III-B and III-C is based on test track data collected by Hutton (*5*).

Truck lengths of 70 and 75 ft were considered. An overall length of 70 ft represents a STAA tractor semitrailer truck with a 53-ft trailer unit. The overall length of 75 ft represents a STAA "double bottom" truck with a conventional cab-behind-engine tractor and two 28-ft trailers.

Case I—No Control

The current formula for Case I intersection sight distance includes the driver's perception-reaction time. The AASHTO formula implicitly accounts for vehicle characteristics through the 1.0 sec time to regulate speed assumption.

As discussed earlier, McGee et al. (*2*) proposed an alternative equation for Case I intersection sight distance that explicitly included deceleration rate (see Equation 2). The McGee equation estimates sight distances that are less than the AASHTO criteria. The equation does not adequately address Case I intersection sight distance because it does not consider vehicle lengths. A tractor-trailer requires more time to cross an intersection than a passenger car because of its increased length. Therefore, a further modification of the equation is proposed to account for the length of the crossing vehicle (B) and the deceleration rate of the conflicting vehicle (A):

$$ISD_A = 1.47 V_A t_{pr} + (W + L_B) \frac{V_A}{V_B} - \frac{d_A (W + L_B)^2}{2.93 V_B^2} \qquad (4)$$

where

ISD_A = d_a, minimum intersection sight distance for Vehicle A (ft) (see Figure 1A),
V_A = design speed for Vehicle A (mph),
V_B = design speed for Vehicle B (mph),
t_{pr} = perception-reaction time (sec) (assumed: t_{pr} = 2.0 sec),
W = width of roadway on which Vehicle A is traveling (ft),
L_B = vehicle length of Vehicle B (ft), and
d_A = deceleration rate of Vehicle A (mph/sec) (if the vehicle accelerates, d_A is a negative value).

Table 2 and Figure 2 compare the Case I intersection sight distances based on the AASHTO Green Book criteria and those given by Equation 4 for truck lengths of 70 and 75 ft. The results indicate that longer trucks require more distance than is provided by the AASHTO criteria for Vehicle B speeds up to 60 mph. The percent change in the sight distance required for Vehicle A ranges from an increase of 69 percent (when V_A = 70 mph and V_B = 20 mph) to a decrease of 5 percent (when V_A = 20 mph and V_B = 70 mph).

Use of Equation 4 for Case I intersection sight distance is recommended because it explicitly considers both deceleration rate and vehicle length. Sight distances calculated from this formula are more sensitive to the vehicle length than to the deceleration term. The revised equation is still highly dependent on the driver perception-reaction time.

Case II—Yield Control

The Case II intersection sight distance procedure is merely an application of the AASHTO stopping sight distance formula, using the revised stopping sight distances for trucks shown in Table 1. The percent increase in sight distance for the worst- and best-performing truck drivers in comparison with the current AASHTO criteria is shown in Table 3.

Case III-A—Crossing Maneuver

The current AASHTO criteria for Case III-A intersection sight distance include two vehicle characteristics: vehicle acceleration from a stop and vehicle length. Both characteristics are used to determine the acceleration time parameter (t_a) used in the criteria. AASHTO Green Book Figure IX-21 provides distance versus time curves for acceleration by a passenger car, a single-unit truck, and a WB-50 truck. Vehicle length is necessary to establish the length of the hazard zone, in addition to the distance from the front of the vehicle to the edge of the intersecting pavement (AASHTO assumes 10 ft) and the width of the intersection. Table 4 lists the sight distance required for an AASHTO WB-50 truck to cross a 30-ft intersection, based on the AASHTO acceleration performance curve (AASHTO Green Book Figure IX-21).

The WB-50 design vehicle is sensitive to changes in assumed length because a given percentage change in the length of a long vehicle is greater in absolute terms than the same percentage change in the length of a short vehicle, and the lower acceleration rates of large trucks result in a longer acceleration time (t_a) over a given distance. A factor to consider in the above sensitivity analysis is that the accuracy with which curves can be read is limited. Because the curves are relatively flat, it is difficult to determine the change in t_a for small changes in distance traveled (for example, because of small changes in vehicle length).

The acceleration time to clear a hazard zone has also been calculated using an equation developed by Gillespie (*4*). The

TABLE 2 COMPARISON OF CASE I INTERSECTION SIGHT DISTANCES (ISD)

			VEHICLE B SPEED (mph)					
	Sight		20 mph	30 mph	40 mph	50 mph	60 mph	70 mph
Veh A Speed (ft)	Dist. Calc. (ft)	AASHTO Values (ft)	ISD (ft)	ISD (ft)	ISD (ft)	ISD (ft)	ISD (ft)	ISD (ft)
Veh A & Veh B = 70' tractor semi-trailer truck								
20	88	90	125	109	99	92	87	83
30	132	130	202	170	152	140	132	126
40	176	180	278	231	205	188	177	169
50	221	220	355	292	258	237	222	212
60	265	260	431	352	311	285	267	255
70	309	310	507	413	363	333	312	298
Veh A & Veh B = 75' tractor semi-trailer-full trailer truck								
20	88	90	127	111	101	94	88	85
30	132	130	206	174	155	143	134	128
40	176	180	285	236	209	192	180	172
50	221	220	364	299	263	241	226	215
60	265	260	443	361	317	290	272	259
70	309	310	522	423	371	340	318	302

See Figure 1-A for vehicle A and vehicle B sight triangles.

ASSUMPTIONS: W = 24 ft

d_A for 70' tractor semi-trailer truck = 3.63 mphps

d_A for 75' tractor semi-trailer-full trailer truck = 3.63 mphps

d_A values from Table 33 in reference 3, 85 percentile average deceleration rate on wet pavement with an initial speed of 40 mph

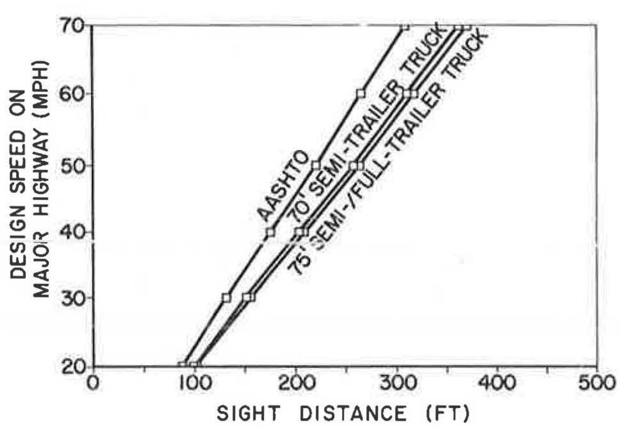

FIGURE 2 Comparison of Case I intersection sight distances (Vehicle B speed = 40 mph).

time (t_c) required for a truck to clear a hazard zone—starting from a full stop and remaining in initial gear during the maneuver—can be estimated by the following equation:

$$t_c = 0.682 \frac{L_{HZ} + L_T}{v_{mg}} + 3.0 \text{ (sec)} \quad (5)$$

where

L_{HZ} = length of the hazard zone (ft),
L_T = length of the truck (ft), and
v_{mg} = maximum speed in a selected gear (mph) (determined by Gillespie as 8 mph for a level surface).

Gillespie also presented a maximum speed in initial gear versus grade curve for determination of clearance time for trucks accelerating on a grade. Equation 5 assumes that the gear design, engine speed, and the tire size are such that the truck's

TABLE 3 PERCENT INCREASE IN INTERSECTION SIGHT DISTANCES (ISD) OVER AASHTO CRITERIA

Speed	AASHTO SSD (1) (ft)	Worst-Performance Truck Driver ISD (ft)	Worst-Performance Truck Driver Percent Increase	Best-Performance Truck Driver ISD (ft)	Best-Performance Truck Driver Percent Increase
20	125	150	20.00	125	0.00
30	200	300	50.00	250	25.00
40	325	500	53.85	375	15.38
50	475	725	52.63	525	10.53
60	650	975	50.00	700	7.69
70	850	1275	50.00	900	5.88

TABLE 4 COMPARISON OF CASE III-A INTERSECTION SIGHT DISTANCES (ISD)

	AASHTO	GILLESPIE--INTERSECTION CLEARANCE TIME	
VEHICLE B SPEED (mph)	WB-50 TRUCK (55') ISD (ft)	70' TRACTOR SEMI-TRAILER TRUCK ISD (ft)	75' TRACTOR SEMI-TRAILER-FULL-TRAILER TRUCK ISD (ft)
20	370	423	435
25	463	528	544
30	556	634	653
35	648	740	762
40	741	845	870
45	833	951	979
50	926	1057	1088
55	1019	1162	1197
60	1111	1268	1306
65	1204	1374	1414
70	1297	1479	1523

Assumed:
Width of pavement: 30'
Distance from edge of pavement to front of vehicle: 10'
t_a determined from Figure IX-21 in AASHTO Green Book
t_a = 10.6 seconds for 55' truck
t_c determined from Gillespie's equation
t_c = 12.38 seconds for 70' truck
t_c = 12.80 seconds for 75' truck

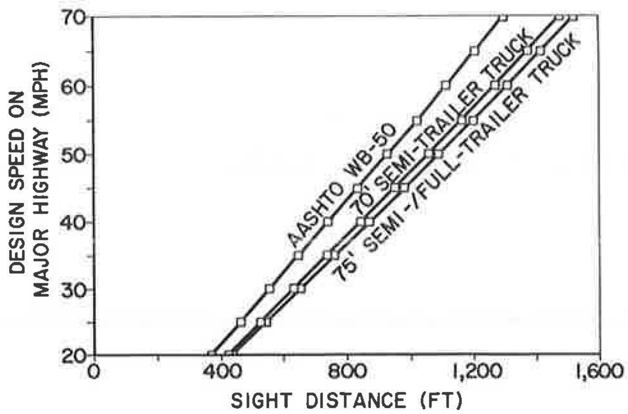

FIGURE 3 Comparison of Case III-A intersection sight distances.

maximum speed is 60 mph. It also assumes that a truck will remain in the initial gear without shifting while negotiating the hazard zone.

Intersection sight distances based on the Gillespie model are also shown in Table 4. Use of the Gillespie model for a 70- and 75-ft truck resulted in a 17 and 21 percent increase in time, respectively, compared with an AASHTO WB-50 truck. These longer times produce a 14 percent increase in sight distance for a 70-ft tractor semitrailer truck and a 17.5 percent increase for a 75-ft tractor semitrailer–full-trailer truck. Figure 3 illustrates the results presented in Table 4.

Cases III-B and III-C—Turning Left or Right into a Crossroad

The vehicle characteristics considered in intersection sight distance for Cases III-B and III-C are acceleration rate, vehicle length, and vehicle turning path. The acceleration rate is a function of the distance traveled and the vehicle type. Cases III-B and III-C require considerably longer sight distances than Case III-A because more time is needed to turn left or right and accelerate to the design speed than is required to cross the intersecting roadway.

Because the intersection sight distance criteria presented in the Green Book for Cases III-B and III-C lack the information to determine the parameter values needed to derive the design curves of AASHTO's Figure IX-27, the following assumptions were necessary:

1. Vehicle B (vehicle on major highway) maintains design speed throughout the turning maneuver by Vehicle A.
2. In 1970, Hutton published a paper on the acceleration performance of highway diesel trucks accelerating from a stopped position to a maximum speed on a straight and level surface (*5*). The acceleration distance and time for Vehicle A are based on the Hutton curve data. The distance traveled by Vehicle A during a turning maneuver can be estimated for trucks with weight-to-horsepower ratios of 100, 200, and 300. Hutton also estimates the time (t_t) for Vehicle A to complete the turning maneuver. Table 5 gives the distance and time that would be required for Vehicle A to accelerate from a stop to various speeds.
3. The distance traveled by Vehicle B is equal to the design speed of the major highway multiplied by the time for Vehicle A to accelerate from a stopped position to the design speed.
4. A proposed methodology for quantifying AASHTO's tailgate distance is to consider the variation in average spacing between vehicles traveling at selected design speeds. This dimension is referred to as the "minimum separation" between the front bumper of the vehicle on the major road and the rear bumper of the turning vehicle (see Figure 4). No field data are available on the minimum separations actually accepted by drivers in making turning maneuvers at intersections. One approach to determine the minimum separation is to determine the space gaps that drivers use when traveling at short headways. In other words,

$$MS = 1.47 h_{min} V - L \tag{6}$$

where

MS = minimum separation (ft),
h_{min} = minimum acceptable headway (sec),
V = vehicle speed (mph), and
L = vehicle length (ft).

The following shows the minimum separations derived from this approach for a minimum acceptable headway of 1 sec and a vehicle length of 19 ft:

Design Speed (mph)	*Minimum Separation (ft)*
25	18
30	25
35	32
40	40
45	47
50	55
55	62
60	69
65	77
70	84

It is known that some vehicles will travel at these minimum separations. It is possible that even shorter minimum separations might be maintained for brief intervals during a turning maneuver.

Using the above assumptions and the information presented in the AASHTO Green Book, the following equations were used in this sensitivity analysis (see Figure 4 for dimensions in Case III-B):

$$ISD_A = Q - H \tag{7}$$

$$Q = 1.47 * V_B * t_A \tag{8}$$

$$t_A = t_t + J \tag{9}$$

$$H = P - D_{np} - MS - L + R \tag{10}$$

$$D_{np} = \pi * R/2 \tag{11}$$

where

ISD_A = d_1 or d_2, sight distance along the major highway from the intersection for Vehicle A (ft) (see Figure 1B),
Q = distance traveled by Vehicle B during Vehicle A's turning maneuver (ft),
H = distance of Vehicle B from intersection when at

TABLE 5 ACCELERATION TIMES AND DISTANCES FOR TRUCKS (*6*)

	WEIGHT/HORSEPOWER RATIO					
	100 LB/HP		200 LB/HP		300 LB/HP	
Speed (mph)	Time (sec)	Distance (ft)	Time (sec)	Distance (ft)	Time (sec)	Distance (ft)
25	15	400	20	500	25	600
30	17	500	25	700	37	1000
35	24	800	35	1100	50	1600
40	30	1100	49	1800	65	2400
45	38	1600	60	2500	85	3700
50	47	2200	76	3600	107	5500
55	57	3000	92	4900	*	*
60	67	4000	107	6400	*	*
65	77	5000	*	*	*	*
70	85	6000	*	*	*	*

*Information not available

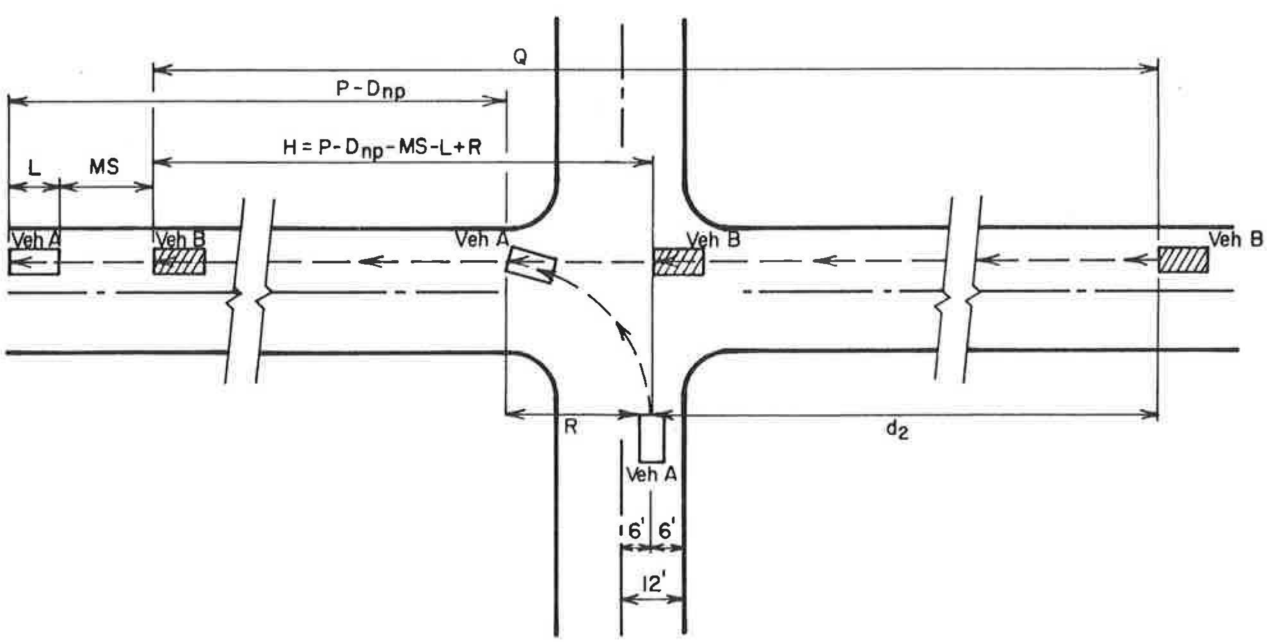

FIGURE 4 Distances considered in Case III-B criteria.

assumed minimum separation distance from Vehicle A (ft),

V_B = velocity of Vehicle B (mph),

t_A = time for a stopped vehicle to move into traffic stream and accelerate to design speed (sec),

J = sum of the perception time and the time required to actuate the clutch or automatic shift (sec) (assumed: J = 2.0 sec),

t_t = time for Vehicle A to complete the turning maneuver (sec) (based on Hutton data),

P = total distance traveled by Vehicle A from stopped position to location when design speed is achieved (ft) (based on Hutton data),

D_{np} = distance Vehicle A traveled during the turning maneuver that is not parallel to highway (ft),

MS = minimum separation (ft),

L = length of Vehicle A (ft),

R = radius of turn for Vehicle A (ft) (based on assumed values from Table IX-20 in the AASHTO Green Book).

Any differences in sight distance lengths between Case III-B and Case III-C would be caused by the different turning radii (R) between a left turn and a right turn.

The percent changes in required sight distance resulting from changes in the vehicle characteristics were determined by comparing the sight distances calculated from the above assumptions (for trucks with 200 and 300 weight-to-horsepower ratio) with the sight distances shown in AASHTO Figure IX-27, Curve *B-2a* and *Ca*. Table 6 presents the sight distances calculated with the above assumptions and their percent differences from the AASHTO criteria. Figure 5 compares the revised sight distances in Table 6 directly with the AASHTO sight distances. For each weight-to-horsepower ratio, the revised intersection sight distances are greater (between 51 and 139 percent) than the AASHTO criteria.

SUMMARY OF FINDINGS

A revised model developed in this study indicates that Case I intersection sight distance is quite sensitive to vehicle length, which is not considered in the current AASHTO criteria. Sensitivity analysis results indicate that trucks require

TABLE 6 COMPARISON OF CASE III-B AND III-C INTERSECTION SIGHT DISTANCES (ISD)

SPEED VEH B V_B (mph)	DISTANCE VEH A P (ft)	TIME VEH A t_t (sec)	DISTANCE VEH B Q (ft)	MINIMUM SEPARATION MS (ft)	CALCULATED ISD ISD_A (ft)	AASHTO ISD (ft)	PERCENT INCREASE
design vehicle - 200 lbs/hp, 70-foot							
25	500	20	809	18	430	325	32
30	700	25	1,191	25	620	450	38
35	1,100	35	1,904	32	940	580	62
40	1,800	49	2,999	40	1,343	750	79
45	2,500	60	4,101	47	1,753	950	84
50	3,600	76	5,733	55	2,292	1,190	93
55	4,900	92	7,600	62	2,866	1,440	99
60	6,400	107	9,614	69	3,387	1,730	96
65-70	DATA UNAVAILABLE						
design vehicle - 300 lbs/hp, 75-foot							
25	600	25	992	18	519	325	60
30	1,000	37	1,720	25	854	450	90
35	1,600	50	2,675	32	1,217	580	110
40	2,400	65	3,940	40	1,689	750	125
45	3,700	85	5,755	47	2,211	950	133
50	5,500	107	8,012	55	2,675	1,190	125
55-70	DATA UNAVAILABLE						

NOTE: Radius of turn, R - 60 feet

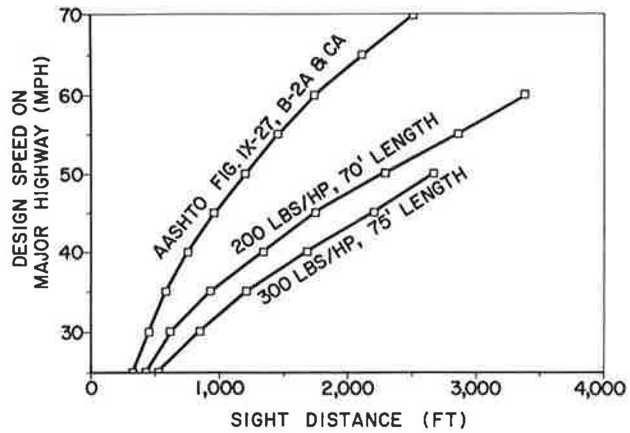

FIGURE 5 Comparison of Case III-B and III-C intersection sight distances.

greater Case I intersection sight distance than the current AASHTO criteria for all approach speeds considered and for all crossing vehicle speeds up to 60 mph.

The Case II intersection sight distance procedure is an application of the stopping sight distance formula. Stopping sight distance requirements for trucks depend on driver braking performance. The best-performing driver requires up to a 25 percent increase in intersection sight distance; the worst-performing driver needs a 20 to 54 percent increase in required sight distance. The increased driver eye height for trucks, compared with passenger cars, may offset the need for part of this increase where sight distance is limited by a vertical obstruction.

A sensitivity analysis found that 70- and 75-ft combination trucks require substantially longer intersection sight distance than an AASHTO WB-50 truck for Case III-A. In particular, intersection clearance times based on the model developed by Gillespie indicate that a 70-ft truck requires 14 percent more sight distance than an AASHTO WB-50 truck and that a 75-ft truck requires 17.5 percent more sight distance.

The sensitivity analysis also found that the selected trucks would require substantially more intersection sight distance than passenger cars for Cases III-B and III-C. The additional sight distance requirements of trucks vary as a function of weight-to-horsepower ratio. A 200-lb/hp, 70-ft truck requires between 51 and 103 percent additional sight distance compared with a passenger car, and a 300-lb/hp, 75-ft truck requires between 78 and 139 percent additional sight distance.

The analysis presented in this paper is based on extending current AASHTO intersection sight distance models with data on the characteristics and performance of vehicles permitted since the 1982 STAA, but excluded from the AASHTO Green Book. Each intersection case resulted in increased sight distance requirements. For Cases I, II, and III-A, the largest additional truck sight distance requirements range from approximately 125 ft to 450 ft. Cases III-B and III-C result in an increase in sight distances of nearly 1,700 ft in some situations. The existing criteria for Cases III-B and III-C can require intersection sight distances of up to 1,700 ft. The revised requirements for trucks can be as large as 3,400 ft.

It is clear from operational experience that sight distances as long as 3,400 ft are not necessary for safe operations at intersections, even where large trucks are present. Very few intersections have such long sight distances available, and it is unlikely that either passenger car or truck drivers could accurately judge the location and speed of an oncoming vehicle at a distance of 3,400 ft. Rather, this result indicates that the current AASHTO model for Cases III-B and III-C for truck intersection sight distance, on which this analysis is based, is unrealistic. In particular, it is unrealistic to assume that potentially conflicting vehicles on the main road will make only minor adjustments in speed if a truck from the side road makes a left or right turn.

There is a need to revise or replace the AASHTO model for Cases III-B and III-C intersection sight distance, especially for trucks. Two alternative approaches are available. First, the AASHTO model could be revised to incorporate deceleration by the main road vehicle when a truck executes a turning maneuver from the side road. Although more realistic, this approach would increase the complexity of the model. The deceleration behavior of drivers would have to be based on field studies for a range of vehicle types, driver types, intersection geometrics, and approach speeds.

An alternative approach to establishing practical sight distance values is to base the criteria on gap lengths safely accepted by the side road trucks. The sight distance criteria should be developed to ensure that truck drivers on the side road would have sight distance that is at least equal to their acceptable gap length. Sight distances established from gap acceptance investigations would better represent actual operations at an intersection.

Truck drivers need to view an adequate length of roadway to determine if there is an adequate gap on the major road to safely complete the maneuver. The gap lengths that truck drivers accept can be estimated through field studies. Factors that should be considered in the studies include

- Location of intersection (rural or urban),
- Traffic volume (peak hour, daily, and seasonal variations),
- Vehicle mix characteristics (composition and vehicle configuration), and
- Geometric elements (horizontal and vertical alignment and cross-section descriptions).

FUTURE RESEARCH

Field studies can provide the data to further develop the revised concepts for Case III truck intersection sight distance. The specific results that are necessary to evaluate the potential of a gap acceptance concept for intersection sight distance include

1. Gap distances the trucks on minor roads will accept and reject during their maneuver onto or across the major roadway,
2. Development of a speed profile (deceleration behavior) for major road vehicles during the maneuvers of a truck on a minor road,
3. Acceleration characteristics (time/distance relationships) of the truck on the minor roadway during a crossing or turning maneuver, and
4. Safe minimum separation distance between the turning vehicle (truck) and the oncoming vehicle.

These data could also be used to revise the current AASHTO model to incorporate deceleration by the vehicle on the main road. The preliminary findings presented in this paper indicate that the issues regarding truck intersection sight distance are also applicable to the needs of passenger car drivers. As such, the future research efforts identified above are equally important to consider in examining modifications to AASHTO's current intersection sight distance policy.

ACKNOWLEDGMENT

The work reported in this paper was sponsored by the U.S. Department of Transportation, Federal Highway Administration.

REFERENCES

1. *A Policy on Geometric Design of Highways and Streets.* AASHTO, Washington, D.C., 1984.
2. H. W. McGee, R. S. Rizzo, and B. Tustin. *Highway Design and Operations Standards Affected by Vehicle Characteristics.* Report FWHA/RD-86/ 044. FHWA, U.S. Department of Transportation, 1984.
3. P. S. Fancher. Sight Distance Problems Related to Large Trucks. In *Transportation Research Record 1052*, TRB, National Research Council, Washington, D.C., 1986.
4. T. D. Gillespie. Start-Up Acceleration of Heavy Trucks on Grades. In *Transportation Research Record 1052*, TRB, National Research Council, Washington, D.C., 1986.
5. T. D. Hutton. *Acceleration Performance of Highway Diesel Trucks.* Paper No. 70664, Society of Automotive Engineers, Detroit, Mich., 1970.

Publication of this paper sponsored by Committee on Geometric Design.