Sight Distance Requirements for Trucks at Railroad-Highway Grade Crossings

Kay Fitzpatrick, John M. Mason, Jr., and John C. Glennon

The sight distance requirements for large trucks at railroad-highway grade crossings are compared with current AASHTO policy. The key elements affecting sight distance requirements include driver characteristics such as perception-reaction time and vehicle characteristics such as vehicle speed, length, acceleration, and braking distances. The results from sensitivity analyses are compared with current policy and are summarized for each sight distance consideration. The findings imply that current criteria for sight distance along the highway and along the tracks for a moving highway vehicle may not be adequate for large trucks. In contrast, the current AASHTO values for sight distance along the tracks for a stopped highway vehicle adequately reflect current truck performance capabilities.

The 1986 FHWA *Railroad-Highway Grade Crossing Handbook* (*1*) states that railroad-highway grade crossings are unique in that they are the intersection of two transportation modes. These modes differ both in the physical characteristics of their traveled ways and in their vehicle operations. A railroad-highway grade crossing may be viewed as a special type of highway intersection, with the three basic elements of highways present: the driver, the vehicle, and the physical intersection. As with a highway intersection, drivers must appropriately yield the right-of-way to intersecting traffic; unlike highway intersections, the intersecting traffic—trains—does not yield the right-of-way. Drivers of motor vehicles have the flexibility to change their path of travel and can change their speed within a relatively short distance. Locomotive engineers are restricted to moving their trains down a fixed path and require relatively long distances and times to change speed. Because of this, drivers need adequate clear sight triangles to avoid collisions with trains.

This paper includes both a critical review of the current procedures and a sensitivity analysis to determine the sight distance requirements for the kinds of trucks permitted by the 1982 Surface Transportation Assistance Act (STAA), which are not currently included in the AASHTO Green Book. No changes in the general design procedure are recommended on the basis of this analysis. It does, however, provide specific information on the effects of current physical and performance characteristics of trucks on sight distance requirements.

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CURRENT RAILROAD-HIGHWAY GRADE CROSSING SIGHT DISTANCE POLICY

Both the FHWA Handbook (*1*) and the AASHTO Green Book (*2*) use the same principles for determining safe sight triangles at railroad-highway grade crossings. They both consider sight distance requirements for a moving highway vehicle and for a highway vehicle accelerating from a stop at the crossing, as shown in Figure 1. For the moving-vehicle situation, the sight distance (d_H) along the highway must, as a minimum, be the safe stopping sight distance for the given

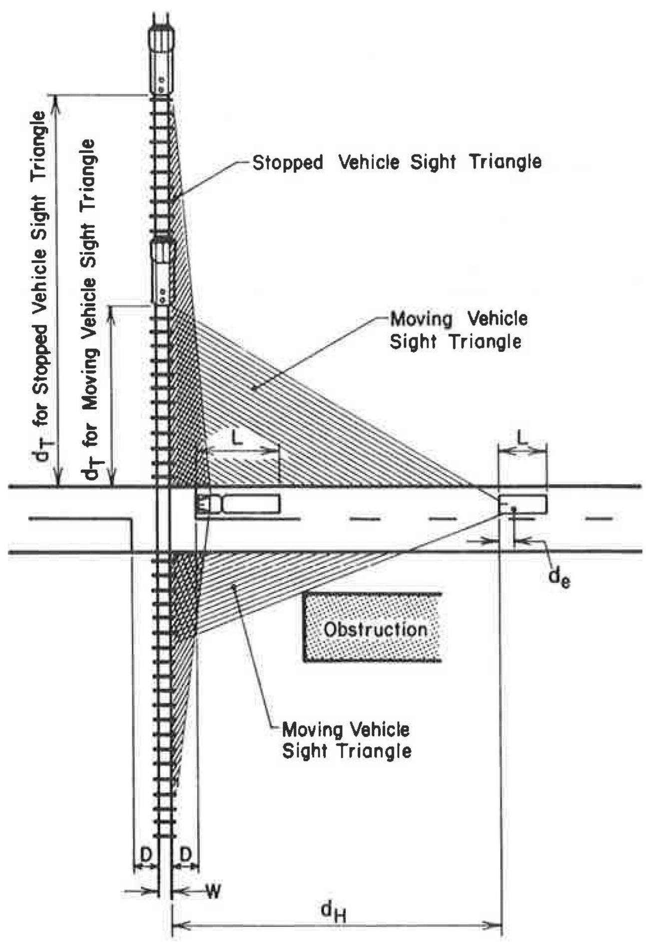

FIGURE 1 Dimensions considered in railroad-highway grade crossing sight distance (*1*).

approach speed. The sight distances along the track for this situation are the distances traveled by the train during the time the highway vehicle traverses both the highway distance (d_H) and the distance to clear the crossing. For the stopped-vehicle situation, the highway vehicle starts from a minimum safe distance from the crossing. The distances along the track for this situation are those traveled by the train at various speeds while the highway vehicle accelerates and just clears the crossing.

Sight Distance Along the Highway for a Moving Vehicle

The minimum sight distance measured along the highway (d_H) is from the nearest rail to the driver of a vehicle. It is the sum of the minimum stopping sight distance and the minimum clearance distance between the tracks and the driver after the vehicle stops. This distance allows an approaching vehicle to avoid collision by stopping without encroaching on the crossing area. The minimum sight distance formula used in the FHWA Handbook (*1*) and the AASHTO Green Book (*2*) is

$$d_H = 1.47V_v t_{pr} + \frac{V_v^2}{30f} + D + d_e \qquad (1)$$

where

d_H = sight distance along the highway (ft),
V_v = velocity of vehicle (mph),
t_{pr} = perception/reaction time of driver (sec) (assumed: t_{pr} = 2.5 sec),
f = coefficient of friction used in braking (see Table 1 for assumed values),
D = clearance distance from front of vehicle to the nearest rail (ft) (assumed: D = 15 ft), and
d_e = distance from driver to the front of vehicle (ft) (assumed: d_e = 10 ft).

The coefficient of friction values f are from the AASHTO Green Book criteria for stopping sight distance. These values, the result of several studies cited in the Green Book, represent the marginal deceleration rates for a passenger car in locked-wheel braking on a wet pavement.

Sight Distance to and Along Tracks for a Moving Vehicle

The legs of the clear "approach sight triangle" are formed by d_H, the distance of the vehicle from the track, and d_T, the distance of the train from the crossing. The equation for d_H is discussed above. The minimum distance along the track (d_T) is from the nearest edge of the highway travel lane being considered to the front of the train. It is the product of the train speed and the time required by the highway vehicle to both traverse the highway leg (d_H) and clear the crossing. The distance formula used in both the FHWA Handbook and the AASHTO Green Book is

$$d_T = \frac{V_t}{V_v}\left(1.47\ V_v t_{pr} + \frac{V_v^2}{30f} + 2D + L + W\right) \qquad (2)$$

TABLE 1 COEFFICIENTS OF FRICTION, f (*2*)

Speed (mph)	f
10	0.40
20	0.40
30	0.35
40	0.32
50	0.30
60	0.29
70	0.28

where

d_T = sight distance along the railroad tracks for a moving vehicle (ft),
V_t = velocity of train (mph),
V_v = velocity of vehicle (mph),
t_{pr} = perception-reaction time of vehicle (sec) (assumed: t = 2.5 sec),
f = coefficient of friction used in braking (see Table 1 for assumed values),
D = clearance distance from the vehicle to the nearest rail (ft) (assumed: D = 15 ft),
L = length of vehicle (ft) (assumed: L = 65 ft), and
W = distance between outer rails (ft) (assumed for a single track: W = 5 ft).

The FHWA Handbook and AASHTO Green Book assume a 65-ft truck crossing a single track at 90 degrees on a flat terrain. The coefficient of friction values assumed are those in Table 1. Cautions are offered that adjustments should be made for unusual vehicle lengths and acceleration capabilities, as well as for multiple tracks, skewed crossings, and grades.

Sight Distance Along Tracks for a Stopped Vehicle

The third sight distance consideration is the sight triangle needed to allow a stopped vehicle to accelerate and cross the tracks before the train reaches the crossing. It includes the perception-reaction time of the driver and vehicle characteristics such as maximum speed of vehicle in starting gear, acceleration capability of vehicle, and length of vehicle. The required distance (d_T) along the tracks is determined in the FHWA Handbook and AASHTO Green Book as

$$d_T = 1.47V_t\left(\frac{V_g}{a_1} + \frac{L + 2D + W - d_a}{V_g} + J\right) \qquad (3)$$

where

d_T = sight distance along the railroad tracks for a stopped vehicle (ft),
V_t = velocity of train (mph),
V_g = maximum speed of vehicle in first gear (fps) (assumed: V_g = 8.8 fps),
a_1 = acceleration of vehicle in first gear (fpsps) (assumed: a_1 = 1.47 fpsps),
L = length of vehicle (ft) (assumed: L = 65 ft),
W = distance between outer rails (ft) (assumed for a single track: W = 5 ft),

D = clearance distance from front of vehicle to the nearest rail (ft) (assumed: D = 15 ft),
J = sum of perception-reaction time of driver and time required to activate the clutch or an automatic shift (sec) (assumed: J = 2.0 sec), and
d_a = distance vehicle travels while accelerating to maximum speed in first gear (ft) = $V_g^2/2a_1$.

The FHWA Handbook and the AASHTO Green Book also assume a 65-ft truck crossing a single track at 90 degrees on a flat terrain for this procedure. Adjustments should be made for longer vehicle lengths, slower acceleration capabilities, multiple tracks, skewed crossings, and other than flat highway grades.

CRITIQUE OF POLICY

A review of driver characteristics by McGee et al. (*3*) addressed changes in sight distance requirements that accompany changes in driver characteristics. The driver characteristic reviewed for railroad-highway grade crossing sight requirements (as presented in the first edition of the FHWA Handbook) was perception-reaction time. Their findings indicate that the sight requirements are relatively insensitive to a change in the perception-reaction time.

A review of the cases in the AASHTO Green Book by McGee et al. (*4*) found the formulation for calculating the minimum corner sight triangle for a moving vehicle to be correct and reasonable. They also found that the concept for determining the minimum sight distance along a track for a vehicle at a stopped position was correct. The concept adequately considers both the driver and vehicle requirements.

Wilde et al. (*5*) reported that the lack of uniformity in driver behavior indicates a high level of uncertainty concerning the correct response to grade crossings, and that this may be a major cause of crossing accidents. Vehicle speed variations were higher as the distance to the crossing decreased. Specific speed variations for trucks were not reported.

Schoppert and Hoyt (*6*) identified factors influencing safety at railroad-highway grade crossings in their NCHRP report. They reviewed a sample of 3,627 accidents: one-third involved trains, one-third occurred when the train was present but not involved, and one-third occurred when the train was not even present. They found the following:

- The distribution of vehicle speeds at the crossing differs from that along the highway prior to the influence of the crossing. These conditions were believed to contribute significantly to multiple-vehicle accidents at crossings.
- Trucks were involved in accidents with trains relatively more frequently than other vehicles. This statistic makes a strong argument for using truck design values for sight distance calculations.
- High truck involvement in accidents may be attributable to the truck's greater length, which causes it to occupy the crossing longer.

AASHTO stopping sight distance criteria (*2*) use coefficients of friction that are intended to represent the deceleration rates used by a passenger car in locked-wheel braking on a wet pavement. Trucks cannot safely make a locked-wheel stop without the risk of losing control of the vehicle. A discussion of braking distances by Harwood et al. (in this Record) shows that the deceleration rates used by trucks to make controlled stops are generally lower than the deceleration rates used by passenger cars making locked-wheel stops.

The FHWA Handbook does not cite the studies used as the basis for the following assumptions:

- The speed of the vehicle in selected starting gear is 8.8 fps, and
- The acceleration of the vehicle in starting gear is 1.47 fpsps.

Nevertheless, the use of these assumptions for computing the sight distance along the tracks for a stopped vehicle appears to be reasonable.

SENSITIVITY ANALYSIS

The current sight distance policies directly or indirectly use different vehicle types as the design vehicle. By using deceleration rates for a passenger car in locked-wheel braking on a wet pavement, sight distance along the highway for a moving vehicle is derived with a passenger car as the design vehicle. The derivation for sight distances along the tracks for a moving vehicle mixes design vehicle characteristics by using passenger car deceleration rates but a 65-ft vehicle length (typical for a WB-60 truck). The design vehicle for sight distance along tracks for a stopped vehicle is a 65-ft truck, with reasonable assumptions for both acceleration and the maximum speed in first gear.

Following is a sensitivity analysis to determine the railroad-highway sight distance requirements for the types of trucks permitted since the 1982 STAA, which are not currently included in the AASHTO Green Book. This sensitivity analysis is a simple extension of the existing sight distance considerations to reflect current truck characteristics and performance. Table 2 presents the equations derived and the parameters currently used in the three sight distance considerations. They include a driver-related characteristic (perception-reaction time) and vehicle-related characteristics (stopping sight distance, vehicle length, and maximum speed and acceleration of vehicle in first gear). Table 3 contains the values of the vehicle-related parameters (including vehicle length, stopping sight distance, and vehicle acceleration) that have been varied in the sensitivity analysis.

Truck lengths of 70 and 75 ft were used in the analyses. 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.

The stopping sight distances used are those derived by Harwood et al. (in this Record), based on estimates of truck braking distances developed by Fancher (*7*). 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 expertise. This variation exists because many truck drivers lack experience in emergency

TABLE 3 SUMMARY OF PARAMETERS VARIED IN SENSITIVITY ANALYSIS FOR RAILROAD-HIGHWAY GRADE CROSSING SIGHT DISTANCE

Consideration	Vehicle Length (ft)	Stopping Sight Distance (SSD)			Additional Assumptions
Sight distance along a highway	NA	Truck Driver Performance			NA
		Speed	Worst	Best	
$d_H = SSD + D + d_e$		20 mph	150'	125'	
		30 mph	300'	250'	
$d_H = SSD + 10 + 15$		40 mph	500'	375'	
		50 mph	725'	525'	
$d_H = SSD + 25$		60 mph	975'	700'	
		70 mph	1275'	900'	
Sight distance to and along tracks for a moving vehicle	70' tractor semi-trailer truck 75' tractor semi-trailer-full trailer truck (double bottom)	Truck Driver Perforance			NA
		Speed	Worst	Best	
		20 mph	150'	125'	
		30 mph	300'	250'	
		40 mph	500'	375'	
$d_T = \frac{V_t}{V_v} (SSD + 2D + L + W)$		50 mph	725'	525'	
		60 mph	975'	700'	
$d_T = \frac{V_t}{V_v} (SSD + 2 * 15 + L + 5)$		70 mph	1275'	900'	
$d_T = \frac{V_t}{V_v} (SSD + 35 + L)$					
Sight distance along tracks for a stopped vehicle	70' tractor semi-trailer truck 75' tractor semi-trailer-full trailer truck (double bottom)	NA			t_c = time to clear hazard zone (from Gillespie's equation (9))
$d_T = 1.47V_t(t_c + J)$					
$d_T = 1.47V_t \, [0.682 * (2 * D + W + L)/Vmg + 3.0 + 2.0]$					
$d_T = 1.47V_t \, [0.682 * (2 * 15 + 5 + L)/8 + 3.0 + 2.0]$					
$d_T = V_t \, [0.125L + 11.73]$					

TABLE 2 SUMMARY OF PARAMETERS FOR RAILROAD-HIGHWAY GRADE CROSSING SIGHT DISTANCE

Equations	Perception-Reaction Time (sec)	Stopping Sight Distance (SSD)	d_e (ft)	D (ft)	W (ft)	Length of Vehicle (ft)	V_g (fps)	a_1 (fpsps)
		SSD Values[2]						
Sight distance		Speed SSD						
along a highway	$t_{pr} = 2.5$	20 mph 125'	10	15	NA	NA	NA	NA
		30 mph 200'						
$d_H = SSD + D + d_e$		40 mph 325'						
		50 mph 475'						
$d_H = SSD + 10 + 15$		60 mph 650'						
		70 mph 850'						
$d_H = SSD + 25$								
		SSD Values[2]						
Sight distance to and		Speed SSD						
along tracks for a	$t_{pr} = 2.5$	20 mph 125'	NA	15	5		NA	NA
moving vehicle		30 mph 200'						
		40 mph 325'						
		50 mph 475'						
$d_T = \frac{V_t}{V_v} [SSD + 2D + L + W]$		60 mph 650'				65 WB-60		
		70 mph 850'						
$d_T = \frac{V_t}{V_v} [SSD + 2 * 15 + 65 + 5]$								
$d_T = \frac{V_t}{V_v} [SSD + 100]$								
Sight distance along tracks for a stopped vehicle	$J = 2.0$	NA	NA	15	5		8.8	1.47
$d_T = 1.47V_t [\frac{V_G}{a_1} + \frac{L + 2D + W - d_a}{V_g} + J]$ $d_a = \frac{V_g^2}{2a_1}$						65 WB-60		
$d_T = 1.47V_t [\frac{8.8}{1.47} + \frac{65 + 2 * 15 + 5 - (8.8^2/(2 * 1.47))}{8.8} + 2.0]$								
$d_T = 16.9V_t$								

braking, and because different drivers accept varying amounts of "risk" in what is potentially a hazardous operation that could lead to truck jackknifing. Fancher (7) 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 the 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.

Since truck size, weight, and performance characteristics have been changing, more recent truck acceleration information is needed. In 1986, Gillespie (8) reported clearance times for trucks crossing an intersection. The 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 was estimated by the following equation:

$$t_c = 0.682 \frac{L_{HZ} + L}{V_{mg}} + 3.0 \text{ sec} \quad (4)$$

where

- L_{HZ} = length of the hazard zone (ft) = $2D + W$,
- D = clearance distance from front of vehicle to the nearest rail (ft) (assumed: D = 15 ft),
- W = distance between outer rails (ft) (assumed for a single track: W = 5 ft),
- L = 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).

Equation 4 assumes that the gear design, engine speed, and the tire size are such that the truck's maximum speed is 60 mph on a level surface. It also assumes that a truck will remain in the initial gear without shifting while negotiating the hazard zone. Gillespie also developed a maximum speed in initial gear versus grade curve for determination of clearance time for trucks accelerating on a grade.

Sight Distance Along Highway for a Moving Vehicle

The sight distance along the highway to the crossing (d_H) increases significantly in comparison with the current FHWA criteria when the increased stopping sight distances of trucks are considered. Table 4 presents the required sight distances for current criteria in comparison with trucks with the worst-performing and best-performing drivers. (The stopping sight distances for these drivers are shown in Table 3.) The results shown in Table 4 are shown depicted in Figure 2. Although the effect appears minimal for a truck with the best-performing driver (between 7 to 22 percent increase in sight distance), significant increases in sight distances are required for a truck with the worst-performing driver (between 30 and 54 percent increase).

Sight Distance Along Tracks for a Moving Vehicle

A sensitivity analysis of the sight distance requirements along the track from the crossing (d_T) found similar results (see Table 5 and Figure 3 for a 70-ft truck length). A 70-ft truck requires a 23 percent increase in sight distance at 20 mph and up to a 47 percent increase at 70 mph for a worst-performing driver. A best-performing driver of a 70-ft truck requires a maximum of a 20 percent increase in sight distance. A 75-ft

TABLE 4 SENSITIVITY ANALYSIS FOR SIGHT DISTANCE ALONG A HIGHWAY (d_H)

	VEHICLE SPEED, V_V (mph)					
	20	30	40	50	60	70
	d_H (ft)	d_H (ft)	d_H (ft)	d_H (ft)	d_H (ft)	d_H (ft)
Current values	135	225	340	490	660	865
Sight Distances for a truck with worst-performance driver	175	325	525	750	1000	1300
Sight Distances for a truck with best-performance driver	150	275	400	550	725	925

Note: FHWA rounded all calculated distances up to the next higher 5-foot increment.

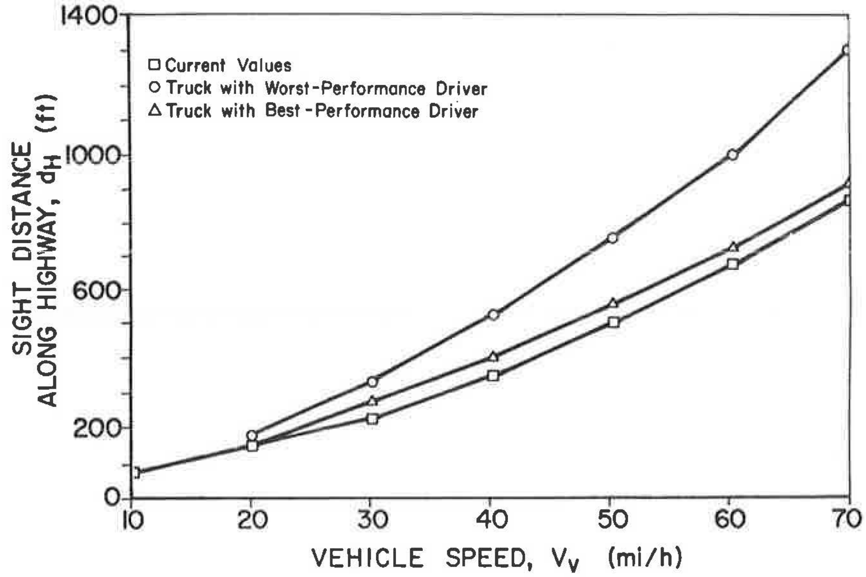

FIGURE 2 Sensitivity analysis for sight distance along highway (d_H).

truck requires similar increases in sight distance (a maximum 22 percent increase for a best-performing driver and up to a 49 percent increase for a worst-performing driver). Not only did the greater truck length increase the required sight distance, but the braking distance for the worst driver for both truck lengths also significantly increased the required sight distance.

Sight Distance Along Tracks for a Stopped Vehicle

The sight distance requirement along the tracks for a stopped vehicle is not very sensitive to vehicle length. Table 6 and Figure 4 present the results of increasing the current design vehicle length of 65 ft to 70 and 75 ft and using the equation developed by Gillespie (*8*) for the time to clear a hazard zone (Equation 4 in this paper). The sight distance values calculated using AASHTO assumptions—of a 65-ft truck, 8.8 fps for maximum speed of vehicle in first gear, and 1.47 fpsps for acceleration of vehicle in first gear—are longer than those calculated using a 70- or 75-ft truck length and the Gillespie model for clearance times (t_c). This is the result of the Gillespie model providing lower values of clearance times (t_c) than the current AASHTO criteria.

SUMMARY OF FINDINGS

The sensitivity analyses demonstrate that trucks moving ahead to the railroad-highway grade crossings require increased sight distance along the highway (d_H) primarily because of their longer braking distances. The added sight distance requirements are substantial for trucks with the worst-performing driver, but are minimal for trucks with the best-performing driver.

Similar conclusions were reached for sight distance needed along the tracks from the crossing (d_T) for a moving vehicle. Substantially longer sight distances are required for a truck with the worst-performing driver (up to 49 percent increase in sight distance).

In contrast, the current requirements for sight distance required along the tracks for a stopped vehicle, based on a 65-ft truck, were found to be adequate for the 70- and 75-ft trucks when the Gillespie (*8*) model for clearance time is used.

CONCLUSIONS

The sight triangles required for highway vehicles approaching a railroad-highway grade crossing are considerably larger than those required by the FHWA Handbook and the AASHTO Green Book if the needs of truck drivers are fully considered. Currently, with a minimum FHWA or AASHTO sight triangle for assumed speeds, a truck driver can easily face a dilemma. If a train appears at the track apex of this sight triangle as the truck reaches the highway apex, the truck driver must decide to proceed at a constant or increased speed rather than either slowing or stopping. If he decides to stop, he will collide with the train before coming to a full stop. If he begins to stop and then decides to proceed, he will collide with the train before clearing the crossing.

To provide an adequate margin of safety for truck drivers at railroad-highway grade crossings, current FHWA (*1*) and AASHTO (*2*) sight triangle values for moving vehicles should be increased to allow for longer trucks and for some measure of the greater stopping distances of trucks compared with passenger vehicles. To arrive at representative values, a decision regarding the level of truck driver performance is required. The range of values calculated earlier should provide some guidance for this task.

Considering that bigger sight triangles may be necessary to accommodate large trucks at railroad-highway grade cross-

TABLE 5 SENSITIVITY ANALYSIS FOR SIGHT DISTANCE TO AND ALONG TRACKS (d_T)

Train Speed V_t (mph)	Vehicle Speed, V_v (mph)					
	20	30	40	50	60	70
	d_T (ft)	d_T (ft)	d_T (ft)	d_T (ft)	d_T (ft)	d_T (ft)
CURRENT AASHTO PROCEDURES USING A 65-FOOT TRUCK						
10	105	100	105	115	125	135
20	210	200	210	225	245	270
30	310	300	310	340	370	405
40	415	395	415	450	490	540
50	520	495	520	565	615	675
60	620	595	620	675	735	810
70	725	690	725	790	860	940
80	830	790	830	900	980	1075
90	930	930	930	1010	1105	1210
SIGHT DISTANCES FOR A 70-FOOT TRUCK WITH WORST-PERFORMANCE DRIVER						
10	128	135	151	166	180	197
20	255	270	303	332	360	394
30	383	405	454	498	540	591
40	510	540	605	664	720	789
50	638	675	756	830	900	986
60	765	810	908	996	1080	1183
70	893	945	1059	1162	1260	1380
80	1020	1080	1210	1328	1440	1577
90	1148	1215	1361	1494	1620	1774
SIGHT DISTANCES FOR A 70-FOOT TRUCK WITH BEST-PERFORMANCE DRIVER						
10	115	118	120	126	134	144
20	230	237	240	252	268	287
30	345	355	360	378	403	431
40	460	473	480	504	537	574
50	575	592	600	630	671	718
60	690	710	720	756	805	861
70	805	828	840	882	939	1005
80	920	947	960	1008	1073	1149
90	1035	1065	1080	1134	1208	1292

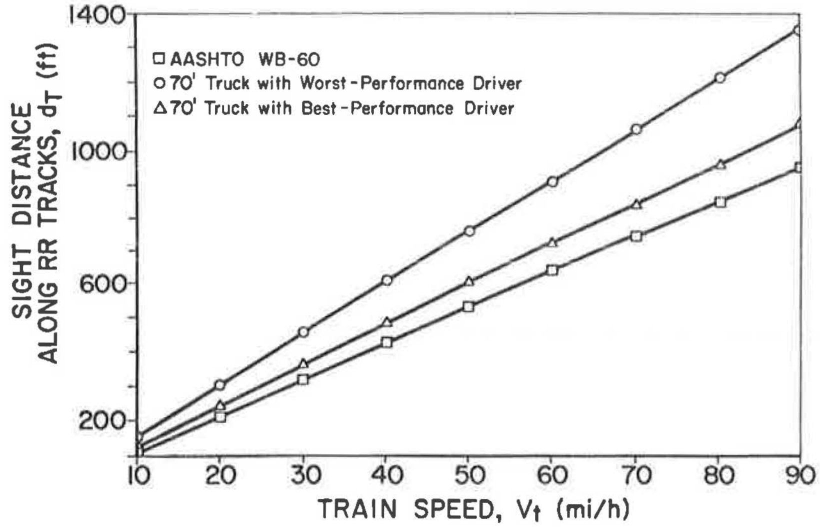

FIGURE 3 Sensitivity analysis for sight distance along tracks (d_T) for a moving vehicle at 40 mi/h.

TABLE 6 SENSITIVITY ANALYSIS FOR SIGHT DISTANCE ALONG TRACK FOR A STOPPED VEHICLE

TRAIN SPEED V_t (mph)	AASHTO PROCEDURE AASHTO WB-60 TRUCK d_T (ft)	70' TRACTOR-SEMI TRAILER TRUCK d_T (ft)	75' TRACTOR-SEMI TRAILER-FULL TRAILER TRUCK d_T (ft)
10	240	206	212
20	481	412	423
30	721	617	635
40	962	823	847
50	1202	1029	1058
60	1443	1235	1270
70	1683	1441	1482
80	1924	1646	1693
90	2164	1852	1905

ASSUMED:

t_c determined from Gillespie's equation

t_c = 12.0 seconds for 70' truck

t_c = 12.4 seconds for 75' truck

L_{hz} = 2D + W = 2*15' + 5' = 35'

V_{mg} = 8.0 mph

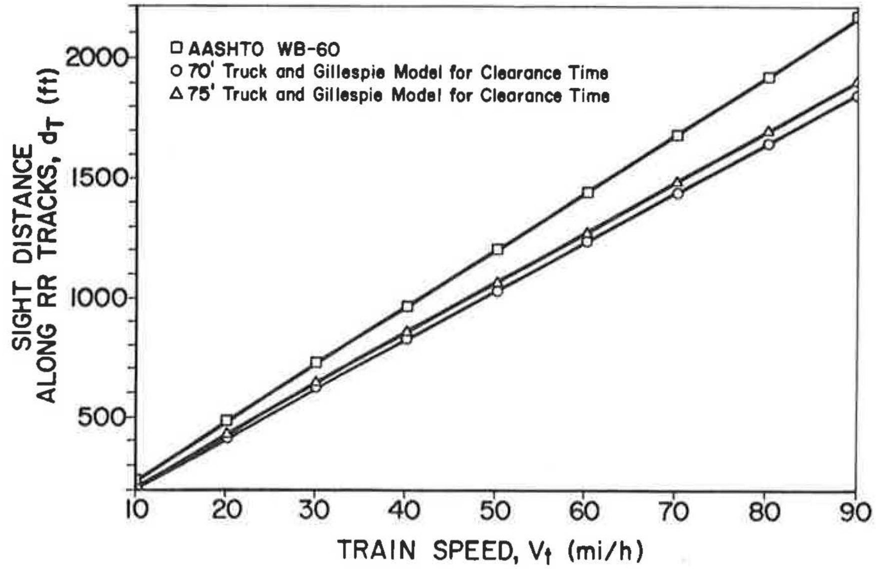

FIGURE 4 Sensitivity analysis for sight distance along tracks for a stopped vehicle (d_T).

ings, many more crossings than previously thought may have physical constraints that make the available sight triangle unacceptable. Therefore, if the needs of truck drivers are truly considered, the need for positive and active traffic controls at grade crossings may be greater than previously thought.

In contrast to the moving-vehicle analysis described above, the current FHWA and AASHTO sight distance criteria for stopped vehicles appear to adequately accommodate the needs of truck drivers.

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