Intersection Design Considerations To Accommodate Large Trucks

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

The geometric and operational considerations of large trucks at intersections are addressed. The discussion summarizes the related findings of an FHWA study of truck characteristics for use in highway design and operations. Also cited are the implications of the Turner truck proposal, comparisons with Canadian Interprovincial trucks, and the preliminary results of recent research on AASHTO intersection sight distance procedures. A brief review of channelization requirements of large trucks, the effects large trucks have on intersection capacity and traffic signalization, and advance warning sign placement considering truck stopping distance and deceleration rates is provided.

At-grade intersections vary greatly in type, size, and function. The geometric features of an intersection are influenced by four basic elements: human factors, traffic characteristics, physical elements, and economic factors (*1*). This paper addresses the geometric and operational considerations of large trucks at intersections. The discussion draws primarily on a recently completed study by Harwood et al. that identified, evaluated, and assessed large truck characteristics for use in highway design (*2*). Several other publications are referenced that provide guidance on related issues not fully addressed in the AASHTO 1990 Green Book (GB90) policy (*1*). Among the more salient documents are the Turner proposal, Canadian Interprovincial truck regulations, and intersection sight distance procedures (*3–5*).

The truck characteristics section of this paper demonstrates the implications of a changing commercial vehicle fleet. The findings of the TRB special study of the Turner truck proposal highlight the effects of the prototypes on future at-grade intersection designs. A comparison of Canadian truck weights and dimensions with the AASHTO GB90 policy is also provided. The phenomenon known as offtracking, as influenced by pavement cross-slope, is explained for both low-speed and high-speed maneuvers. A comparison of truck offtracking performance considering turning angle and radius is presented for specific truck-trailer combinations.

TRUCK PHYSICAL CHARACTERISTICS

The size and operating characteristics of vehicles that are expected to use an at-grade intersection are primary considerations in its design. Vehicle characteristics that affect intersection design are physical characteristics such as width, length, number of axles, distance between axles, and number of articulation points. Vehicle operating characteristics such as offtracking, acceleration, and deceleration also influence the overall intersection design. For highway design purposes, trucks are generally classified as single-unit or straight trucks, straight trucks with trailer, tractor-semitrailers, tractor-semitrailer–full trailer (commonly referred to as a double or twin trailer truck), and tractor-semitrailer–full trailer–full trailer (commonly referred to as a triple).

Trends in Truck Size and Weight

As the demand for movement of freight by trucks has increased, trucks have become larger and heavier. For example, in 1927 the median weight limit for combination trucks was less than 40,000 lb; the median weight limit rose to 48,000 lb in 1940, 72,000 lb in 1964, and 80,000 lb in 1982 (*6*). In 1949, the median length limit was 50 ft for a combination truck. This had increased to 55 ft by 1964 and 65 ft by 1982 (*6*). Width limits have been more stable, with most states setting a maximum width of 96 in. until 1982, when federal legislation increased the allowable width to 102 in.

Until 1956, truck size and weight regulations were established by state and local jurisdictions. However, the Federal Aid Highway Act of 1956 established maximum limits on Interstate highways for vehicle width (96 in.) and gross weight (73,280 lb). Federal legislation in 1975 allowed vehicles up to 80,000 lb to operate on the Interstate system.

The 1982 Surface Transportation Assistance Act (STAA) expanded the role of the federal government in the regulation of truck size and weight. For the first time, the federal government required states to change existing truck size and weight limits in the interest of national uniformity.

The act applies to trucks operating on the National Truck Network. This network includes the Interstate system and certain other highways for a total mileage of about 183,000 mi. The act requires the states to allow trucks of the following dimensions and number of trailers to operate on the National Truck Network. Provisions of the act that affect highway design are as follows:

- Trailers up to 48 ft long in a tractor-semitrailer combination cannot be prohibited by the states. Grandfather provisions in the act allow the continued operation of trailers larger than 48 ft in states where they were legal before passage of the STAA.

J. M. Mason, Jr., Pennsylvania Transportation Institute, Pennsylvania State University, 201 Research Office Building, University Park, Pa. 16802-4710. K. Fitzpatrick, Texas Transportation Institute, The Texas A&M University System, College Station, Tex. 77843. D. W. Harwood, Midwest Research Institute, 425 Volker Boulevard, Kansas City, Mo. 64110. J. True, Federal Highway Administration, HSR-20, 6300 Georgetown Pike, McLean, Va. 22101.

- Trailers up to 28 ft long in a tractor-semitrailer–full trailer (double) combination cannot be prohibited by the states. Again, a grandfather provision allows the continued operation of longer trailers if they were legal in a state before the passage of the STAA.
- The width limit was increased from 96 to 102 in.

The STAA is important from a highway design standpoint because longer and wider trucks have become more common and need to be accounted for in the design of at-grade intersections.

Current Design Vehicles

The GB90 includes 15 design vehicles: 1 passenger car, 2 buses, 4 types of recreational vehicles, and 8 trucks. The dimensions of these vehicles for use in design can be found in Table II-1 of GB90 (*1*). The GB90 recommends that the "design vehicle" be likely to use the facility with considerable frequency or to have special characteristics. For example, the turnpike double is unique because it has an overall length of about 118 ft and in a low-speed turn offtracks about 25 ft. This is in contrast to a tractor-semitrailer with a 48-ft trailer, which has an overall length of about 65 ft and offtracks about 17.3 ft.

Turner Proposal

TRB recently completed a comprehensive study of the Turner truck proposal (*3*). This proposal, suggested in 1984 by former Federal Highway Administrator Francis C. Turner, recommends an approach for reducing pavement wear while increasing truck productivity. Pavement wear would be reduced by lower axle loads (more axles per truck), and truck productivity would be improved by increasing gross vehicle weight.

The TRB study estimated the costs and benefits of the Turner proposal in the areas of truck productivity, safety, traffic, bridges, and pavements. In conducting the study, four prototype trucks were used. Three baseline trucks were used for comparison purposes. The four prototype trucks are described in Table 1.

As previously discussed, one characteristic that affects at-grade intersection design is low-speed offtracking. Table 2 gives the low-speed offtracking characteristics of the four prototype trucks and the three baseline trucks used in the TRB study (*3*). An examination of Table 2 shows that the nine-axle B-train double offtracks about 3.5 ft more than a conventional five-axle tractor-semitrailer with a 45-ft trailer.

A nine-axle B-train double would have difficulty in maneuvering at an at-grade intersection designed to accommodate a five-axle trailer-semitrailer with a 45-ft trailer. The 11-axle double trailer combination prototype was excluded from the study because it was determined that this truck type would require costly bridge improvements.

Canadian Truck Limits

In 1988, the Canadian Council of Ministers of Transportation and Highway Safety agreed to a memorandum of understanding establishing uniform truck weights and dimensions (*4*). The approved weights and dimensions apply only to trucks engaged in interprovincial commerce. The following four categories of trucks are covered: tractor-semitrailer, A-train, B-train, and C-train. Figure 1 shows the allowable dimensions for these four categories of trucks. The dimensions shown are direct conversions from metric to the nearest tenth of a foot.

TABLE 1 Four Turner Prototype Trucks (*3*)

Characteristic	Seven-Axle Tractor-Semitrailer	Nine-Axle Double	11-Axle Double	Nine-Axle B-Train Double
Dimensions[a]				
Overall length (ft)	60	81	81	81
Trailer length (ft)	48	33	33	33
Trailer axle width (in.)	102	102	102	102
Weight[b] (lb thousands)				
Gross if limited by axle weights only[c]	91	111	141	111
Gross if also limited by federal bridge formula	91	111	127	111
Payload	60	73	101 or 87	73
Tractor	Conventional	Conventional	Conventional	Conventional
Trailer	Flatbed, van, bulk	Flatbed, van, bulk	Flatbed, van, bulk	Flatbed, van, bulk
Tires[d] (no. on loaded axles)	1 or 2	1 or 2	1 or 2	1 or 2
Dolly	None	Single or double drawbar	Single or double drawbar	None
Suspension[e]				

[a]For evaluating impacts, axle spacings and kingpin and fifth wheel positions must also be specified.
[b]Empty weights and axle weight distributions must also be specified.
[c]Single axle, 15,000 lb; tandem axles, 25,000 lb; triaxles, 40,000 lb; steering axle practical limit, 11,000 lb.
[d]Tire size and pressure must also be specified.
[e]Suspension types, use of lift axles, use of steerable axles, use of belly axles, or other arrangements within multiaxle groups must be specified.

TABLE 2 Offtracking Characteristics of Turner Prototype Trucks and Baseline Trucks (*3*)

Characteristic	Polarity of Measure	Baseline Vehicle			Prototype Vehicle			
		Five-Axle Tractor-Semitrailer[a]	Five-Axle Twin Trailer[b]	Nine-Axle Turnpike Double[c]	Seven-Axle Tractor-Semitrailer[d]	Nine-Axle B-Train Double[e]	Nine-Axle Double[e]	Eleven-Axle Double[e]
Low-speed offtracking (ft)	Lower values better	15.36	14.27	25.11	15.81	18.87	15.96	13.17

[a]With 45-ft semitrailer.
[b]With 28-ft trailers.
[c]With 45-ft trailers.
[d]With 48-ft semitrailer.
[e]With 33-ft trailers.

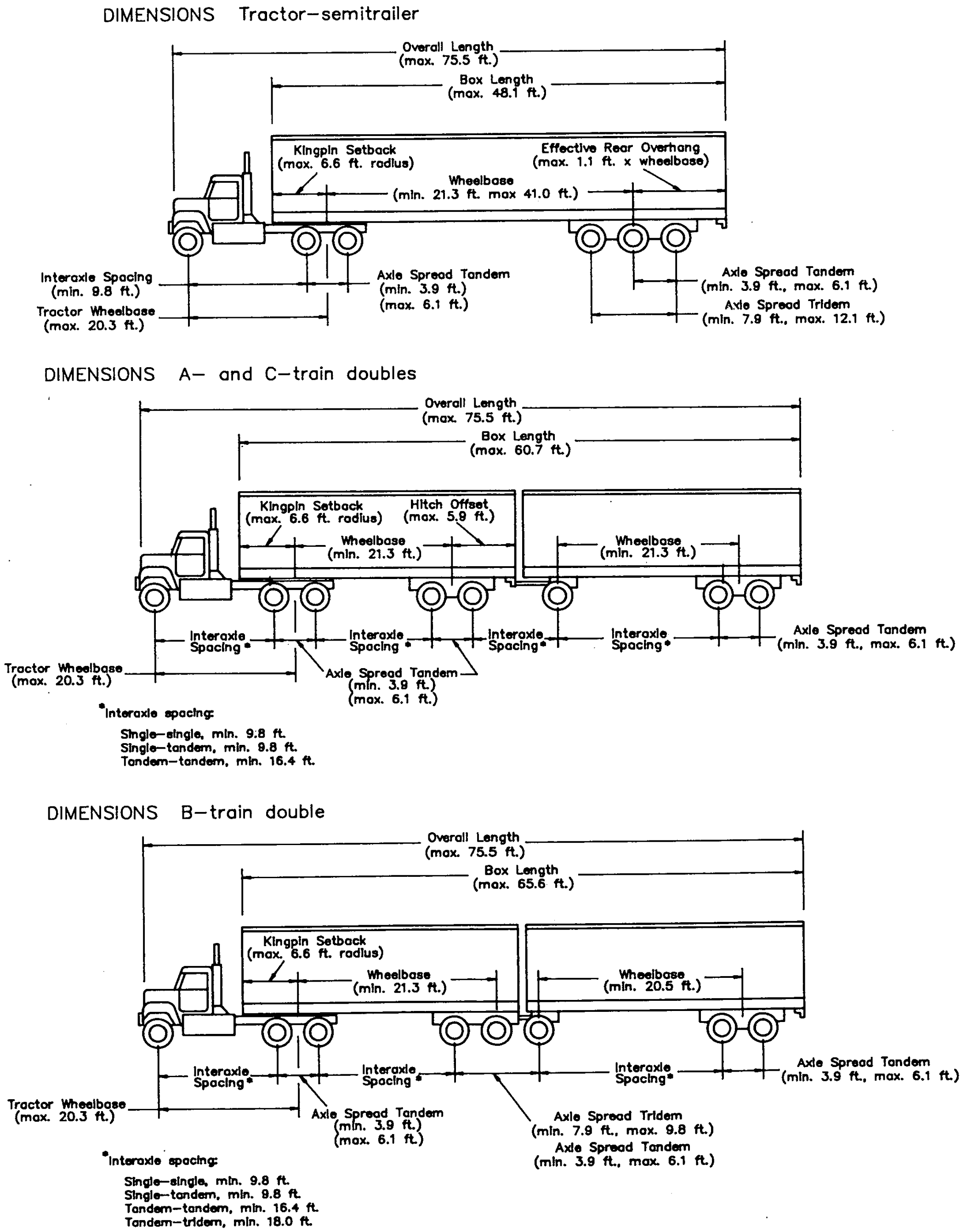

FIGURE 1 Canadian Interprovincial truck dimensions (*4*).

In comparing these vehicles with the current design vehicles contained in the GB90, the following points are offered:

- The Canadian tractor-semitrailer has dimensions that are similar to the GB90 Interstate semitrailers WB-62 and WB-67.
- The Canadian doubles are somewhat larger than the GB90 double (WB-60). For example, the WB-60 has a tractor wheelbase of 9.7 ft, whereas the Canadian tractor may have a wheelbase as long as 20.3 ft. Also, the trailer wheelbases of the Canadian doubles are longer than those of the WB-60. Longer wheelbases increase offtracking, which is an important factor in at-grade intersection design.

The discussion of the Canadian vehicles is presented as a guide for those involved in the design of at-grade intersections where these vehicles would be expected to operate.

OFFTRACKING

Offtracking is the phenomenon by which the rear wheels of a vehicle do not follow the same path as the front wheels. Offtracking occurs in all types of vehicles but is relatively small in passenger cars. However, offtracking by large trucks is an important consideration in intersection design.

Figure 2 shows offtracking by a truck making a turning maneuver. The most appropriate descriptor of offtracking for use in intersection design is the "swept path width," shown in Figure 2 as the difference in paths between the outside front tractor tire and the inside rear trailer tire.

Many sources, including the GB90, have identified two distinct types of offtracking. Low-speed offtracking is a purely geometrical phenomenon wherein the rear axles of a truck track toward the inside of a horizontal curve relative to the front axle. Figure 2 shows low-speed offtracking. There has been considerable research on low-speed offtracking as it pertains to level roadway pavement surfaces. Low-speed offtracking has been generally understood to be a function of the truck axle and hitch point spacings, the turn radius, and the turn angle.

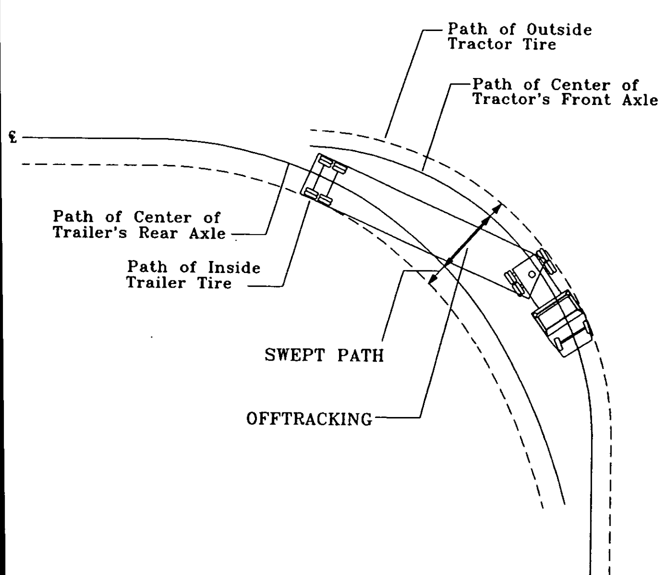

FIGURE 2 Swept path width and offtracking of a truck negotiating a 90-degree intersection turn (*2*).

Recent research by Glauz and Harwood has shown that low-speed offtracking is also influenced by pavement cross-slope, including superelevation on horizontal curves (*7*). Offtracking increases with increasing pavement cross-slope. For example, the low-speed offtracking of a truck with a 48-ft semitrailer on a curve with a 500-ft radius is increased by 20 percent on a curve with a superelevation of 0.08 ft/ft.

High-speed offtracking is a dynamic, speed-dependent phenomenon. It is caused by the tendency of the rear of the vehicle to move outward because of the lateral acceleration of the vehicle as it negotiates a horizontal curve at high speeds. High-speed offtracking is a function not only of truck and roadway geometrics but also of the vehicle speeds and the suspension, tire, and loading characteristics of the vehicle.

Intersection design can generally be based on low-speed offtracking without considering speed-dependent or superelevation effects. This is the case because most intersection turning maneuvers by trucks are conducted at low speeds on pavements with very little cross-slope.

Determination of Low-Speed Offtracking for Use in Intersection Design

There are four methods for determining offtracking for use in intersection design: offtracking plots and templates, computer models, offtracking charts, and offtracking equations. Each of these approaches is briefly described in the following subsections.

Turning Plots and Templates

Offtracking for use in intersection design is determined most commonly from plots depicting the turning paths of trucks. A turning angle of 90 degrees is appropriate for most intersection situations. Of course, unusual geometric situations requiring other turning angles, including skewed intersections, are not uncommon. Turning plots for various combination trucks can be found in the GB90 (*1*).

Turning templates have historically been developed using graphical techniques, such as the Tractrix Integrator (*8*). This approach has been used to create templates that can be used by designers to trace the swept path width of a vehicle to scale on the plan view of an intersection so that the geometrics of the intersection and turning roadways can be selected to accommodate a particular design vehicle (*9*).

Computer Models

A number of state departments of transportation, universities, and consultants have computer models, both PC based and mainframe, to generate truck offtracking values. These models vary in sophistication and output. For example, some models only provide turning plots of the vehicle swept paths, whereas others provide both the plots and numerical values.

The California Department of Transportation (Caltrans) has recently enhanced an existing PC offtracking model to include numerical output of offtracking and swept paths as well as the turning plot (*10*).

Offtracking Charts

With the availability of computer models with numerical output, offtracking charts can be prepared to conveniently summarize the offtracking performance of specific vehicles. Figure 3 shows the offtracking performance of a combination truck with a 48-ft semitrailer. Charts of this type for a variety of vehicles are presented by Harwood et al. (*2*), and four typical charts are presented by Glauz and Harwood (*7*). Figure 3 shows that, for a given truck, offtracking decreases with increasing turn radius. For a given radius, offtracking increases with increasing turn angle until a maximum or steady-state value is reached.

The swept path width can be determined by adding 7.58 ft to the offtracking values in Figure 3. The value of 7.58 ft is equivalent to one-half of the typical rear tractor steering axle width (6.66 ft) plus one-half of the typical rear trailer axle width (8.50 ft).

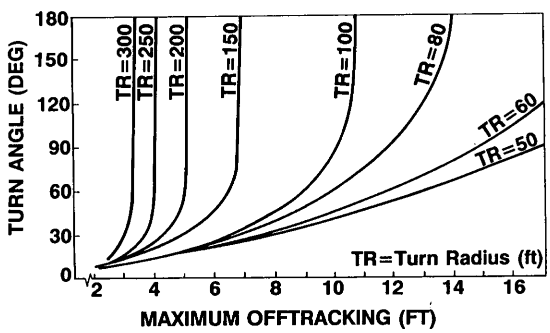

FIGURE 3 Offtracking plot for STAA single 48-ft (14.6-m) semitrailer truck with conventional tractor (*2*).

Offtracking Equations

Several published equations can be used to determine truck offtracking. All of these equations predict the maximum or steady-state offtracking (i.e., the offtracking value of the vertical portion of each curve in Figure 3). For smaller turn angles, the actual offtracking may be less than this maximum.

The best known offtracking equation is the Western Highway Institute (WHI) offtracking formula (*11*). The WHI formula is a special case of a more general formula developed by Glauz and Harwood, which includes the speed-dependent and superelevation effects (*7*).

Comparison of Truck Offtracking Performance

Table 3 summarizes the maximum offtracking of a variety of truck types of turns on 50-, 100-, and 300-ft radii and for turn angles of 60, 90, and 120 degrees. The truck axle spacings used to derive these values are similar, but not identical, to the design vehicles recommended in the GB90 (*1*,*2*). The table shows clearly that offtracking (*a*) decreases with increases in turn radius, (*b*) increases with increases in turn angle (until a maximum is reached), and (*c*) increases with increases in trailer length (because of increased spacing between the front and rear trailer axles). Double-trailer trucks with 28-ft trailers generally have offtracking that is less than, or equal to, even the shortest single-trailer combination trucks.

INTERSECTION SIGHT DISTANCE

AASHTO Procedures

AASHTO policy provides sight distance values for vehicles stopped on the minor approach of an at-grade intersection (i.e., Case III). Case IIIA represents the sight distance needed to complete a crossing maneuver for a stopped vehicle. Case

TABLE 3 Offtracking for Selected Combinations of Turn Radius and Turn Angle (*2*)

	Maximum offtracking (ft)[a]								
Turn radius (ft):	50			100			300		
Turn angle:	60°	90°	120°	60°	90°	120°	60°	90°	120°
Design Vehicle									
Single with 37-ft trailer (WB-50)	9.3	11.8	13.3	6.0	6.5	6.6	2.1	2.1	2.1
Single with 45-ft trailer	12.1	15.5	NA	8.0	9.0	9.4	2.9	2.9	2.9
STAA single with 48-ft trailer and conventional tractor	13.0	16.9	NA	8.8	10.0	10.5	3.3	3.3	3.3
STAA single with 48-ft trailer and long tractor	13.4	17.4	NA	9.1	10.4	10.8	3.4	3.4	3.4
Long single with 53-ft trailer	14.4	19.5	23.4	10.3	12.1	12.8	4.1	4.1	4.1
STAA double with cab-over-engine tractor	9.2	11.3	12.6	5.8	6.1	6.2	1.9	1.9	1.9
STAA double with cab-behind-engine tractor	9.6	11.9	13.4	6.0	6.4	6.4	2.1	2.1	2.1

[a]Add 7.58 ft to entries in this table to get maximum swept path width.
NA = Not available

IIIB, Curve B-1 represents the sight distance to the left for a left-turning vehicle. Cases IIIB and IIIC (turning left or right onto a cross road), Curves B-2a & Ca and B-2b & Cb represent the sight distances to a major-road vehicle in the lane being entered when the major-road vehicle is traveling at design speed or reducing to average running speed, respectively.

The intersection sight distance (ISD) procedures presented in GB84 and GB90 are based primarily on consideration of the passenger car as the design vehicle. However, highway design and operational criteria should consider the characteristics of all vehicles using a facility with reasonable frequency. AASHTO policy provides actual sight distance values for trucks in Case IIIA only.

The intersection sight distance discussions presented in the GB84 for Cases IIIB and IIIC lacked sufficient information to derive the AASHTO sight distance values (shown in GB84, Figure IX-27). Equations were developed to reproduce the GB84 ISD values on the basis of specific information presented in the GB84 (*2,5*). Using truck data information from the GB84 and the developed equations, WB-50 sight distances were determined for the different Case IIIB and IIIC sight distance procedures. The sight distance values for a turning WB-50 when the major-road vehicle reduces speed to the average running speed are shown as curve WB-50 in Figure 4.

Operational experiences indicate that sight distances as long as 3,000 ft (see Figure 4) are not necessary for safe operations at intersections even when trucks are present. Very few intersections have such long sight distances available, and it is unlikely that drivers could accurately judge the location and speed of an oncoming vehicle at a distance of 3,000 ft. Rather, the results indicate that using the procedures that are based on the GB84 for Cases IIIB and IIIC (for truck intersection sight distance determinations) are not practical. Further investigation into the operations at intersections is needed to determine viable sight distance values for trucks.

Field Observations

Intersection sight distance values were estimated using the findings from pilot field studies as input into the developed ISD equations (*2*, paper by Fitzpatrick et al. in this Record). Data were collected for the following parameters: minor-road vehicle acceleration, major-road vehicle deceleration and speed reduction, and the minimum separation between the major-road vehicle and the turning vehicle.

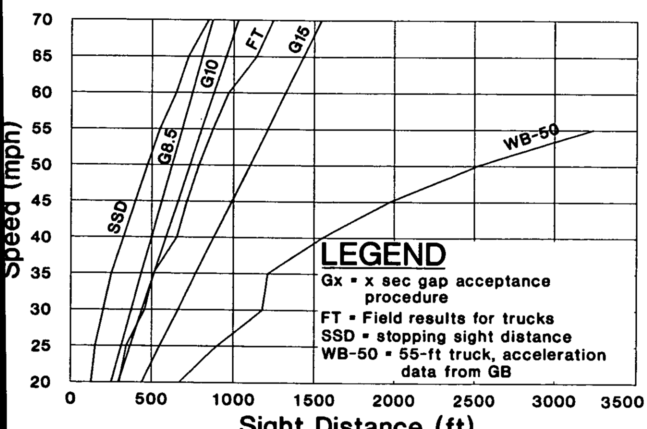

FIGURE 4 Comparison of five-axle truck sight distances for right and left turns.

The FT curve in Figure 4 shows the sight distance values for five-axle trucks. Although the values are based on limited pilot field study, the findings illustrate the difference in required sight distance values when data from actual intersection operations are considered. The five-axle truck results are between 55 and 73 percent less than the values obtained from using the Green Book truck data in the developed equations.

Gap acceptance information was also collected in the referenced field studies. These data were used to develop an alternative method for determining intersection sight distance. Figure 4 also shows the sight distances based on selected accepted gap lengths of 8.5, 10.0, and 15.0 sec. These gaps represent the following:

- 8.5 sec, the 50 percent probability of a five-axle truck driver accepting a gap;
- 10.0 sec, the 85 percent probability of a five-axle truck driver accepting a gap at a high-volume (20,000 major road ADT) location; and
- 15.0 sec, the 85 percent probability of a five-axle truck driver accepting a gap at a low-volume (7,000 and 14,000 major road ADT) location.

The results from the pilot field studies indicate that the sight distances used by drivers in an operational setting are significantly less than the sight distances calculated using GB84 truck characteristics. Alternative procedures for determining sight distances that also consider drivers' visual limitations need to be considered. Both the field studies and the sensitivity analyses also indicate the need to update truck acceleration data. A complete discussion of the field studies and intersection sight distance is contained elsewhere (*2*, paper by Fitzpatrick et al. in this Record).

Ramp Terminals

Sight distance criteria for ramp terminals are intended to ensure that a vehicle stopped at the terminal will have adequate time to turn left and clear the intersection without colliding with a vehicle coming from the left. Ramp terminals should be designed on the basis of the same sight distance design elements as those used for other at-grade intersections. Therefore, sight distance criteria for ramp terminals are similar to the Curve B-1 procedure. An added sight distance consideration is the location of bridge parapet walls or bridge railings.

CHANNELIZATION

Channelization serves to control and direct traffic movement. The GB90, Table IX-4, provides minimum design dimensions for various oblique-angle turns. As indicated earlier, the turning characteristics of large trucks, such as offtracking and swept path width, require special consideration in the geometric layout of at-grade intersections. If the curb radius is large enough that trucks can make right turns without encroaching on adjacent lanes, the paved area at the intersection can become so large that through drivers may not understand where to position their vehicles. In such instances, it becomes necessary to construct a channelizing island to properly control traffic. If the curb radius is so small that trucks cannot make right turns without encroaching on adjacent lanes, the truck either encroaches and interferes with adjacent traffic or it does not encroach and its rear wheels run over and possibly damage the curb or shoulder. In addition, the truck's front overhang may strike traffic control devices located near the outside of its turning path, or the trailer's right rear tire may strike those devices located near the inside of its turning path when offtracking.

A study of at-grade, right-turn maneuvers by large trucks established channelization guidelines in a form similar to the GB90, Table IX-4, information (*12*). The cross street and swept path widths were identified on the basis of a computer simulation program, Truck Offtracking Model (TOM), developed by Caltrans (*10*). The design vehicles selected were two singles (WB-50 and WB-55), two doubles (WB-70 and WB-105), and one triple (WB-100). Truck dimensions were based on the then-current GB84 and supporting literature. The offtracking characteristics of the WB-55 and WB-70 were very similar to the STAA 48-ft single trailer and STAA doubles, respectively.

In addition to the design vehicles, parameters considered in the Texas study were curb return simple radius and degree of turn angle (*12*). The minimum turning radii of the outside and inside wheelpaths for each of five design vehicles varied slightly from AASHTO policy because of shorter tractor and longer trailer axles spacing assumptions. The minimum turning radii represented turns negotiated at less than 10 mi/hr. This assumption minimizes the effects of driver characteristics and the slip angle of the wheels.

The Texas study found that as the curb return radius increases toward 200 ft, the area of an island becomes larger and the width of a turning lane decreases (*12*). The size of islands for large turning angles indicates that the size of the otherwise unused and uncontrolled areas of pavement can be eliminated by the use of channelization. Turning roadways for flat-angle turns, less than 75 degrees, involve relatively large radii and require channelization designs to fit site controls and traffic conditions. Furthermore, since truck configurations follow a spiral path into a curve, it would be desirable to fit the edge of the pavement closely to the minimum path of the design vehicle by using three-centered compound curves or simple curves with tapers to minimize the amount of unused pavement.

TRAFFIC ENGINEERING ELEMENTS

Passenger Car Equivalencies

Molina et al. developed passenger car equivalencies (PCEs) for trucks traveling straight through a level, signalized intersection on the basis of vehicle type and position (*13*). PCE values were determined for single-unit (SU) trucks and four-axle and five-axle truck tractor-semitrailer combinations. The recommendations of the study indicated that truck types should be distinguished to account for the presence of heavy versus light trucks when analyzing the capacity of an at-grade intersection.

Although the 1985 HCM accounts for trucks as part of the heavy-vehicle adjustment procedure, the heavy-vehicle factor was found to be different for SU trucks and tractor-semitrailer truck combinations (*19*). The authors, using the heavy-vehicle adjustment values found in Table 9-6 of the HCM, calculated a PCE value of 1.5, which they indicate probably is the average of the PCE values for all heavy truck types at signalized intersections. PCE values of 3.7 and 1.7 are recommended in their study as being representative of heavy and light trucks, respectively.

Vehicle Change Interval

Harwood conducted a sensitivity analysis of the differences in vehicle change interval requirements for passenger cars and trucks (*2*). In his analysis, Glauz compared the vehicle change interval requirements based on the FHWA *Traffic Control Devices Handbook* (TCDH) criteria for passenger cars and from information in a 1984 FHWA study (*15,16*). The criteria that were varied in the sensitivity analysis included perception-reaction time, deceleration rate, percent roadway gradient, length of vehicle, and width of intersection.

Since no data were available for perception-reaction time requirements for trucks, the perception-reaction times for trucks

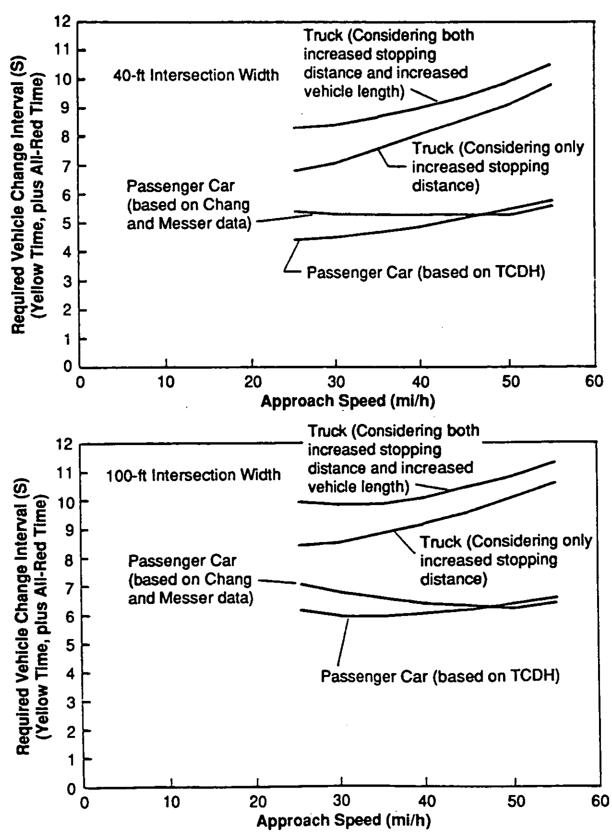

FIGURE 5 Required vehicle change intervals at signalized intersections for passenger cars and trucks (*2*).

TABLE 4 Additional Pavement Construction Costs To Accommodate Design Vehicles Larger Than AASHTO WB-50 Truck at Urban Intersections (*2*)

Posted or 85th percentile speed (mi/h)	Distance from warning sign to potential hazard (ft)[a]						
	Condition A[b] (high judgment needed)	Condition B[c] (stop required)	Condition C[d] (deceleration to stated advisory speed [mi/h])				
			10	20	30	40	50
20	250	e	e	NA	NA	NA	NA
25	325	e	125	e	NA	NA	NA
30	425	175	225	150	NA	NA	NA
35	500	250	325	250	100	NA	NA
40	600	325	450	375	225	NA	NA
45	675	425	600	500	325	175	NA
50	775	525	750	650	525	325	NA
55	850	650	900	825	675	500	225
60	950	775	1,075	1,000	875	675	425
65	1,025	900	1,225	1,200	1,050	850	600

a All distances are based on the assumption that the warning sign is legible to drivers for 125 ft (38 m) in advance of the sign. For large [48-in by 48-in (122-cm by 122-cm)] signs, the legibility distance can be increased by 200 ft (61 m) and each of the entries in this table can therefore be reduced by 75 ft (23 m).
b Includes 12.0-s Perception-Intellection-Emotion-Volition (PIEV) time.
c Includes 2.5-s PIEV time and deceleration rates for driver with 70% braking control efficiency driver.
d Based on comfortable deceleration rate equal to two-thirds of the deceleration rate used for Condition B.
e No suggested minimum distance provided; at these speeds, sign location depends on physical conditions at site.
NA = Not available

approaching yellow signal indications were assumed to be equal to the values observed in the Chang and Messer study (*16*). The deceleration rate was assumed to be 5 ft/sec^2, which is a comfortable rate on a dry pavement but may be a critical rate for some drivers on a poor, wet pavement surface. Assumed length of vehicle values were 19 ft for passenger cars and 75 ft for trucks. Width of intersection used for comparison included a 40-ft-wide intersection as a "moderate" value and 100 ft for a "wide" intersection. Figure 5 compares the required vehicle change interval for trucks based solely on their increased braking distances with the required vehicle change interval incorporating both their increased braking distances and their increased lengths.

The analysis demonstrated that trucks may require vehicle change intervals that are 40 to 110 percent longer than passenger cars, depending on approach speed, approach grade, and intersection width. Because longer change intervals would increase delays on the other approaches, additional study of the overall operational and safety impacts is necessary before any modification is recommended in existing criteria.

Sign Placement

MUTCD Section 2C-3 presents criteria for advance placement of warning signs to provide adequate time for drivers to perceive a potentially hazardous condition, identify the condition, decide what maneuver to make, and begin to perform that maneuver (*17*). Current criteria for horizontal and vertical placement of signs are not based on any explicit vehicle characteristic. However, the criteria for longitudinal placement of warning signs depend significantly on the deceleration capabilities of a vehicle.

Harwood et al. have developed a modified version of the MUTCD criteria for the placement of advance warning signs on the basis of their findings regarding truck stopping distances and comfortable deceleration rates. Table 4 presents the modified criteria for trucks (*2*). However, there are no available data on whether trucks encounter any safety problems at signs placed in accordance with existing criteria or whether there would be any safety benefits from adopting the modified criteria. The recommended advance warning sign distances for trucks could be reduced if antilock brakes were to become widely used.

CONCLUSIONS

This paper has presented several key design considerations to accommodate large trucks at intersections. The key features of the principle elements are discussed in the following subsections.

Physical Characteristics

Although the GB90 currently includes 15 design vehicles, future truck combinations will probably follow some form of the Turner-type truck. Information provided regarding Canadian trucks indicates that the Canadian tractor-semitrailer combinations are similar to the AASHTO WB-62 and WB-67 types: Canadian doubles are generally larger than the AASHTO GB90 WB-60 double-trailer combinations.

Offtracking

Turning roadway design speed governs the type and amount of offtracking that the truck-trailer units will generate. Fundamentally, low-speed offtracking decreases with increased turn radius, increases with increased turn angle, and increases with trailer length. Double (twin) trailers of 28-ft length typically offtrack less than single-trailer combination trucks.

Intersection Sight Distance

Recommended sight distances for truck turning maneuvers at intersections are not explicitly discussed in the GB90. Equations have been developed to reproduce the GB84 and GB90 procedures. Field observations of actual truck turning maneuvers yield shorter intersection sight distance values than calculated using the GB84 and GB90 procedures and reported truck acceleration information.

Channelization

Specific guidelines are not available to fully evaluate the need and scope of intersection channelization to accommodate trucks on turning roadways. It seems desirable to fit the pavement edges of the turning roadway to a spiral or taper geometry to minimize excess pavement and to conform more closely to the truck's offtracking.

Traffic Engineering Elements

Several studies have investigated the effects of large trucks at signalized intersections. Preliminary PCE values of 1.7 and 3.7 have been proposed for SU and tractor-semitrailer truck combinations, respectively. A sensitivity analysis has demonstrated that trucks require change intervals that are significantly longer than passenger cars. Additional study is necessary to fully evaluate the impacts of modifying current TCDH criteria.

A revised tabulation of the MUTCD criteria for the advance placement of warning signs has been developed. The modifications were based on increased stopping distances and comfortable deceleration rates for trucks.

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