Passing Sight Distance Design for Passenger Cars and Trucks

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Safe and effective passing zones on two-lane highways require both adequate sight distance to opposing vehicles and adequate passing zone length. Current design and marking criteria for passing zones on two-lane highways are reviewed. A recently developed model of the kinematic relationships among the passing, passed, and opposing vehicles is employed to evaluate the current design and marking criteria. The model is used both to evaluate the current criteria, which are based solely on passenger cars, and to consider the passing requirements when the passed vehicle, the passing vehicle, or both, are large trucks.

Two major aspects of passing and no-passing zone marking criteria determine the safety and operational effectiveness of the passing and no-passing zones marked on two-lane highways: passing sight distance and passing zone length. Safe passing maneuvers require both adequate passing sight distance and adequate passing zone length. Recent debate over passing zone design and marking criteria, however, has tended to focus only on passing sight distance and to ignore passing zone length. This paper gives thorough consideration to the important roles of both these factors based on recent advances in modeling the kinematic relationships among the passing, passed, and opposing vehicles.

Current passing and no-passing zone marking criteria use the passenger car as the design vehicle. This paper considers the effect on passing sight distance and passing zone length requirements if the passed vehicle, the passing vehicle, or both are large trucks.

CURRENT PASSING SIGHT DISTANCE CRITERIA

Passing sight distance is needed where passing is permitted on two-lane, two-way highways to ensure that passing drivers, who use the lane normally reserved for opposing traffic, have a sufficiently clear view ahead to minimize the possibility of collision with an opposing vehicle.

Design Criteria

The current design criteria for passing sight distance on two-lane highways in the AASHTO Green Book (*1*) are based on the results of field studies (*2, 3*) conducted between 1938 and 1941 and validated by another study (*4*) conducted in 1958. The AASHTO policy defines the minimum passing sight distance as the sum of the following four distances:

d_1 = distance traveled by the passing vehicle during perception-reaction time and during initial acceleration to the point of encroachment on the left lane,

d_2 = distance traveled by the passing vehicle while it occupies the left lane,

d_3 = distance between passing vehicle and opposing vehicle at the end of the passing maneuver (that is, clearance distance), and

d_4 = distance traveled by an opposing vehicle for two-thirds of the time the passing vehicle occupies the left lane, or ⅔ of d_2.

Design values for these four distances were derived using the field study results and the following assumptions:

- The passed vehicle travels at uniform speed.
- The passing vehicle reduces speed and trails the passed vehicle as it enters the passing section. (This is called a delayed pass.)
- When the passing section is reached, the passing driver requires a short perception-reaction period to perceive the clear passing section and to begin to accelerate.
- Passing is accomplished under what may be termed a delayed start and a hurried return in the face of opposing traffic. The passing vehicle accelerates during the maneuver, and its average speed during the occupancy of the left lane is 10 mph higher than that of the passed vehicle.
- When the passing vehicle returns to its lane, there is a suitable clearance length between it and any opposing vehicle.

The design values for the four components of passing sight distance, shown in Figure III-2 of the AASHTO Green Book, are presented here as Figure 1. Table 1 shows the derivation of the design values for passing sight distance, which is also shown in Figure 1. The columns in Table 1 not headed by a value of design speed represent the field study results from the sources cited earlier (*2–4*). The columns headed by design speeds of 20 mph through 70 mph contain values that were interpolated or extrapolated from the field data presented in the intervening columns.

It should be noted that the speeds used to compute the design values for passing sight distance in Table 1 differ from the design speed of the highway. The speed of the passed vehicle is assumed to be equal to the average running speed of traffic (as represented by the intermediate volume curve in

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TABLE 6 SIGHT DISTANCE REQUIREMENTS FOR PASSING BY TRUCKS

Design or Prevailing Speed (mph)	AASHTO Policy	MUTCD Criteria	Required Passing Sight Distance (ft) Truck Passing Passenger Car	Truck Passing Truck
20	800	-	350	350
30	1,100	500	600	675
40	1,500	600	875	975
50	1,800	800	1,125	1,275
60	2,100	1,000	1,375	1,575
70	2,500	1,200	1,625	1,875

NOTE: Based on revised Glennon Model.

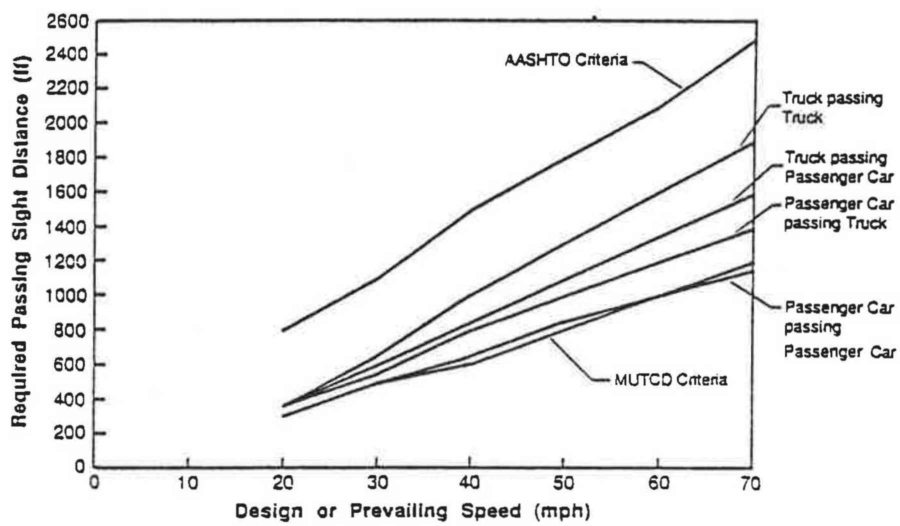

FIGURE 2 Required passing sight distance for passenger cars and trucks in comparison with current criteria.

a deceleration rate of 5 ft/sec^2 (0.15 g), which would be a comfortable deceleration rate on a dry pavement and a critical deceleration rate for a poorly performing driver on a poor, wet pavement, has been assumed.

Table 6 presents the passing sight distance requirements for a 75-ft truck passing a 19-ft passenger car under the assumptions discussed above. The passing sight distance requirements for a truck passing a passenger car are 25 to 425 ft more than for a passenger car passing a passenger car, depending on speed.

Truck Passing Truck

The passing sight distance requirements for a truck passing a truck have also been examined and are presented in Table 6. The analysis was analogous to that done above for a truck passing a passenger car, except that the passed vehicle length was changed to 75 ft. The passing sight distance requirements for a truck passing another truck were found to be 25 to 675 ft longer than for a passenger car passing a passenger car, depending on speed.

Comparison of Results

Figure 2 compares the passing sight distance requirements determined in the sensitivity analysis with the current AASHTO and MUTCD policies. The figure indicates that the current MUTCD criteria are in good agreement with the requirements for a passenger car passing another passenger car. The other passing scenarios—passenger car passing truck, truck passing passenger car, and truck passing truck—each require progressively more sight distance, but substantially less than the current AASHTO criteria.

Effect of Driver Eye Height at Crest Vertical Curves

Where passing sight distance is restricted by a vertical curve, the truck driver has an advantage over a passenger car driver because of greater eye height. As with stopping sight distance, however, the truck driver has no comparable advantage when passing sight distance is restricted by a horizontal sight obstruction, such as a wall or a line of trees on the inside of a horizontal curve.

Table 7 presents the required minimum vertical curve lengths

TABLE 7 MINIMUM VERTICAL CURVE LENGTHS TO MAINTAIN REQUIRED PASSING SIGHT DISTANCE

Algebraic Difference in Grade (%)	Design or Prevailing Speed (mph) 20	30	40	50	60	70
Passenger Car Passing Passenger Car[a]						
2	70	180	320	500	680	940
4	140	360	640	980	1,280	1,630
6	210	540	890	1,240	1,540	1,890
8	280	670	1,020	1,370	1,670	2,020
10	350	750	1,100	1,450	1,750	2,100
Passenger Car Passing Truck[a]						
2	80	220	420	680	1,020	1,360
4	160	430	830	1,280	1,730	2,130
6	240	640	1,090	1,540	1,990	2,390
8	320	770	1,220	1,670	2,120	2,520
10	400	850	1,300	1,750	2,200	2,600
Truck Passing Passenger Car[b]						
2	60	180	370	610	910	1,270
4	120	350	740	1,210	1,710	2,210
6	180	520	1,060	1,560	2,060	2,560
8	240	680	1,230	1,730	2,230	2,730
10	300	790	1,340	1,840	2,340	2,820
Truck Passing Truck[b]						
2	60	220	460	790	1,200	1,690
4	120	440	920	1,510	2,110	2,710
6	180	660	1,260	1,860	2,460	3,060
8	240	830	1,430	2,030	2,630	3,230
10	300	940	1,540	2,140	2,740	3,340

[a] Based on sight distance requirements from Table 5 for passenger car driver eye height of 42 in.
[b] Based on sight distance requirements from Table 6 for truck driver eye height of 75 in.

Note: Curve lengths are expressed in feet.

to maintain passing sight distance over a crest for the four passing scenarios addressed in Tables 5 and 6. Table 7 is based on an eye height of 42 in for a passenger car driver and 75 in for a truck driver. The use of 75 in to represent truck driver eye height is very conservative; the literature shows that truck driver eye height ranges from approximately 71.5 to 112.5 in (*17–19*). Sensitivity analyses for the average truck driver eye height of 93 in did not yield vertical curve lengths much shorter than those for the 75-in eye height.

Table 7 indicates that increased driver eye height partially compensates for the greater sight distance requirements of trucks. For all speeds above 20 mph, a longer minimum vertical curve length is required to maintain adequate passing sight distance for passing maneuvers involving trucks than for a passenger car passing another passenger car. Nevertheless, except at high speeds and when there are large algebraic differences in grades (sharp crests), a truck can safely pass a passenger car on any vertical curve where a passenger car can safely pass a truck.

REVISED CRITERIA FOR PASSING ZONE LENGTH

There are currently no design or marking criteria for minimum passing zone length other than the default value of 400 ft set by the MUTCD. One possible criterion for minimum passing zone length is the distance required for a vehicle traveling at or near the design speed of the highway to pass a slower vehicle. Recent debate over the role of trucks in passing sight distance criteria has largely ignored the longer passing distances and, thus, longer passing zone lengths required for passing maneuvers involving trucks.

An analysis of passing distances has been conducted based on the following assumptions:

- The distance required to complete a pass is the sum of the initial maneuver distance (d_1) and the distance traveled in the left lane (d_2).
- The passing driver does not begin to accelerate in prep-

aration for the passing maneuver until the beginning of the passing zone is reached.

- The initial maneuver distance (d_1) for passes by both passenger cars and trucks can be determined using the AASHTO relationship presented in Equation 1. The passing vehicle is assumed to accelerate at a constant rate (a) until the desired speed differential (m) with the passed vehicle is reached. Thus, t_1 can be calculated as m/a.
- The acceleration rate (a) and initial maneuver time (t_1) for passes by passenger cars as a function of design speed can be approximated by the AASHTO estimates in Table 1. Because of the lower performance capabilities of trucks, their acceleration rates during the initial maneuver are assumed to be half those used by passenger cars.
- The distance traveled in the left lane (d_2) can be estimated as

$$d_2 = V \left[\frac{2.93\,(V - m) + L_I + L_P - \dfrac{0.73m^2}{a}}{m} \right] \qquad (5)$$

This relationship is used in preference to the AASHTO expression for d_2 because it explicitly contains the lengths of the passing and passed vehicles (L_p and L_I) and the speed difference between the vehicles (m). It would be desirable to calibrate Equation 5 with field data.

- Equation 5 is based on the premise that the passing vehicle initially trails the passed vehicle by a 1-sec gap; it then returns to its normal lane leading the passed vehicle by a 1-sec gap. The passed vehicle is assumed to travel at constant speed and the passing vehicle is assumed to maintain an average speed differential equal to m during its occupancy of the left lane; the latter assumption is consistent with AASHTO policy, but more restrictive than the Glennon model (*12*), which assumes only that a speed differential equal to m is reached before the passing vehicle reaches the critical position.
- Passenger cars will accelerate when passing and maintain an average speed equal to the design speed of the highway, maintaining the same average speed differences used to derive Table 5. When passing, trucks are assumed to maintain only half of the speed difference of passenger cars, in keeping with the assumptions used to derive Table 6.
- The assumed lengths of passenger cars and trucks are 19 ft and 75 ft, respectively.

The sensitivity analysis results for the distance required to complete a pass are presented in Table 8 for the four passing scenarios considered previously—passenger car passing passenger car, passenger car passing truck, truck passing passenger car, and truck passing truck. The required passing distances for these four scenarios are illustrated in Figure 3. Except at very low speeds, all of the passing distances are much larger than the MUTCD minimum passing zone length of 400 ft.

Table 8 and Figure 3 show that in order to complete a passing maneuver at speeds of 60 mph or more under the stated assumptions, trucks require passing zones at least 2,000 ft long. There are relatively few such passing zones on two-lane highways, yet trucks regularly make passing maneuvers. The explanation of this apparent paradox is that, because there are very few locations where a truck can safely make a delayed pass, truck drivers seldom attempt them. Most passing maneuvers by trucks on two-lane highways are flying passes that require less passing sight distance and less passing zone length than delayed passes. Thus there may be no need to change current passing sight distance criteria to accommodate a truck passing a passenger car or a truck passing a truck as shown in Table 6. It makes little sense to provide enough passing sight distance for delayed passes by trucks when passing zones are not generally long enough to permit such maneuvers.

CONCLUSIONS

There is close agreement between the current MUTCD criteria for passing sight distance and the sight distance requirements for a passenger car passing another passenger car based on an analytical model recently developed by Glennon (*12*). Application of the Glennon model indicates that successively longer passing sight distances are required for a passenger car passing a truck, a truck passing a passenger car, and a truck passing a truck. There is no general agreement concerning which of these situations is the most reasonable basis for designing and operating two-lane highways. All of the passing sight distance criteria derived here are shorter than the

TABLE 8 PASSING ZONE LENGTH REQUIRED TO COMPLETE A PASS FOR VARIOUS PASSING SCENARIOS

Design or Prevailing Speed (mph)	Passing Vehicle Speed (V) (mph)	Speed Difference (m) Used by Passing Vehicle: Passenger Car	Speed Difference (m) Used by Passing Vehicle: Truck	Minimum Length of Passing Zone (ft): Passenger Car Passing Passenger Car	Passenger Car Passing Truck	Truck Passing Passenger Car	Truck Passing Truck
20	20	13	6.5	150	225	275	350
30	30	12	6	350	475	600	725
40	40	11	5.5	600	825	975	1,175
50	50	10	5	975	1,250	1,450	1,750
60	60	9	4.5	1,475	1,850	2,075	2,450
70	70	8	4	2,175	2,650	2,900	3,400

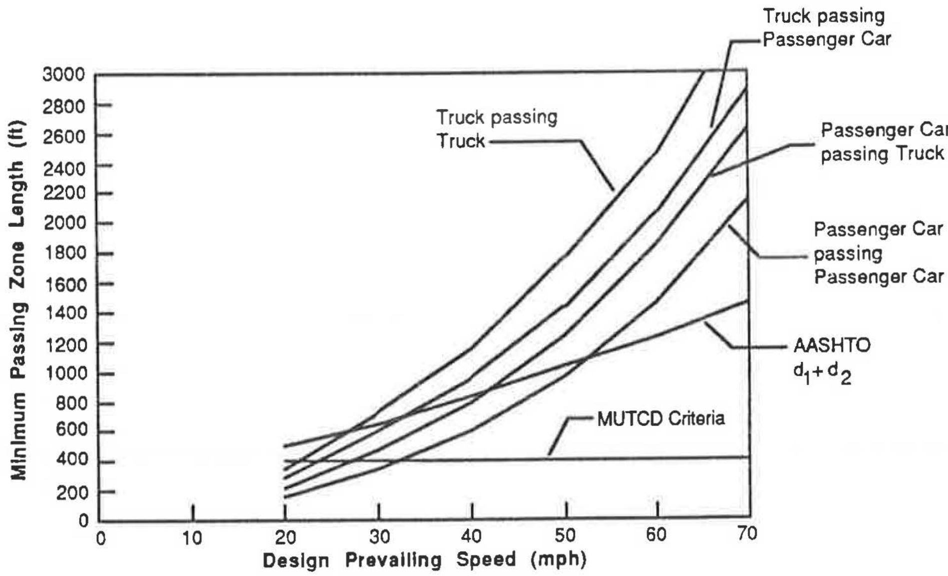

FIGURE 3 Minimum passing zone length to complete a pass at or near the highway design speed.

AASHTO design criteria, which are based on very conservative assumptions.

The analysis results indicate that, if a passenger car passing a passenger car is retained as the design situation, only minor modifications are needed to the MUTCD passing sight distance criteria. If a more critical design situation is selected (for example, a passenger car passing a truck), passing sight distances up to 250 ft longer than the current MUTCD criteria would be required. It is important to recognize that such a change in passing zone marking criteria would completely eliminate some existing passing zones and shorten others, even though passenger cars can safely pass other passenger cars in those zones. Clearly this would reduce the level of service on two-lane highways. This reduction in level of service would only be justified if there were demonstrated safety benefits. The current state-of-the-art of two-lane highway safety research has not addressed the question of whether there are such benefits. We do not know whether small increases in passing sight distance criteria will reduce accidents or whether passenger car drivers have more difficulty in judging the criticality of passing maneuvers when the passed vehicle is a truck rather than a passenger car. Research on these safety issues should be undertaken before any change is made in passing sight distance criteria to accommodate the sight distance requirements of passenger cars passing trucks.

The increased driver eye height of trucks partially, but not completely, offsets the increased passing sight distance requirements when the truck is the passing vehicle. Except at very sharp crests on high-speed highways, however, a truck can safely pass a passenger car on any crest where a passenger car can safely pass a truck. Thus the selection of the passenger car passing a truck as the design situation would, in most cases, also safely accommodate a truck passing a passenger car. There is great doubt about the wisdom of marking passing zones based on a truck as the passing vehicle, because it can be demonstrated that few passing zones on two-lane highways are long enough to accommodate delayed passes by trucks.

There are no current criteria for passing zone lengths, except for the default 400-ft guideline set by the MUTCD. For all design speeds above 30 mph, the distance required for one vehicle to pass another at or near that design speed is substantially longer than 400 ft, indicating a need for longer passing zones. Furthermore, there is research that indicates a higher rate of conflicts between passing and opposing vehicles in passing zones less than 800 ft in length. This research, together with the analyses in this paper, may justify an increase in minimum passing zone length to at least 800 ft for highways with a prevailing speed over 40 mph. The analyses in this paper also show that the required passing distances and passing zone lengths are increased substantially when the passing vehicle, the passed vehicle, or both, are trucks. Nevertheless, as in the case of passing sight distance criteria, there is no research that indicates whether there would be safety benefits from minimum passing zone lengths above 800 ft. Such research is needed because elimination of all passing zones shorter than the lengths shown in Table 8 could seriously degrade the level of service on two-lane highways.

This paper makes a strong case that Equations 3 and 4 provide a more reasonable representation of passing sight distance requirements on two-lane highways than either the current AASHTO or MUTCD criteria. Similarly, Equations 1 and 5 provide a realistic method for determining the distance required to make a delayed pass. These models follow more logically from the AASHTO assumptions concerning delayed passes than do either the AASHTO or MUTCD models. Furthermore, these models are sensitive to vehicle length in a way that the current AASHTO and MUTCD models are not. Given the explicit, quantitative estimates of passing sight distance and passing zone length requirements for different passing scenarios made in this paper, some readers may be disappointed that we have not made more specific recommendations for changes in current criteria. We lack sufficient data to make such recommendations. Neither our models nor the current AASHTO and MUTCD models have any direct, demonstrated relationship to the safety of passing maneuvers on two-lane highways. Such demonstrated safety relationships are needed before any change in passing and no-passing zone criteria can be reasonably contemplated.

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