Truck Length And Weight Issues: Passing And Turning At Intersections

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ABSTRACT

This paper addresses two issues—one associated with the length of trucks and the other associated with the weight to power ratio of heavy trucks.

The length issue involves a passenger car attempting to pass a heavy truck on a two lane road. The amount of time required to pass the truck depends upon the length of the truck, the length of the passing vehicle, and the relative velocity between the two vehicles. The problem in this situation is to determine the sight distance needed to pass safely or to abort the pass if there happens to be an oncoming vehicle.

The weight issue is associated with a heavy truck making a left turn (right turn in the UK). This situation also involves a sight distance problem. The truck driver needs to determine when it is safe to pull out into the intersection. In order to do this, the driver needs to have enough sight distance to judge whether the truck can make the turn and get up to a reasonable speed without causing an oncoming vehicle to decelerate too aggressively. The amount of time available to the oncoming vehicle depends upon the weight to power ratio of the truck, the initial traveling speed and subsequent deceleration of the oncoming vehicle, and the length of the truck.

The paper presents design concepts and ideas that can be applied in areas where truck traffic is likely to be encountered. Current road design policy in the U.S. does not account for issues related to passing long trucks or to trucks turning at intersections. The paper relates traveling speed to sight distances using pertinent characteristics of truck length, weight, and power, thereby providing information contributing to the development of practical design practices or policies pertaining to trucks and roads.

INTRODUCTION

Sight distance has been and continues to be a major factor in highway design [1]. Concepts such as stopping sight distance, passing sight distance, decision sight distance, intersection sight distance, etc., they all rely on providing an adequate, unobstructed line of sight. If an adequate sight distance for the speed of travel exists, drivers should be able to make timely decisions and perform adequate control actions to avoid a crash with slower moving vehicles, or other obstructing objects in their path.

This paper considers passing sight distance (PSD) and intersection sight distance (ISD) as related to the size and weight properties of heavy trucks. The analyses presented here are aimed at highway and truck design policy. As it was said in [2]: "Regulations necessarily simplify and compromise." To the extent that policies are like regulations, the policy suggestions presented in this paper are based upon fundamentally simple analyses of situations pertinent to PSD and ISD issues. The goal is to present basic information that will aid in the process of developing size and weight policy for driving situations involving heavy truck traffic on two-lane roads, and roads with signed intersections.

ANALYSIS OF PASSING SIGHT DISTANCE (PSD)

This analysis (and the later analysis of intersection sight distance) involves both quantitative and conceptual ideas. The quantitative part is a straight forward analysis of vehicle motion. The conceptual part involves not only the choice of a driving situation to serve as a design case but also viewing the chosen driving situation in terms of gathering the needed information, processing that information, and deciding how the resulting information is to be used. The discussion proceeds forward assuming that recognizing the situation, evaluating the situation, and deciding what to do are three key steps in using information in an intelligent manner.

SELECTION OF A PSD DESIGN SITUATION

AASHTO Practice The passing sight distance, as determined by AASHTO, is aimed at enabling the driver to see far enough ahead to safely initiate and complete a pass. In doing so, AASHTO makes use of data and values that are based on field observations conducted between 1938 and 1941. Another study from 1957 was used to validate the data.

The total passing sight distance is defined as D. It is the total clear distance in the left lane that is required for a vehicle to successfully complete a passing maneuver. According to the passing scenario used in AASHTO's policy, this distance is the sum of four segments (see Figure 1):

d_1 — Initiation of the passing maneuver. Driver's perception and reaction to road conditions, decision making, and acceleration onto the left lane.

d_2 — Occupation of left lane. From the point when the passing vehicle entered the opposing lane, until the maneuver was completed and the passing vehicle is fully returned to the right lane.

d_3 — Clearance length. Distance between the passing vehicle when it returns to the right lane, and the opposite vehicle in the left lane.

d_4 — Opposing vehicle. The distance covered by the opposing vehicle in the left lane during 2/3 of the time the passing vehicle occupied the left lane.

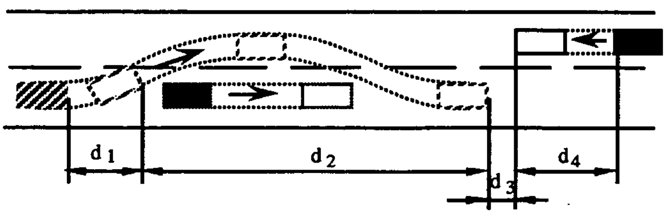

Figure 1. AASHTO's passing scenario

The AASHTO policy uses the following assumptions:

1. The overtaken vehicle travels at a uniform speed.
2. The passing vehicle trails the overtaken vehicle as it enters a passing section.
3. When the passing section is reached, the driver requires a short period of time to perceive the clear passing section and to react to start the maneuver.
4. Passing is accomplished under what might 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 overtaken vehicle.
5. When the passing vehicle returns to its lane, there is a suitable clearance length between it and an oncoming vehicle in the other lane.

Criticism of the AASHTO Practice Passing-sight distance (PSD) requirements used in the design of two-lane highways are currently determined according to the AASHTO *Green Book* [1]. Highway markings are warranted according to the *Manual of Uniform Traffic Control Devices* (MUTCD) [3]. During the last two decades, the AASHTO practice has been criticized by researchers as a method that does not represent real passing situations, and a method that is based on outdated data. Incompatibilities between the *Green Book* and the MUTCD practices have also been identified.

In particular, Glennon [4, 5] and other researchers [6] have offered the following criticisms of the AASHTO practice for determining passing-sight distance and the MUTCD practice for highway markings:

- The studies that were used to acquire the data on which these practices are based are outdated (1938, 1941).
- There are significant discrepancies between the AASHTO passing sight distances and those highway markings warranted by MUTCD (it should be noted, though, that in the *Green Book* , AASHTO points to the fact that the computed passing sight distances "should not be confused with other distances used as the warrants for placing no-passing-zone pavement stripes on completed highways." [1, p. 134])
- Questionable speeds are used in establishing AASHTO's PSDs. At low speeds, the passing vehicle travels significantly faster than design speed, and at high speeds it travels significantly slower.
- The definition of the PSD as the sum of the four distances is very conservative. It assumes the driver is determined to complete the pass, and it ignores the possibility of aborting the maneuver.
- MUTCD's criteria are based on an average between passing sight distances for a "delayed" pass and for a "flying" pass, not on any particular passing maneuver. A delayed pass is when the passing vehicle tracks behind the impeding vehicle for a while, so that when the pass is executed it involves accelerating and lane changing. In the second type of pass, the passing vehicle approaches the other vehicle from behind and, while maintaining the higher speed, it executes the pass.
- Neither AASHTO nor MUTCD addresses vehicles other than passenger cars. The influence of trucks can not be assessed from those formulations, as vehicle length is not a parameter.

A "Critical-Position" Model for PSD The revised model suggested by Glennon to determine passing sight distance on two-lane highways is based on a "critical-position" concept. According to this concept, there is a point during the passing maneuver at which the driver of the overtaking vehicle will need the same passing sight distance to either safely complete the pass or safely abort it. That point is also referred to in the literature as the "point of no return" [7]. The sight distance value required to either successfully complete or successfully abort the passing maneuver is the passing sight distance suggested by Glennon for both design and highway-marking warrants.

The passing maneuver, according to Glennon, is comprised of four phases. The four phases are illustrated in Figure 2. At first, when the passing maneuver is being initiated, the required sight distance is the shortest. It is based on the driver's need to abort the pass, since he/she can almost immediately return to the right lane in the face of an oncoming vehicle. As the pass progresses and the passing vehicle encroaches deeper into the left lane, the PSD increases, since more time will be required to abort and return to the right lane. Passing sight distance needs are still based on aborting the pass during this second phase. The critical point of the pass constitutes the third phase of the maneuver. At this point, the passing vehicle is "trapped" in the left lane and is in its most vulnerable position. The driver needs the same clear distance ahead to either safely complete the pass or safely abort it. Beyond this point (phase four of the pass), the PSD starts to decrease and is based on the distance needed to complete the pass. Given constant conditions, after the critical position or the "point of no return," the driver of the overtaking vehicle can only complete the pass. He/she can no longer safely abort the maneuver.

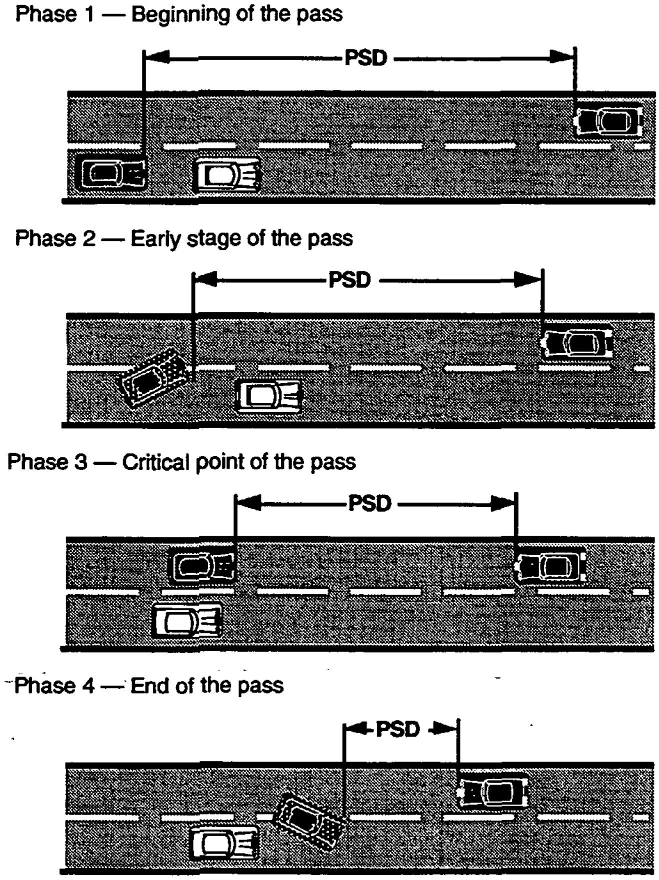

Figure 2. Glennon's passing scenario

The model suggested by Glennon's sets significantly shorter passing-sight distance for cars than those determined by the AASHTO policy. This is because the passing-sight distance is now the sight distance needed to be able to complete the pass when the vehicle is at the point of no return. In effect, this eliminates the distance d_1 that is included in the AASHTO policy, and it shortens distance d_2.

However, the idea of providing only enough sight distance for a point-of-no-return driving style is frightening. It allows no safety margin to compensate for any miscalculation by the driver. Furthermore, numerical results indicate that the results for the critical point approach are sensitive to changes in the values chosen for gaps and clearances between vehicles [8]. It appears that both data gathering and policy studies are needed to extend or modify the critical-position approach.

Nevertheless, the critical-position approach has introduced new ideas that have potential for improving the concepts used in determining policy on passing-sight distance provisions for long trucks. Specifically, there are two features of importance hereinafter: (1) the lengths of the passing and passed vehicles are included in the analysis, and (2) the analysis involves a decision as to whether to abort the pass or to complete it.

The PSD Design Situation Selected for this Paper Consider the relative motion between a passing vehicle of length (Lp) and a truck combination of length (Lt) as illustrated in Figure 3. It is convenient to imagine a coordinate system that moves with the vehicle being passed. The origin of this system is at a distance (a) behind the rear of the truck combination. Conceptually, this is the point where (for design purposes) the driver of the passing vehicle decides whether to abort the pass or to complete it.

Although the critical-point approach includes a clever analysis for determining the point of no-return, the analysis presented here provides a strategy for a more conservative determination of PSD. Nevertheless, the situation analyzed here does not include a distance d_1 per the AASHTO policy. The idea here is that, it is not important how the driver gets to the origin of the pass. In other words, the origin of the pass is where the "design" driver of the passing vehicle decides to abort the pass or to complete the pass.

In order to have a simple analysis, it is assumed, as in the AASHTO policy, that the motion of the passing vehicle is described by an average relative velocity (Rdot) that is equal to the difference between the average velocity of the

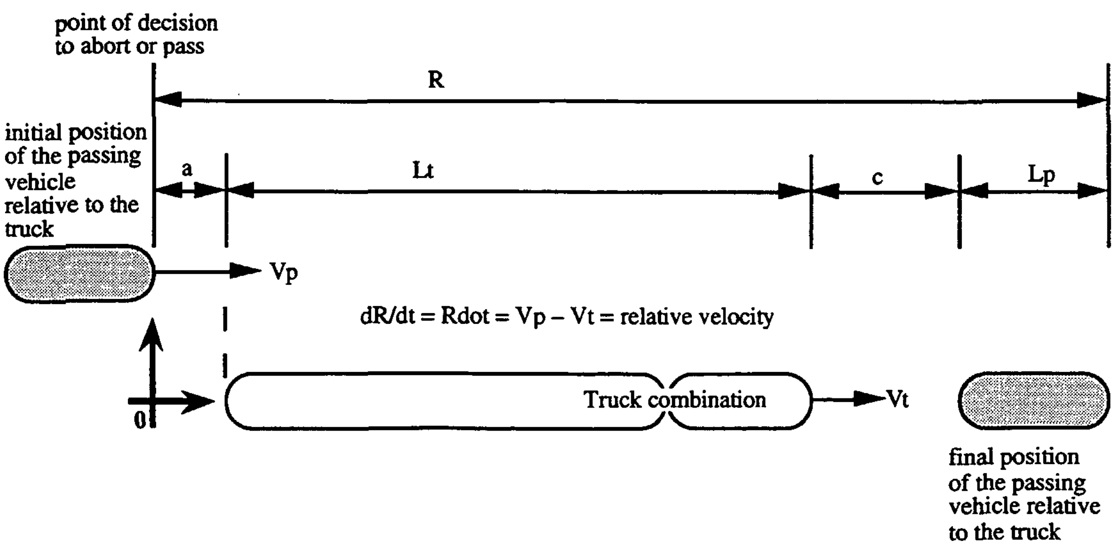

Figure 3. Proposed PSD design method

passing vehicle (Vp) and the velocity of the vehicle being passed (Vt); viz.,

$$Rdot = Vp - Vt \quad (1)$$

Note that this is also the speed of the passing vehicle as observed in the moving coordinate system described heretofore.

Equation 1 is fundamental to determining the time and distance relationships pertaining to the passing situation. However, before completing the pass, let's consider the abort situation.

For example, say that the passing vehicle is going 10 mph (16 kph) faster than the truck at some initial distance (Ro) behind it. At this point, the driver decides to abort the pass. This means that the driver decelerates to change the passing vehicle into an aborting vehicle. If the truck maintains its speed, the position (R) of the rear of the truck relative to the aborting vehicle is given by the following equation:

$$R = Ro + Rdoto \cdot t - D \cdot t^2/2 \quad (2)$$

where:
t is time,
D is the average deceleration of the aborting vehicle, and
Rdoto is the relative speed when the abort in initiated.
In addition,

$$Rdot = Rdoto - D \cdot t \quad (3)$$

Let Tf be a final time when R = Ro (that is when the aborting vehicle returns to the point where the pass ended and the abort started). Then Equation 2 implies (after some thinking) that

$$Tf = 2 \cdot Rdoto/D \quad (4)$$

$$Rdot\ (Tf) = -Rdoto \quad (5)$$

Equation 5 means that, for a constant-deceleration abort, the aborting vehicle will end up traveling slower than the truck by the same amount it was originally traveling faster than the truck. For example, if the truck had been traveling 40 mph and the aborting vehicle was originally traveling at 50 mph, this vehicle would end its abort at 30 mph. However, consider the case where the aborting vehicle was starting to pass a slowly-moving truck at a relative velocity which was higher than the truck's actual speed. The abortion in this case (at least theoretically), would require putting the vehicle in reverse gear and travelling backwards. Such a case demonstrates that results given in the literature can be misleading for slow moving vehicles [8]. At highway speeds, scenarios like this are unlikely to occur. Nevertheless, one should be aware that aborted passes can be disconcerting to the driver of a vehicle that might be positioned behind the aborting vehicle.

The meaning of Equation 4 can be illustrated by a simple example. For example, let Rdoto = 15 ft/sec (4.5 m/sec or about 10 mph) and D = 5 ft/sec^2 (0.155 g). In this case, Tf = 6 sec, which, as we will find later, is usually less than the time needed to pass a long truck.

In the case of a completed pass, the passing time (Tp) is given by the following relationship (see Figure 3):

$$Tp = R/Rdot \quad (6)$$

where

$$R = a + Lt + c + Lp \quad (7)$$

The distances (a) and (c) are measured in the coordinate system that is moving with the truck being passed. They may be thought of in terms of time periods such that: a = At·Rdot, and c = Ct·Rdot.

INFORMATION PERTAINING TO THE PSD DESIGN SITUATION

Equations 1, 6, and 7 are basic relationships pertaining to the passing vehicle. The distance traveled by the passing vehicle during the passing time (Tp) is given by:

$$Dp = Vp \cdot Tp \quad (8)$$

Assume that an oncoming vehicle is traveling in the opposite direction, in the same lane as the passing vehicle, and at the same speed (Vp). The distance covered by the oncoming vehicle during the passing time, is therefore also equal to Dp.

When the pass is completed and the passing vehicle returns to its lane, a clearance distance (Coc) exists between the passing vehicle and the oncoming vehicle. Upon inclusion of that distance, the PSD is given by the following equation:

$$PSD = 2 \cdot Tp \cdot Vp + Coc \quad (9)$$

In terms of a time period, this clearance is given by Coc = COt·2·Vp.

For example, the gaps and clearances might be described as lasting for one second. This would mean that at a relative passing speed of 15 ft/sec (4.5 m/s) and a traveling velocity of (100 ft/sec 30 m/s), a = 15 ft (4.5 m), c = 15 ft (4.5 m) , and Coc = 200 ft (60 m). Coc is so large because the relative velocity between the passing vehicle and the oncoming vehicle is 200 ft/sec (60 m/s).

Pavement striping might be designed to provide drivers with information regarding a pass decision. As shown in Figure 4, there might be three types of markings. The first marking will be along roadway sections where the full PSD per equation 9 is available. The second marking will be along sections that do not "qualify" for marking 1, but a sight distance of Tp·Vp + Coc exists. Drivers might be on the left of such marking only for the purpose of completing a pass. No pass should be initiated under marking 2, and a roadside sign might provide a range cue as to where that marking ends. The third marking is the equivalent of the current solid stripe (penalty stripe): drivers should not be to the left of this marking. Such a marking scheme would inform the passing drivers where they must return to their lane, and aid their decision whether a pass can be completed before the penalty stripe.

EVALUATION OF PSD PER THE DESIGN SITUATION

One aspect of evaluating the design situation is to develop a feeling for the sensitivity of the results to changes in the values of the quantities involved in describing the

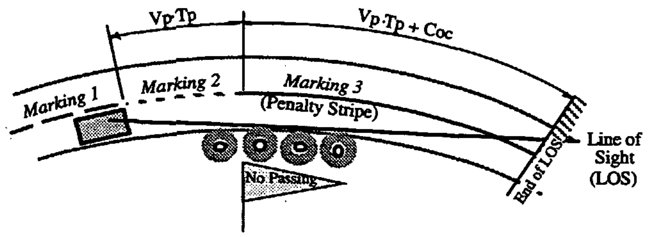

Figure 4. No-passing zone and penalty stripe

situation. In this situation, which is described by a relatively simple set of considerations, a spreadsheet type of approach is a good way to present information that can be used to relate subjective ideas to quantitative results. Table 1 can be examined to see the influences of changes in certain of the basic descriptors of design vehicles and drivers.

Table 1 is a spreadsheet consisting of rows labeled 1 through 10 and columns labeled A through P. Symbols and units, defining the quantities given in the table, are listed across row 1. Specific values for these quantities are listed below the headings for each column. Rows 2 through 10 contain results for nine different sets of input information.

The input information is given in columns A, B, C, D, H, I, and M corresponding to clearance and gap times At and Ct, velocities Vp and Vt, lengths Lt and Lp, and oncoming clearance time COt, respectively. The input information has been chosen so that row 2 represents a baseline case representing a first trial using what is deemed to be a reasonable set of values of the input information. Inspection of the table shows that rows 3 through 9 represent situations in which one parameter is varied at a time. For example, At is changed from its baseline value of 1 sec. to 2 sec. for use in obtaining the calculated values given in row 3.

Calculated values are presented in Table 1 for the relative velocity "Rdot", the distances "a" and "c", the time periods "TLt" and "TLp" (the lengths of time required to pass the truck and to get the back end of the passing vehicle in front of the truck), the time for the pass "Tp", the clearance distance with respect to the oncoming vehicle "Coc", the passing sight distance "PSD", and the striping distance "stripe". The reason, for including quantities that are intermediate to determining PSD and stripe, is to provide insight into the importance of the various parameters.

Inspection of Table 1 (rows 2, 3, 4, and 9) indicates that variations involving one second increases in At, Ct, and COt result in an additional 200 ft compared to the baseline (that is, 2000 ft compared to 1800 ft). Rows 7 and 8 also indicate 200 ft increases over the 1800 ft baseline PSD. For these cases (rows), Tp (the passing time) is increased by one second by increasing the trailer length by 15 ft (row 7) and increasing the passing vehicle's length by 15 ft (row 8). The reason that 15 ft translates into one second is that the relative velocity is 15 ft/s. As illustrated by these examples, it is convenient to relate vehicle lengths to time periods using the relative velocity between the vehicles. In fact, the time periods At, Ct, TLt, and TLp add up to the passing time and their relative importance is proportional to their magnitudes. This means that the time to travel the length of the truck (TLt) is by far the most important quantity in the evaluation of Tp.

Row 5 corresponds to a situation in which the relative velocity has been doubled to 30 ft/s by making the passing vehicle travel faster. This of course results in much less time needed to travel the distance equal to Lt + Lp, and accordingly Tp and Psd are much shorter. In contrast, Row 6 represents a case in which the relative velocity has been reduced from 15 ft/s to 10 ft/s. Both of these cases illustrate the importance of relative velocity when passing a long truck.

Row 10 is simply a case using a combination of the choices used in the other rows that will lead to a long PSD (twice as long as the baseline as it turns out). Cases 5, 6, and 10 (rows 5, 6, and 10) indicate that a wide range of answers for PSD can be obtained without resorting to unreasonably extreme changes in the design parameters used for planning PSD requirements. In particular, the choices of Vp and Vt may have a large influence on the answer.

Case 5 is specially interesting because Tp is equal to only 5 seconds and the time to abort as discussed previously is 6 seconds for Rdoto = 15 ft/s and D = 5 ft/s^2. However in case 5, Rdoto = 30 ft/s which yields an abort time (Tf) equal to 12 seconds. What this means is that the passing vehicle is well beyond the point of no return used in the critical point approach. In other words case 5 is unrealistic (even though it is useful for illustrating the importance of relative velocity). As long as

Table 1. Passing distance results for various parameters

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	At (sec)	Ct (sec)	Vp (ft/s)	Vt (ft/s)	Rdot (ft/s)	a (ft)	c (ft)	Lt (ft)	Lp (ft)	TLt (sec)	TLp (sec)	TP (sec)	COt (sec)	Coc (ft)	PSD (ft)	stripe (ft)
2	1	1	100	85	15	15	15	75	15	5	1	8	1	200	1800	1000
3	2	1	100	85	15	30	15	75	15	5	1	9	1	200	2000	1100
4	1	2	100	85	15	15	30	75	15	5	1	9	1	200	2000	1100
5	1	1	115	85	30	30	30	75	15	2.5	0.5	5	1	230	1380	805
6	1	1	100	90	10	10	10	75	15	7.5	1.5	11	1	200	2400	1300
7	1	1	100	85	15	15	15	90	15	6	1	9	1	200	2000	1100
8	1	1	100	85	15	15	15	75	30	5	2	9	1	200	2000	1100
9	1	1	100	85	15	15	15	75	15	5	1	8	2	400	2000	1200
10	2	2	100	90	10	20	20	90	30	9	3	16	2	400	3600	2000

Tp is greater than Tf, the calculations make sense. Generally there is no problem with this as long as the relative velocity between the passing vehicle and the truck as used for design calculations is modest (i.e., not large). In any event, it is a good idea to use Equation 4 to check to see if Tf is less than Tp.

PSD POLICY SUGGESTIONS

The information given in this paper suggests that one develop new policies regarding passing sight distance. We suggest using neither the current AASHTO policy nor the critical point approach. Rather the approach used in this paper represents a compromise between those two approaches that is ready for use in a policy development activity.

The use of a spreadsheet for trying out ideas for a policy appears to be attractive. Given a simple model of the design situation one can readily determine the consequences of various design approaches. People who have reason to advocate short PSDs as well as people who have reason to advocate long PSDs can see how their desires are influenced by the selection of values for design parameters. It is anticipated that if agreement progresses to the point where the discussion is over the last few feet, the participating sides may use very comprehensive and sophisticated analyses and testing to support their position. Nevertheless a simpler model, akin to the one presented here and amenable to a spreadsheet approach, would be a good choice for expressing the policy in a readily understandable manner.

ANALYSIS OF INTERSECTION SIGHT DISTANCE (ISD)

SELECTION OF AN ISD DESIGN SITUATION

Consider a long heavy truck that is stopped at an intersection with a main cross road. The situation is illustrated in Figure 5. The driver is going to make a left turn onto the cross road if the road appears to be clear. Presume that there is limited sight distance to the truck driver's right. In this situation the truck driver pulls out onto the crossroad when there is no vehicle in sight. The worst case possibility is that there is an oncoming vehicle just out of sight so that the oncoming vehicle passes the first point of observation just after the truck starts into the intersection. The basic question in this situation is what should the intersection-sight-distance be so that the truck will not be a difficult hazard to oncoming vehicles that enter the field of view just when the truck starts out from the side road?

INFORMATION PERTAINING TO THE ISD DESIGN SITUATION

The following nomenclature applies to the design situation illustrated in Figure 5:

Intersection radius (Rd), truck length (Lt), traveling speed of vehicles on main road (Vo), the speed (V) of the vehicle with initial velocity Vo as shown in Figure 5, truck average acceleration from the stop (At), deceleration of vehicles on the main road (D), reaction time of the driver on the main road (Tr).

Other pertinent nomenclature is as follows:

Scale factor (k) between P/W and At where P is engine power and W is truck weight, that is, $At = k \cdot P/W$.

Typical values of a set of parameters for an initial example are as follows:

Rd = 30 ft, Lt = 70 ft, Vo = 80 ft/sec, Tr = 2 sec., At = 1 ft/sec^2 (0.031g), D = 5 ft/sec^2 (0.155g), W = 80,000 lb, P = 300 hp (165,000 ft lb/sec), hence, P/W = 2.06 ft/sec, and k = 0.48 (1/sec).

Given the ISD design situation as described above, pertinent design equations and relationships are as follows:
Stopping distance for the oncoming vehicle:

$$Sd = Vo^2/2 \cdot D \tag{10}$$

(Using the example values, Sd = 640 ft. and the time to stop is 16 sec.)
The general relationship for headway range, R, is:

$$R = Rsm + Rdot^2 /(2\ (D + At)) \tag{11}$$

where Rsm is the range safety margin (a value of 15 ft will be used for Rsm in the example situation), Rdot is the relative velocity (V – Vt), and the relative acceleration is –(D + At). Equation 11 is a basic expression used in the study of headway control and it is discussed in detail in references [9] and [10]. (Reference [10] is included in these proceedings.)

It is convenient to use Equation 11 in connection with the "phantom" truck shown in Figure 5. The phantom truck needs to travel the same distance (or very nearly the same distance) as the real truck to clear the intersection.

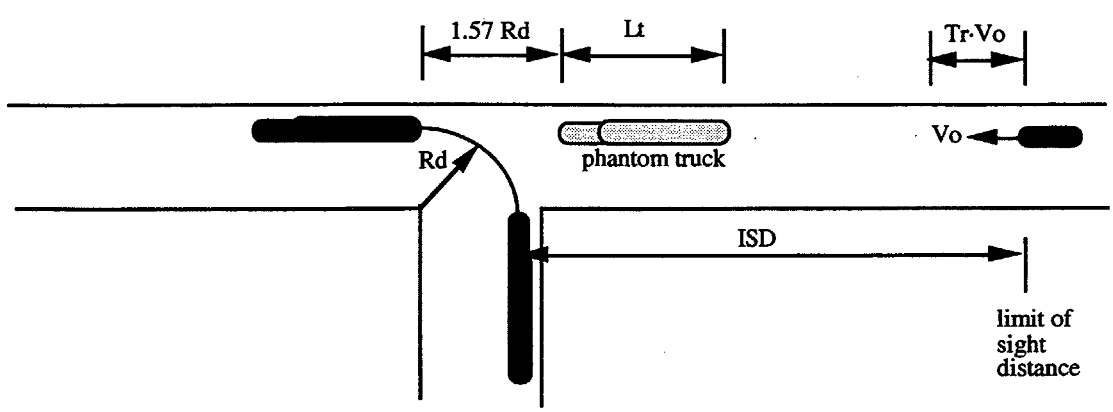

Figure 5. Design Situation for ISD.

This distance is given by 1.57 Rd + Lt (in the example case, 117.1 ft). Incidentally, at 1 ft/sec^2, basic kinematics shows that the example truck would have taken 15.3 sec to clear the intersection. The point is that the phantom truck is like the real truck once both trucks have cleared the intersection. If Equation 11 is used to determine a value of Ro, which is to be used in determining ISD, the result needs to be checked to see whether the phantom vehicle would have cleared the intersection. Ideally, one would like for at least the rear of the phantom vehicle to have reached the start of the intersection before the oncoming vehicle reaches a point that is a distance Rsm (see Equation 11) before the start of the intersection.

Some of these ideas and certain other kinematic matters are illustrated in Figure 6.

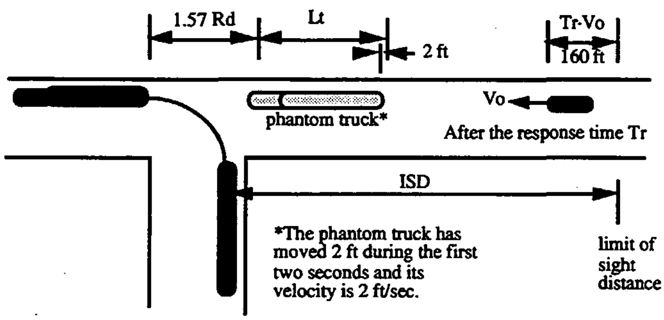

Figure 6. Example situation at the time the oncoming vehicle starts decelerating.

Based on the situation illustrated in Figure 6, Equation 11 may be used with Rdoto = V – Vt = 78 and D + At = 6 ft/sec^2 to determine Ro; and the result for the example case is Ro = 15 + 78^2 / 12 = 522 ft. In this situation the intersection sight distance is:

$$ISD = Tr \cdot Vo + Ro + Lt + 0.57 \cdot Rd - 0.5 \cdot At \cdot Tr^2 = 767 \text{ ft} \quad (12)$$

In contrast the distance for stopping at the intersection would be 640 + 160 ft = 800 ft. To the trucker it might seem that 800 ft would be good, however if the cost of each 10 feet of sight distance is dear, the road rehabilitator and maintainer may see the 33 ft difference as important.

EVALUATION OF ISD PER THE DESIGN SITUATION

As in the case of PSD, a spreadsheet approach is a good way to present information that can be used to develop conceptual ideas using quantitative results. Table 2 can be examined to see the influences of changes in certain of the basic descriptors of design vehicles and drivers on ISD.

Inspection of Table 2 yields findings that furnish insight as to the compromises that may need to be resolved if an ISD policy were to evolve. For example, the approach characterized by the phantom truck will sometimes lead to shorter values of ISD than those associated with an ISD that is based upon an intersection stopping sight distance policy. This statement can be verified by looking at the results in column O for ISD and column P, labeled "Sd + Tr·Vo" which means the distance needed for oncoming vehicles to stop at the intersection (if they need to) using 0.155 g deceleration and a driver reaction time of 2 seconds. The reason for this is that the truck gets up to very low speeds in cases 6 and 7 (rows 6 and 7 in the table), and Rsm (column A) is 15 ft. If Rsm were zero, for example, in these cases, ISD would always be shorter than the distance given in column P. Nevertheless, the point is that ISD and an intersection stopping distance policy are not much different.

The scaling parameter k (column E) is the most uncertain quantity used in this spreadsheet. It determines the longitudinal acceleration of the truck. For k = 0.48, the average acceleration from a stop of an 80,000 lb truck with a 300 hp engine is approximately 1 ft/s^2. This performance needs to be measured for a variety of heavily laden vehicles with engines of various horsepower in order to establish an acceptable value for k in this approach.

However, if an intersection stopping distance policy were to be adopted then the design truck's power to weight ratio would be an important factor to consider in ensuring that oncoming traffic did not have to wait long for the truck to clear the intersection and get up to a reasonable speed. Although traffic flow is not considered here in this paper, traffic flow could be an important factor in arriving at a policy for heavily traveled sections of road. One can conceive of many nuances depending upon the nature of the traffic situation involved.

Returning to the results in the table, row 4 presents results for a case in which the traveling speed on the main road is 45 mph (66 ft/s). Of course, the ISD is shorter compared to the other cases which are at a traveling speed of 55 mph (80 ft/s). Clearly, there is a tradeoff between the ISD provided and the speed limit of the main road.

Due to the value of the factor k (0.48 1/s) used, the influence of using a 200 hp engine compared to a 300 hp engine is 808 ft versus 768 ft (see rows 6 and 1). This case is an example in which ISD is longer than the distance required to stop at the intersection. Nevertheless, one might

Table 2. Intersection distance results for various parameters

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	Rsm (ft)	Tr (sec)	Vo (ft/s)	Lt (ft)	k (1/sec)	HP	W (lbs)	At (ft/s·s)	D (ft/s·s)	Vo·Tr (ft)	Sd (ft)	.5AtTr·Tr	Ro (ft)	Rd (ft)	ISD (ft)	Sd+Tr·Vo
2	15	2	80	70	0.48	300	80000	0.99	5.00	160	640.00	1.98	523.11	30	768.23	800.00
3	15	1	80	70	0.48	300	80000	0.99	5.00	80	640.00	0.50	536.08	30	702.69	720.00
4	15	2	66	70	0.48	300	80000	0.99	5.00	132	435.60	1.98	357.12	30	574.24	567.60
5	15	2	80	60	0.48	300	80000	0.99	5.00	160	640.00	1.98	523.11	30	758.23	800.00
6	15	2	80	70	0.48	200	80000	0.66	5.00	160	640.00	1.32	561.87	30	807.65	800.00
7	15	2	80	70	0.48	300	80000	0.99	6.44	160	496.89	1.98	424.63	30	669.75	656.89
8	15	2	80	70	0.48	300	80000	0.99	5.00	160	640.00	1.98	523.11	45	776.78	800.00

consider the extra sight distance provided by the ISD with the intention of preventing oncoming vehicles from having to make a complete stop at the intersection. On the other hand, if vehicles on the main road are stopped at the intersection, their brake lights could be on, thereby providing a warning to following vehicles that there is an obstacle in their path. (Same as they would get if a vehicle on the main road were going to make a left turn after oncoming traffic cleared the intersection.)

ISD POLICY SUGGESTIONS

Given that traffic flow characteristics are worked into a policy making exercise, there is a choice to be made between using the ISD developed here and simply allowing enough distance for vehicles to make a moderate stop at the intersection if they need to. The simplified analysis of ISD presented here is still complex enough that one could argue that an intersection stopping distance policy would be easier to understand and therefore desirable. It is a judgment call but we suggest that the ISD approach demonstrated in this paper would be useful for giving both trucking and highway designers a mechanism for expressing their concerns in arriving at a reasonable policy. Since both calculations (ISD and stopping distance) are readily made using a simple spread sheet, it appears reasonable to make both sets of calculations to provide information to use in developing design practice.

Currently, signs such as "Truck Entrance" are used to warn drivers of a possible hazard. Certainly, warning signs that cause drivers to be alert and to be prepared to stop are needed to aid in controlling the reaction time of the driver.

Although the analysis is simple, there is a need for experimentation and testing to obtain suitable values for basic parameters such as the average acceleration capability of the truck (At), and a suitable deceleration level (D) for the oncoming vehicle.

CONCLUDING STATEMENTS

The treatment of passing sight distance (PSD) (and to some extent the treatment of intersection sight distance (ISD)) is simplified by using relative velocity as the basis for the analytical approach. An important by-product of this approach is that the lengths of vehicles can be interpreted in terms of the period of time needed to pass or to travel a distance relative to a point connected with the vehicle being passed or approached. This allows one to use a passing time concept in analyzing and understanding the development of a policy for PSD. The examples given in this paper illustrate the utility of the passing time concept in examining potential choices of design parameters for use in developing a design situation for a policy that is based upon pertinent properties of trucks and roads.

In both the PSD and ISD analyses, an approach using a simplified model and a spread sheet is believed to have definite advantages in aiding conflicting or opposing parties to reach agreement. It is anticipated that each and every side may use very detailed studies to support their case, but the results from their approaches would need to be interpreted in terms of the simplified analysis used to generate the spreadsheet. Although the information presented here is from analytical work, the proposed approach to policy involves testing and experimentation. In particular, in-field measurements of passing situations are needed to support policy decisions and parameter selections for the PSD design situation. With regard to ISD, measurements of the time it takes a truck, that is turning left, to clear an intersection and the speed the truck is going after clearing the intersection are needed. In addition, an acceptable level of deceleration for on-coming vehicles needs to be determined. At specific locations at which special transportation requirements arise, measurements of the characteristics of the particular trucks involved and the sight distances available at the site may be used to establish parametric values for analyzing those particular situations. In any event, in-field operational data is needed to support the development of design policy.

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