

Driver Perception-Reaction Time: Are Revisions to Current Specification Values in Order?

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The appropriateness of current specification values for the driver characteristic perception-reaction time is examined for several geometric design and traffic operations standards: stopping-sight distance, lateral clearance to sight obstructions on horizontal curves, intersection sight distance, and vehicle change interval. The analysis focuses on three issues. First, a brief review of state-of-the-art knowledge relative to the driver characteristic is presented. The review compares field results with aggregated simulation tests of the discrete components of perception-reaction time. The second issue that is addressed is the sensitivity of the design or operations standard to incremental changes in perception-reaction time. The third issue is a determination of the actual maximum allowable perception-reaction time for the various standards. The findings of the research indicate that the specification values for perception-reaction time are too low for the stopping-sight-distance design standards and the vehicle-clearance-interval standard. Also recommended is that the perception-reaction action for case III intersection sight distance be redefined.

The driver characteristic perception-reaction time is considered a factor in a variety of highway design and operations standards. This paper examines the current specification value for the characteristic for several standards: stopping-sight distance, lateral clearance to sight observation on horizontal curves, intersection sight distance, and vehicle clearance interval.

STOPPING-SIGHT DISTANCE

Driver Characteristic

The current American Association of State Highway and Transportation Officials (AASHTO) standard for stopping-sight distance is in part based on a driver characteristic of brake reaction (P). More precisely, it should be identified as the perception-brake-reaction time. The American Association of State Highway Officials (AASHO) (1) states that "perception time is the time required for motor vehicle operators to come to the realization that the brakes must be applied. It is the time lapse from the instant an object is visible to the driver to the instant he realizes that the object is in his path and that a stop must be made." The brake reaction time is "the time required to apply brakes". This was formerly labeled as the perception-intellection-emotion-volition (PIEV) time.

The current AASHTO specification for this driver characteristic is 2.5 s. As specified in the AASHO Policy on Geometric Design of Rural Highways (1), this value was determined from an assumed perception time of 1.5 s and a brake-reaction time of 1.0 s. The values do not relate to any specific percentile of driver performance but, rather, were selected as being "large enough to include the time taken by nearly all drivers under most highway conditions." The values were based on the results of an assortment of laboratory and field-controlled studies that used alerted drivers (2-4).

The 2.5-s time was again selected as the specification in review drafts of the updated AASHTO manual, A Policy on Geometric Design of Highways and Streets (5). [In this draft version, there is an inconsistency in the terminology and definition of this characteristic. Only brake-reaction time is defined (interval between the driver's recognition of an object and driver's application of brakes), but yet in arriving at the 2.5-s specification, the

perception time was indirectly considered.] The 2.5-s specification appears to be based on the results of the Johansson and Rumar study (6) that measured the brake-reaction times of 321 drivers under an anticipated condition and a much smaller sample under surprise conditions. The researchers concluded that, on 10 percent of the occasions (tests), brake-reaction time was estimated to be 1.5 s. On what basis the additional 1 s was added to arrive at 2.5 s is not clearly stated in the AASHTO manual, but presumably it was added to account for the perception time. A careful review of the Johansson and Rumar study reveals that what was really measured is brake-reaction time exclusive of any perception time, since the subjects, regardless of whether they were alerted or not, knew they were to apply the brakes on hearing a signal (a horn) in the car. As stated in the AASHTO manual, the 2.5 s is supposed to be "large enough to include the reaction time required for nearly all drivers under most highway conditions" (emphasis added). It is implied that 90 percent of drivers constitutes "nearly all" drivers.

Perception-brake-reaction times can be determined in either of two ways: (a) experiments that measure the entire perception-brake-reaction time or (b) by simply adding the individual values experimentally determined for each of the components, i.e., perception, decision, and limb movement. The first method is preferred because it is more realistic. The processes of detection, perception, decisionmaking, and physical response are often overlapping and cannot simply be added as step-by-step tasks. For instance, the driver can take his or her foot off the accelerator while he or she decides whether or not to stop.

There are numerous studies that have attempted to develop data on perception-brake-reaction time or components of it. A good summary of most of these is found in a recent paper by Taoka (7). Table 1 summarizes the results of the various studies on brake-reaction time. The first group are experiments that were conducted under simulated conditions in the laboratory or field-controlled conditions. As such, the values (primarily means) are considered only brake-reaction times under expected conditions. Taoka refers to it as "simply laboratory response time", which is not indicative of actual driving situations.

The second group are results of field driver response experiments that attempt to duplicate actual conditions. All of the studies have deficiencies inherent in their procedure that make their results less than ideal. Most measured subjects were already alerted and anticipating a signal and some were responding to an auditory signal. Visual perception of objects, other than a brake light ahead that would require a motorist to stop, were not considered in these studies.

Visual perception can involve several components: latency, eye movement, fixation and focusing (detection), and, finally, recognition. For the purposes of this study, an object is perceived once it has been detected and recognized as an object.

For a laboratory study, latency would be defined as the delay between the time the stimulus is presented and the time the eyes begin to move to the

Table 1. Summary of studies on brake-reaction time.

Investigation	Sample Size	Mean	SD	Percentile Values							Comments
				50	75	80	85	90	95	99	
Laboratory/Field-Controlled Studies											
Greenshields (8), 1936	1461	0.496	0.0913								Laboratory Automobile
	13	0.86									
	27	0.74									
Forbes and Katz (9), 1936; and DeSilva and Forbes (10), 1937	907	0.64									
Jones and others (9), 1936	889	0.697	0.121								
	truck drivers										
	40	0.47									
Konz and Daccarett (11), 1967	12	0.59									
	40	0.47									
On-the-Road Studies											
Moss and Allen (12), 1925	46	0.54							0.88	1.01	Response to auditory detection
Massachusetts Institute of Technology (MIT) (2), 1934	144 men	0.66		0.60				0.85	1.0		Response to brake light of car ahead
	36 women										
Drew (13), 1968	1000	0.57 (men) 0.62 (women)									Alerted condition
Norman (3), 1953	53	0.73		0.73	0.77	0.83	0.85	0.89	0.96	1.1	Alerted condition
Johansson and Rumar (6), 1971	321	0.75		0.63	0.82	0.86	0.92	1.05	1.21	1.60	Expected auditory
	5	0.89		0.85	1.11	1.16	1.24	1.42	1.63	2.16	Surprise auditory
Mortimer (14), 1970	80	1.30		1.42		1.88			2.56	3.29	Response to brake light of car ahead
Sivak and others (15), 1981	311	1.23	0.62	1.04	1.55	1.70	1.88	2.15	2.36	2.68	Response to brake light

stimulus. This has relevance to the highway when the object is in the peripheral vision of the motorist either because the object is off to the side of the road while the motorist is fixating down the road or, more importantly, if the object is in the travel lane and the motorist is fixating away from the object. Such might be the case if the motorist is inattentive (day dreaming, fatigue, etc.) or distracted or in the course of normal head and eye movements. That a driver might not be fixating down the travel lane is common enough that this scenario should be considered in the perception process. [An argument against this assumption can be based on Rackoff and Rockwell's (16) studies of eye movements and fixations. During the day they found that their test subjects fixated straight ahead 92.6 percent of the time on freeways and 64 percent on rural highways. However, these subjects were in a more attentive state and had helmets on, which would limit their normal head movements.]

Data on latency eye-movement times are provided from laboratory studies by Bartlett and others (17), who examined the cumulative distribution of latencies of eye reaction to stimuli located 10, 20, and 40 degrees off the visual axis. The various percentile values for the 20° curve, which is not unrealistic for driving situations, are as follows:

Percentile	Latency (s)
50	0.24
75	0.27
80	0.29
85	0.31
90	0.33
95	0.35
99	0.45

These data are based on only three subjects, however.

Eye-movement times for a target 20° off the visual axis averages about 0.09 s according to White and others (18). This value is compatible with the 0.15–0.33 s cited by Matson, Smith, and Hurd (19) as the time for moving the eye to fixate to the left or

right in scanning an intersection scene, which is a situation with a much wider angle than 20°.

The time it takes to bring the object into focus on the retina can be considered minimum fixation time. Data on this component are skimpy and they are qualified by their own experimentation apparatus, procedure, and purpose. Matson, Smith, and Hurd (19) cite a range of 0.1–0.3 s for fixation time, and Maurant and others (20) reported a mean fixation time of 0.27 s of various objects during open road driving. No studies were uncovered that would yield reliable distribution profiles for this component.

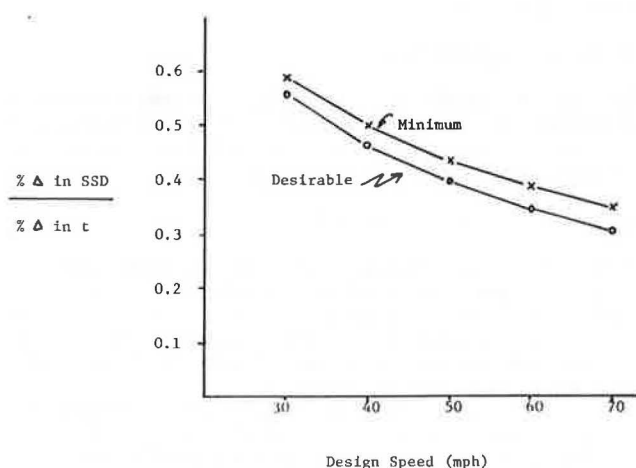
The last component of the perception process is termed the recognition phase and is defined here as the time for the brain to interpret the image that the eye has focused on as a recognizable object. For many targets, this recognition phase is, in all likelihood, instantaneous with detection. But as objects become less familiar to the motorist and where legibility and reading are required, this recognition phase can take on a measurable time period. The object height used for stopping-sight distance is 6 in, which was arbitrarily selected by AASHO as "representative of the lowest object that can create a hazardous condition and be perceived as a hazard by a driver in time to stop before reaching it" (1). Objects this low would be animals, rocks, or other debris. More common objects, particularly at intersections, would be pedestrians and vehicles, both of which exceed the 6-in object height.

The fact that recognition time is a mental process makes it nearly impossible to measure it alone. The recognition component cannot be isolated from the total information-gathering process and, consequently, is measured only as part of the total perception phase. Data that could be used to approximate this component are available from the work of Ells and Dewar (21) and Ells and others (22). Ells and others (22) found the mean response time of 12 subjects responding to sign targets after being detected to be from 0.42 to 0.48 s. In another similar study, Ells and Dewar (21) found this to be about 0.6–0.7 s.

Table 2. Estimated perception-brake-reaction time for various percentiles of driving population.

Element	Perception-Brake-Reaction Time (s) at Following Percentile of Drivers					
	50	75	85	90	95	99
Perception						
Latency	0.24	0.27	0.31	0.33	0.35	0.45
Eye movement	0.09	0.09	0.09	0.09	0.09	0.09
Fixation	0.20	0.20	0.20	0.20	0.20	0.20
Recognition	0.40	0.45	0.50	0.55	0.60	0.65
Decision	0.50	0.75	0.85	0.90	0.95	1.00
Brake reaction	0.85	1.11	1.24	1.42	1.63	2.16
Total ^a	2.3	2.9	3.2	3.5	3.8	4.6

^a Rounded to highest tenth of a second.

Figure 1. Sensitivity indices related to design speeds for minimum and desirable stopping-sight distance.

Although it has not always been recognized, there can be a decision process involved in the perception-brake-reaction time. For the purposes of stopping-sight distance, the amount of decision time is probably inversely proportional to the amount of time remaining before collision. That is to say, if a panic maneuver is necessary to avoid a collision with an opposing vehicle, then the decision time is likely instantaneous with the moment of perception. However, a review of the literature could neither confirm nor refute this hypothesis. The most pertinent data available from the literature are that of Lunenfeld (23), which state that 85th percentile driver decision times for both expected and unexpected situations would be as follows:

Information Content (bits)	Decision Time (s)	
	Expected	Unexpected
0	0	0
1	0.7	1.0
2	1.3	1.6
3	2.0	2.6

For the case of sighting an object in the roadway, the decision is relatively simple, and thus it is likely that the decision time will fall between zero and a maximum of 1.0 s.

The last component is brake reaction. The values suggested are those from the Johansson and Rumar study (6) under an unaltered condition.

The totals for the estimated percentile values range from 2.3 s for the 50th percentile to 4.6 s

for the 99th percentile (see Table 2). The suggested 85th percentile of 3.2 s is 28 percent greater than the current specification value of 2.5 s.

These values should not be considered a statistically reliable distribution of the driving population. They are based on estimates, assumptions, and data from experimental procedures not truly indicative of actual conditions. Furthermore, they are derived from summations of components of the process. As discussed previously this may not be realistic because a human is capable of time-sharing sensory information processing and psychomotor tasks. Nonetheless, although higher, they are not unrealistic when compared with the perception-brake-reaction times cited by Mortimer (14) and Sivak (15) (see Table 1).

It is worthwhile noting that recent Canadian research, as reported by Scott (24), recommends the use of a variable time value for desirable perception-reaction time. The desirable time would vary as a function of vehicle speed: As speed increases, the perception-reaction time likewise increases. The Canadian desirable values range from 2.5 s at a speed of 25 mph to 3.5 s at a speed of 85 mph.

Sensitivity of Standard to Driver Characteristic

One way to state the sensitivity of the standard with respect to a change in the driver characteristic specification is to express the percentage of change in the standard (i.e., stopping-sight distance) that results from a one percent change in the specification of the driver characteristic, assuming all other independent variables remain constant. This value is computed by taking the partial derivative of the standard with respect to the driver characteristic, dividing by the standard, and then multiplying by the driver characteristic. The formula that applies is

$$(dSSD/dP)/(SSD/P) = 1.47 PV/[1.47 PV + V^2/30(f \pm g)] \quad (1)$$

where

SSD = stopping-sight distance (ft),
 P = perception-reaction time (s),
 V = velocity of vehicle (mph),
 f = coefficient of friction between tires and roadway surface, and
 g = grade of roadway.

Application of Equation 1 for both minimum and desirable stopping-sight distances where there is no grade yields the sensitivity indices illustrated in Figure 1. At the design speed of 30 mph, a 1 percent change in the brake-reaction time will yield a 0.580 and a 0.563 percent change in the minimum and desirable stopping-sight distance, respectively. This percentage change decreases with increasing design speed partly due to the lower coefficient of friction values. The stopping-sight distance is less sensitive to a change in the brake-reaction time at higher speeds because the braking distance component $[V^2/30(f \pm g)]$ accounts for a greater proportion of the total distance as speed increases. The other observation is that the minimum values are more sensitive to a change in the perception-brake-reaction time than are the desirable values.

The AASHTO (5) standards for stopping-sight distance are rounded from the computed values. In all but one instance, the rounded values exceed the computed values, thereby providing slightly more than 2.5 s for perception-reaction time. The minimum value for a design speed of 50 mph is less than the

actual computed value (375 versus 376.4 ft). However, the effect of this shortfall is that the maximum allowable perception-reaction time is reduced only to 2.48 s.

Truck stopping-sight distances differ from automobile stopping-sight distances due to the relative efficiencies of the automobile and truck braking systems. Based on the Uniform Vehicle Code (25) performance standards for truck and automobile braking systems, it can be assumed that the average truck braking distance is 60 percent longer than the automobile braking distance. If that is the case, truck drivers are not provided 2.5 s of perception-reaction time. In fact, at higher design speeds, truck braking distance exceeds the total sight distance provided. The table below lists the computed truck perception-reaction time based on the AASHTO rounded design standards:

Design Speed (mph)	Minimum SSD (s)	Desirable SSD (s)
30	--	1.43
40	1.12	0.99
50	0.48	0.42
60	0.36	0
70	0	0

LATERAL CLEARANCE TO SIGHT OBSTRUCTION ON HORIZONTAL CIRCULAR CURVES

Current Standard

Sight distance for drivers of vehicles on horizontal curves can be obstructed by the terrain, cut slopes, walls, buildings, guardrail, etc., on the inside of the curve. In order to provide adequate sight distance for stopping or passing, it is necessary for these obstructions to be set back from the roadway pavement a sufficient distance for the driver to see across the inside of the curve. AASHTO (5) provides design standards for the provision of stopping-sight distance based on the following formulas:

$$m = (5730/D)[1 - \cos(SD/200)] \quad (2)$$

or

$$m = R[1 - \cos(28.65S/R)] \quad (3)$$

where

- m = minimum lateral clearance (or the middle ordinate of the horizontal curve) measured from the centerline of the inside lane to the sight obstruction (ft),
- D = degree of curvature of the centerline of the inside lane (degrees) = $5730/R$,
- S = sight distance measured along the centerline of the inside lane (ft), and
- R = radius of the curve measured to the centerline of the inside lane (ft).

Driver Characteristic

The AASHTO standard for lateral clearance to sight obstructions on horizontal circular curves is simply an application of the stopping-sight-distance formulation, which in turn is based directly on the driver characteristic perception-brake-reaction time. The AASHTO specification for perception-brake-reaction time is 2.5 s.

It should be noted that, on horizontal curves, an object situated on the roadway surface at the stopping-sight distance is not directly in front of the vehicle. Instead, it is off to one side at an angle, as shown in Figure 2. For example, for a

driver of a vehicle traveling at 30 mph on a 10° horizontal curve, the stopping-sight distance on the roadway surface is 20° off center (i.e., the driver's field of view must be rotated 20° from straight ahead in order to look directly at the stopping-sight-distance point). At the maximum design degrees of curvature, the off-center angles range between 30° and 50°. Visual acuity has been observed to decrease significantly outside of an individual's 10° field of view (5° off center). Therefore, in order for a driver to sight an object in the roadway at the stopping-sight distance, the driver's field of view must be shifted away from straight ahead. It must be expected that all drivers do shift their field of view to encompass more of the roadway surface and do have sufficient eye movements to bring the stopping-sight-distance point within foveal view. Based on this expectation, it is assumed that the perception time estimates developed earlier under the section on Stopping-Sight Distance are likewise valid estimates for horizontal curve applications.

Sensitivity of Standard

The direct sensitivity of middle ordinate distance to changes in perception-reaction time is calculated by the following equation, which is a function of the first derivative of Equations 2 and 3:

$$(dm/dRT)(1/m) = (VD/7814)[\cos(SD/22920)] \quad (4)$$

where the trigonometric function is expressed in radians. The instantaneous percentage change in middle ordinate distance as a result of changes in perception-reaction time ranges between 44 and 24 percent per one-tenth second change in perception-reaction time (refer to Table 3).

The sensitivity of the degree of curvature to perception-reaction time is likewise given in Table 3. The table lists only the sensitivities for horizontal curves designed at the maximum degree of curvature. For curves designed at less than the maximum, the sensitivity rates are roughly proportionately smaller. The table shows that, the higher the degree of curvature (and thus the lower the design speed), the greater is its sensitivity to changes in the driver characteristic perception-reaction time. In comparison with the sensitivity of the middle ordinate distance, the sensitivity of the degree of curvature is slightly greater.

Critique of Standard

The AASHTO design standards for lateral clearance on horizontal curves fail to consider three important factors. First, it has been demonstrated earlier in this paper that trucks do not stop at the same deceleration rate as do automobiles.

On vertical curves, the higher driver eye height for trucks compensates to some degree for the relative inefficiency of the truck braking system. However, on horizontal curves, the additional eye height for drivers of trucks does not necessarily provide them with additional sight distance. Therefore, truck stopping-sight distance is not provided for in the AASHTO design standards.

The second factor not addressed directly in the AASHTO design standards is limited visibility conditions (e.g., nighttime). The vehicle's headlight beam must reach the stopping-sight-distance location in order for the driver of the vehicle to have an opportunity to sight an object in the roadway. There are potentially two different reasons why the headlight beam may not reach the necessary distance. Either the horizontal spread of the head-

Figure 2. Angular location of object at stopping-sight distance on horizontal circular curve.

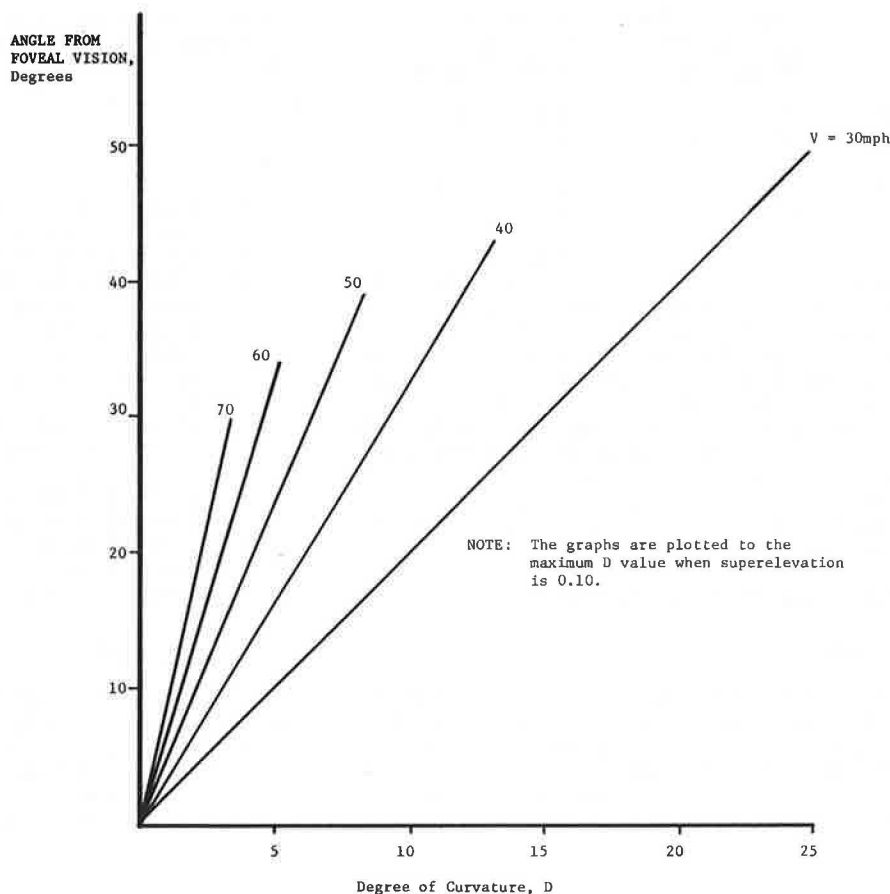


Table 3. Sensitivity of horizontal curve characteristics to changes in perception-reaction time.

Design Speed (mph)	Minimum m at Maximum D (ft)	$[(dm/dRT)(1/m)]$ (%/0.1 s)	Maximum D (°)	$[(dD/dRT)(1/D)]$ (%/0.1 s)
30	20.4	4.42	24.75	-4.55
40	20.4	3.92	13.25	-3.98
Minimum Desirable	28.0	3.71	13.25	-3.79
50	25.3	3.41	8.25	-3.46
Minimum Desirable	37.9	3.15	8.25	-3.21
60	28.6	3.03	5.25	-3.06
Minimum Desirable	45.7	2.76	5.25	-2.80
70	28.6	2.77	3.5	-2.78
Minimum Desirable	53.6	2.43	3.5	-2.46

light beam is not sufficient or the characteristics of the potential sight obstruction may permit a driver with an eye height of 42 in to see in the daylight over the obstruction but do not permit a light beam from a 2-ft-high headlamp to pass over the obstruction and strike the roadway surface at the stopping-sight distance.

The third factor not addressed by the AASHTO standards is the reduced coefficient of friction between the vehicle tires and the roadway surface when a vehicle is traveling on a horizontal curve. Newman and others (26) state that a vehicle braking on a horizontal curve is not afforded the full friction force observed in skid tests. Instead, the actual friction available is a reduced value, which "reflects the amount of side friction used for cornering, and can be calculated as the vector resultant of both total available friction and cor-

nering friction." The table below compares the actual required stopping-sight distance (as predicted by Neuman) with the current design values and compares the actual minimum and current design values for middle ordinate distance:

Design Speed (mph)	Stopping-Sight Distance (ft)		Middle Ordinate Distance (ft)	
	Design	Actual	Design	Actual
30				
Minimum	200	183	21.3	17.8
Desirable	200	206	21.3	22.6
40				
Minimum	275	274	21.7	21.5
Desirable	325	334	30.2	31.9
50				
Minimum	375	386	25.2	26.7
Desirable	475	498	40.2	44.1

Design Speed (mph)	Stopping-Sight Distance (ft)		Middle Ordinate Distance (ft)	
	Design	Actual	Design	Actual
60				
Minimum	525	509	31.4	29.6
Desirable	650	675	48.0	51.7
70				
Minimum	625	616	29.7	28.9
Desirable	850	880	54.9	58.8

Figure 3 illustrates the actual maximum allowable perception-reaction times on horizontal curves designed for desirable stopping-sight distances. The values are plotted to the maximum degree of curvature when the superelevation is 0.10. The figure shows that none of the desirable design values permit the specification for perception-reaction time (2.5 s). Even if the estimated median value (2.3 s) is taken, the desirable stopping sight distance for 50-, 60-, and 70-mph design speeds are not sufficient. Therefore, significant portions of the driving population are being excluded by the current design standards.

INTERSECTION SIGHT DISTANCE--CASE III

Current Standard

Case III intersection sight distance applies to intersections controlled by stop signs on minor roadway approaches. The current standard calls for the driver of a stopped vehicle at the intersection to be able to see enough of the major highway to safely cross before a vehicle on the major highway

reaches the intersection. The AASHTO formulation for computing the required sight distance is as follows:

$$D = 1.467V(J + t_a) \quad (5)$$

where

- D = minimum or desirable sight distance along the major highway from the intersection (ft),
- V = design speed on the major highway (mph),
- J = sum of the perception time and the time required to actuate the clutch or actuate an automatic shift (s),
- t_a = time required to accelerate and traverse the distance S to clear the major highway pavement (s),
- S = distance that the crossing vehicle must travel to clear the major highway (ft) = $D + W + L$,
- D = distance from near edge of pavement to the front of a stopped vehicle (ft),
- W = pavement width along path of crossing vehicle (ft), and
- L = overall length of vehicle (ft).

Driver Characteristic

The driver characteristic perception-reaction time is defined by AASHTO (5) as "the time necessary for the vehicle's operator to look in both directions on the roadway, to perceive that there is sufficient time to cross the road safely, and to shift gears, if necessary, preparatory to starting. It is the

Figure 3. Maximum allowable perception-reaction time on horizontal curves based on desirable stopping-sight-distance standards.

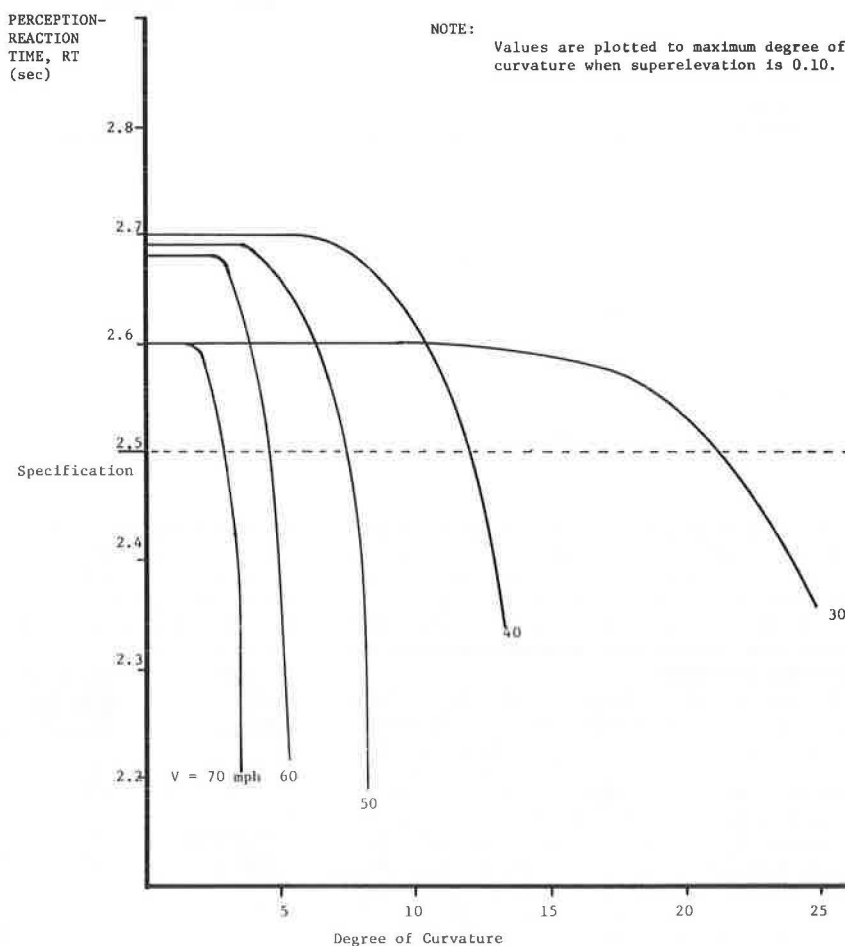
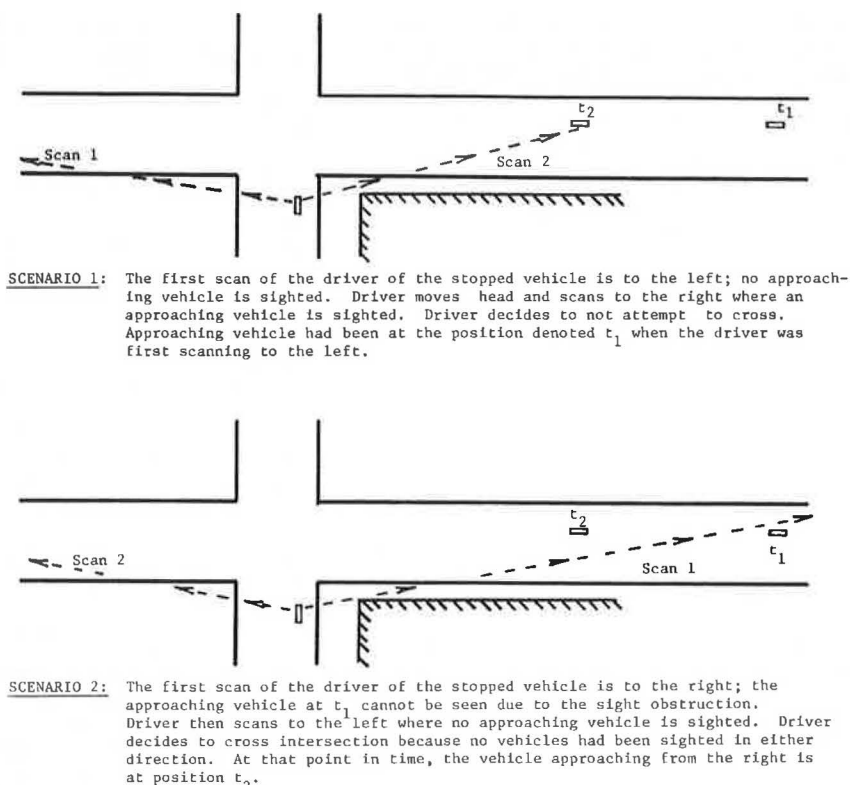


Figure 4. Case III intersection sight distance: driver of stopped vehicle scanning approaching roadways.



time from the driver's first look for possible oncoming traffic to the instant the car begins to move." A value of 2.0 s is the current specification, which represents "the time taken by a small percentage of slower drivers" (5). The historical basis for this value cannot be determined.

In order to develop an estimated distribution of driver characteristic values for the driving population, it is necessary to divide the driver characteristic into a series of steps. Basically the steps are

1. Head and eye movement to scan intersection,
2. Fixation and decision, and
3. Reaction (i.e., move foot from brake to accelerator).

The AASHTO definition of the driver characteristic includes time for the driver "to look in both directions on the roadway". A careful critique of the driver's actual required scan movements reveals that only one head movement (not two, as is called for in the definition) is needed in order for the driver to safely cross the intersection. No matter how many times a driver may scan the two intersection approach legs, the critical head and eye movements on which the decision to proceed or stay is made is the last one. If the driver scans one direction (as illustrated in Figure 4) and sees no approaching vehicle, the decision would be to proceed if a scan of the other direction reveals no approaching vehicle either. In scenario 2 of Figure 4, the driver has performed the two scans and has decided to proceed, even though another scan to the right would reveal an approaching vehicle. The distance that the approaching vehicle travels before the stopped vehicle starts across the intersection is the former vehicle's velocity multiplied by the sum of the time it takes for the driver of the stopped vehicle to move his or her head and/or eyes to the left, to decide to proceed, and to move his

or her foot to the accelerator. Thus, the head- and eye-movement component of the driver characteristic perception-reaction time should account for a scan of only one leg of the intersection.

No empirical research has successfully measured the total perception-reaction time for drivers of stopped vehicles at intersections. In order to develop an estimated distribution of values for the driving population, it is necessary to assign values to individual elements of perception-reaction time and sum them.

Robinson (27) timed driver head movements at an intersection and found that an average scan to one direction (head movement plus fixation plus decision) took 1.1 s. Johansson and Rumar (6) measured the brake-reaction time for drivers in an alerted condition. Brake-reaction time is appropriate in this application because accelerator reaction is simply a motor movement equal and opposite to brake reaction; the driver is in an alerted condition due to the intersection scan. Johansson and Rumar found values ranging from 0.63 s at the 50th percentile to 1.21 s at the 95th percentile. Interestingly, if the 85th percentile value of 0.92 s is added to Robinson's 1.1 s described above, a total perception-reaction time of 2.02 s results (only 0.02 s higher than the current specification).

The 1965 edition of the Traffic Engineering Handbook (28) provides the following data as the total time required for a driver to scan one leg of an intersection:

Item	Time (s)
Shift (head and eye movement)	0.15 to 0.33
Fixate on object	0.10 to 0.30
Total	0.25 to 0.63

The time needed for the driver to decide to proceed can be estimated in the same manner as was done earlier under the section on Stopping-Sight Distance. The estimated values range from 0.50 s at

the 50th percentile to 0.95 s at the 95th percentile. By summing this decision time and the head-and-eye-movement time with Johansson and Rumar's reaction time, another range of estimated values for perception-reaction time results--1.38 to 2.79 s. Note that the average of these two values is 2.08 s. If the midrange values for head and eye movement are estimated to be the 85th percentile values, the 85th percentile value for the total perception-reaction time would be as follows:

Item	Time (s)
Head and eye movement	0.24
Fixation	0.20
Decision	0.85
Reaction	0.92
Total	2.21

Sensitivity of Standard

The percentage change in minimum or desirable sight distance for a unit change in the driver characteristic perception-reaction time ranges from approximately 0.14 percent/s for passenger vehicles to 0.08 percent/s for WB-50 vehicles. The incremental change in intersection sight distance as a function of unit changes in perception-reaction time ranges from 4.4 ft/0.1 s for a 30-mph design speed to 10.3 ft/0.1 s for a 70-mph design speed.

VEHICLE CHANGE INTERVAL

Driver Characteristic

For the driver who sights a traffic signal that has just turned yellow and who decides to stop for the imminent red signal, two driver characteristics are involved: perception-reaction time and comfortable deceleration rate. The following analysis addresses only the former characteristic.

The current specification for the driver characteristic perception-brake-reaction time is 1.0 s as stated in the Transportation and Traffic Engineering Handbook (29) and the Traffic Control Devices Handbook (30). The use of the 1.0-s value can perhaps be traced back to a 1934 MIT research effort (2), which found that 95 percent of the sampled drivers had brake-reaction times of 1 s or less when in an alerted condition. Subsequent studies in the early 1960s of driver reactions to the amber signal by Gazis, Herman, and Maradudin (31) and by Olson and Rothery (32) continued the use of the 1.0-s specification. However, a recent field study by Wortman and Matthias (33) observed driver perception-reaction times that were significantly greater than the specification values. At all sites in the study, the mean observed perception-reaction time was greater than 1.0 s. In fact, at most of the intersections, the 85th percentile value approached 2 s.

Experimentally derived data on driver perception-reaction time were discussed earlier under the section on Stopping-Sight Distance. Applicable to the yellow signal case is the data presented by Johansson and Rumar (6) on brake-reaction times for alerted subjects. The stimulus in the Johansson and Rumar study was auditory (not visual) and thus could be expected to require little, if any, perception time. Likewise, because the subjects were instructed to perform a particular task on hearing the stimulus, no appreciable decision time would be expected. The Johansson and Rumar data distribution is as follows:

Percentile	Alerted Brake-Reaction Time (s)
50th	0.63
85th	0.93
95th	1.21

It should be noted, however, that this distribution depicts a pure case of brake reaction. That is, the decision is made instantaneously on perceiving the circumstances (no decision time) and perception of the situation occurs simultaneously with the onset of the situation (no perception time). Obviously, no driver is able to decide to brake the vehicle at the same instant the yellow indication starts. Rather, the driver must first detect and/or identify that the signal indication has turned to yellow and decide whether to continue through the intersection or to stop prior to the intersection. Detection and/or identification of a signal phase change depends greatly on the amount and criticality of other information that must be processed. Some other factors that compete for a driver's attention include traffic conditions, approach speed, directional uncertainty, and proximity to the intersection. [Note, King provides a thorough discussion of techniques to minimize these distractions in Guidelines for Uniformity in Traffic Signal Design Configurations (34).] With these distractions and other potential temporary blockages (e.g., trucks), it is quite conceivable that a driver will not instantaneously detect a signal phase change.

After the signal phase change is detected, the driver must still decide whether to continue through the intersection or to stop. This decision is more complex than the one facing a driver who sights an impassable object lying in the road. And the signal phase change decision is less complex than that faced by a driver who approaches an uncontrolled intersection and who must judge relative speeds of potentially conflicting vehicles. However, we will assume the same decision time distribution presented earlier under Stopping-Sight Distance. If latency, fixation, and recognition times are assumed to be zero (i.e., instantaneous recognition of the amber signal phase change), the decision-brake-reaction time estimates become the perception-brake-reaction time estimates, as follows:

Percentile	Perception-Brake-Reaction Time (s)
50th	1.13
85th	1.77
95th	2.16

These empirically derived values compare quite favorably with the observed values documented by Wortman and Matthias (33). For example, the mean value observed was 1.30 s as compared with the 1.13-s median value derived above. Wortman and Matthias' average 85th percentile value for all study intersections was 1.8 s; the estimate above is 1.77 s.

It should be noted that the estimates derived above assume the driver's instantaneous perception and recognition of the amber signal phase change. In some, if not most, cases, the driver will indeed give primary attention to the signal when the vehicle approaches and passes through the point at which the appropriate decision changes from "stop if signal changes to yellow" to "proceed even if signal changes to yellow". In other words, the experienced driver is aware of this threshold point and knows that it is not critical to focus attention on the signal well before or well after this point but that it is critical around that distance from the intersection. In some cases, the driver may not be able

to focus attention on the signal when the vehicle is near the threshold point due to other factors, such as traffic congestion. In these instances, the driver does not instantaneously perceive and recognize the amber signal phase change. This lag time actually would be added to the perception-brake-reaction time estimates derived above.

Sensitivity of Standard

The effect of increasing the perception-reaction time on the vehicle clearance interval is 1:1. That is, a 1-s increase in the specification for perception-reaction time necessitates a 1-s increase in the vehicle clearance interval.

RECOMMENDATIONS

The analyses presented above are only a cursory review of the interrelations between the driver characteristic perception-reaction time and several highway design and operations standards. A more thorough analysis is presented in the upcoming Federal Highway Administration (FHWA) research report, *Driver Characteristics Impacting on Highway Design and Operation*.

Throughout the above analyses, a number of observations were made regarding perception-reaction time and the various standards. These comments are summarized below.

The stopping-sight-distance standard does not adequately account for the braking inefficiencies of trucks. Based on the calculations presented earlier, it would appear that trucks are unable to stop within current standard distances. Further research into truck operating characteristics, especially its braking capabilities, would enable the improvement of the stopping distance formulation to more accurately depict the action of a truck stopping.

The analyses contained in this report indicate that several specification values for perception-reaction time may in fact be too low. Because these conclusions are based principally on aggregated simulation results, it is recommended that extensive field testing be undertaken to establish definitive and documentable specification values.

The current specification value for perception-reaction time in the vehicle clearance interval has been criticized as being too low. A concerted effort should be made to establish scientifically developed specification values for both perception-reaction time and vehicle deceleration rate.

The driver characteristic perception-reaction time in the case III intersection sight distance standard should be redefined. It is recommended, however, that the specification value be kept at 2.0 s.

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Abridgment

Corrections to Driver Characteristic Specifications and Standard Formulations for Intersection Sight Distance

KEVIN G. HOOPER AND HUGH W. McGEE

This report documents an evaluation of the American Association of State Highway and Transportation Officials standards for intersection sight distance and how they are affected by driver characteristics. The study involved the development of a population profile for the driver characteristic perception-reaction time, and the calculation of the sensitivity of each standard to realistic changes in the driver characteristic. The study found that, for case I intersection sight distance, the driver is not provided sufficient time or distance to take evasive action from an opposing vehicle, and for case II, adequate sight distance in order to stop before the intersection is not provided despite the intent of the standard to enable such an action. Proper formulations are developed in the paper and proposed as revisions. The effect of these revisions on current standard intersection sight distances is described and quantified. In addition, recommendations are made to increase the perception-reaction-time value for case I from 2.0 to 3.4 s and for case II from 2.5 to 3.4 s.

The 1965 American Association of State Highway Officials (AASHO) Blue Book, A Policy on Geometric Design of Rural Highways (1), and its draft revised versions (2) present standards for adequate sight distance at intersections. Abridged analyses of the interrelations between characteristics and the sight-distance standards for cases I and II follow. Included in these analyses are investigations into the appropriateness of the current standard formulations.

CASE I: ENABLING VEHICLES TO ADJUST SPEED

Current Standard

At an intersection where no approach leg is controlled by stop signs, yield signs, or traffic signals, a driver of a vehicle who approaches the intersection must be provided adequate sight distance both to perceive the potentially conflicting movement of a crossing vehicle and to take the necessary countermeasure. The American Association of State Highway and Transportation Officials (AASHTO) (2) formula for computing the minimum allowable sight distance on each leg is as follows:

$$D = 1.467V(\text{PRAT})$$

(1)

where

D = minimum sight triangle distance (ft),
V = vehicle velocity (mph), and
PRAT = perception-reaction-action time (s).

The formulation assumes that the appropriate minimum distance from an intersection, at the point where the driver first observes a vehicle approaching on an intersecting road, is that which is covered during both the driver's perception and reaction time (which includes 1 s in which the speed of the vehicle is adjusted by the driver's reaction). AASHTO recommends the use of between 2.5 and 3.0 s as the value for the perception-reaction-action time: 1.5-2.0 s for perception and reaction and 1.0 s for the action (acceleration or deceleration).

Driver Characteristic

The perception-reaction process in this case is the ability of a driver to perceive a vehicle moving across his or her path, judge its trajectory in relation to his or her vehicle, and then decide whether some speed adjustment is necessary to avoid collision. A literature review did not uncover any studies on how long it takes drivers to perform this overall task. In the absence of any empirical research, estimates of the actual distribution of perception-reaction times for the driving population have to be based on a sum of the times for the components of the process determined from the available literature.

If one were to model the driver's task for this situation (i.e., before the vehicle actually accelerates or decelerates), the following steps would likely be considered:

1. Driver picks up (through peripheral vision) an object moving toward the intersection;
2. After a latency period, eye or head movement or both detects the object;