Analysis of Influence of Perception-Reaction Time on Case III Intersection Sight Distance

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For years researchers have attempted to conclusively define values to be used for perception-reaction (PR) times for highway design and operations. Several empirically based studies have confirmed values that are used in different design guides and manuals. However there still appears to be no final agreement on what values should be used for various design purposes. PR time is an essential element in determining intersection sight distance (ISD) requirements. Although there has been much discussion of the appropriate values of PR times that should be used for this purpose, an understanding of the relative influence of PR time on ISD would help to determine whether very exact PR times are needed to adequately design intersections. Previous work on the assessment of appropriate PR times is reviewed, and the influence of varying PR times on the determination of Case III ISD values is analyzed to see whether the designer needs to be concerned about the selection of exact PR times. Several conclusions were reached on the bases of the review and the analyses. It was concluded that although there has been a great deal of research on PR times, there appears to be some doubt about how well the current values used for highway design purposes represent real-world conditions. Also for applications related to Case III ISD determination PR time has little influence on the overall ISD requirement. On the basis of these conclusions it is recommended that the current values used for PR time for Case III ISD applications be retained because of their validation from several empirical studies and the insensitivity in change of ISD values relative to changes in PR times.

Driving a vehicle safely through an intersection is a complex job requiring the coordination of sensory, perceptual, cognitive, and motor skills. Complicating the smooth interaction of these tasks are outside influences, such as intersection geometry, and the presence of external factors, such as other vehicles or pedestrians.

In attempting to design safer intersections, an area of importance in the highway geometric area has been sight distance. The AASHTO publication *A Policy on the Geometric Design of Streets and Highways* (*1*), often referred to as the Green Book, is the principal guidance for highway design in the United States, and it details the processes for determining sight distances for a variety of operational situations. Sight distance is necessary to ensure safe vehicle operations related to stopping, intersection movements, and passing situations.

Intersection sight distance is the unobstructed line of sight sufficient to allow approaching drivers to anticipate and avoid potential conflict situations at intersections. There are four intersection situations of interest as described by AASHTO.

- Case I—no control,
- Case II—yield control on minor road,
- Case III—stop control on minor road, and
- Case IV—signal control.

In addition, AASHTO has separated Case III into three subcases dealing with different intersection maneuvers.

- Case IIIA—crossing maneuver,
- Case IIIB—turning left into a major highway, and
- Case IIIC—turning right into a major highway.

A factor used in the determination of intersection sight distance (ISD) that has received a great deal of attention is perception-reaction (PR) time. PR time has generally been thought to be the time needed to perceive a stimulus and, if necessary, the additional time required to take some type of action in response. Numerous studies have attempted to analyze what has simply been called perception and reaction for the purpose of determining a value to be used in roadway design. For ISD situations, AASHTO has established the value of PR times to be used in the various equations that define ISD. Case I uses a PR time of 2.0 sec plus an additional 1.0 sec to adjust speed. The ISD necessary for Case II situations is stopping sight distance (SSD) on the minor roadway. Therefore the PR time is set at 2.5 sec. All Case III situations use a value of 2.0 sec.

Over the years there has been a great deal of discussion of what is an appropriate PR time for use in highway design purposes. This paper reviews this previous work and analyzes the influence of varying PR times on the determination of Case III ISD values to see whether the designer needs to be concerned about the selection of a very exact PR time.

BACKGROUND

A great deal of effort has been expended for the purpose of arriving at a single value for PR time that neatly encompasses the entire driving population. Although AASHTO currently recommends an ISD PR time of 2.0 sec, past research has questioned the use of that number.

The first formal discussion of ISD was published in 1940 in *A Policy on Intersections at Grade* (*2*). The formulas presented in that text used a PR time of 2.0 sec. That value appears to be a direct result of the 1940 AASHO publication *A Policy on Sight Distance for Highways* (*3*). However no explanation other than "simplicity" was provided in the 1940 policy for the assumed value of 2.0 sec. Having only this rather arbitrary determination

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of a PR time for ISD cases, researchers have sought to define an appropriate PR time more scientifically.

One approach for calculating a PR time has been to measure the durations of several of the constituent elements and to sum these time segments to determine a value. Another approach has been to calculate percentile values for the measurable elements and assemble these percentile values into some single value or range of values for PR time.

An example of this general approach can be found in the work of Hooper and McGee (*4*). In trying to validate the 2.0 sec used for PR time in a Case III ISD scenario, the authors conducted an experiment that measured subprocesses that make up the aggregate PR time. For Case III ISD they defined these elements as head and eye movement, fixation, decision, and reaction. Values are presented for each of these subprocesses and then summed (Table 1). Adding these values yields a total PR time for Case III ISD of 2.21 sec. This value is 0.21 sec above the current values, an increase of 10.5 percent. The authors state that the criterion of 2.0 sec should be retained, but that the formulation of the PR time should be redefined, presumably to their model.

This type of approach has been criticized for having two principal drawbacks. The first is that of the implicit assumption that the elements of the process act in series without any time overlap or parallel functioning. The second is that it is highly unlikely that an individual will consistently perform at or near prespecified percentile values for all of the individual elements of the process (*5*).

Additional attempts to determine PR times have focused on empirical studies of the entire PR process. In those studies measurements are made of the time from the onset of the perception process through the completion of the reaction component and the onset of mechanical acceleration or braking. However many of those studies tend to be deficient in that the subjects are already alerted to the fact that their reactions will be tested.

An example of this approach can be found in the work of Hostetter et al. (*6*). As part of a study examining the different Case III scenarios, subjects were observed while trying to complete all three Case III intersection maneuvers. PR times were measured as the time from the first head movement after a stop to the application of the accelerator. On the basis of the results of those experiments a recommendation was made to keep the current specification of 2.0 sec for Case IIIA, but to change the specification for Cases IIIB and IIIC to 2.5 sec.

ANALYSES

Although researchers do not seem to be able to convincingly debunk the current value for PR time, this does not stop discussions of what is an appropriate PR time to use for highway design situations. Although exchanges concerning what particular value of PR time is appropriate are informative, the nature of the AASHTO ISD equations could render these discussions moot. An appreciation of the relative influence of PR time on ISD values would help to determine whether very exact PR values are needed to properly design intersections.

To test this point the impact of PR time on each of the Case III sight distance equations was evaluated in the following series of analyses of each of the Case III maneuvers. Each analysis consists of a brief description of the AASHTO equation and then sensitivity analyses of the various parameters of interest. The sensitivity analyses were carried out in two parts. The first set of sensitivity analyses varied one parameter at a time, holding the others to appropriate default values. The second set of analyses examined the effects of varying two parameters at the same time. The measure of effectiveness used in both cases was elasticity. Elasticity is a concept used in economics to relate one parameter to another. In economic theory elasticity is the slope of the demand-price curve at a given time point. Elasticity is a measure of the change in demand for a unit change in price. The economic elasticity is weighted by the equilibrium point of the demand-price curve. In essence the elasticity is a measure of the sensitivity of the demand curve to price. In the application of this paper the sensitivity of the AASHTO equations are measured with respect to the parameter of PR time. These sensitivities are weighted by the mean. Because both sensitivities measure the change in one variable with respect to a second independent variable, the term *elasticity* is adopted and used throughout this paper as a single-figure measure of an equation's sensitivity (*7*). The elasticity values computed in the sensitivity analyses for this paper are the ratio of change in ISD over the range of interest to the mean ISD divided by the ratio of change in the selected parameter over the range of interest to the mean of that parameter.

TABLE 1 85th Percentile Values for PR Subprocesses for ISD Case III (*4*)

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

CASE IIIA—CROSSING MANEUVER

The AASHTO Green Book states that the sight distance for a crossing maneuver is based on the time it takes for the stopped vehicle to clear the intersection and the distance that a vehicle will travel along the major road at its design speed in that amount of time. In reality, however, the time element also includes a perception-reaction and vehicle transmission actuation component. The sight distance for Case IIIA is calculated from the following equation:

$$\mathrm{ISD} = 0.2784\ V(J + t_a) \tag{1}$$

where

ISD = d_1 (to the left of the vehicle on the minor road) or d_2 (to the right of the vehicle on the minor road) sight distance along the major highway from the intersection (m);
V = design speed of the major highway (km/hr);
J = sum of the perception time and the time required to actuate the clutch or actuate an automatic shift (sec);
t_a = time required to accelerate and traverse the distance (S) to clear the major highway pavement (sec);
$S = D + W + L$, the distance that the crossing vehicle must travel to clear the major highway (m);

D = distance from the near edge of pavement to the front of a stopped vehicle (m);
W = pavement width along the path of the crossing vehicle (m); and
L = overall length of the vehicle (m).

ISD is measured from a driver eye height of 1.0675 m (for passenger cars) to the top of an object 1.2963 m (nominally the overall height of another passenger car) above the pavement.

The J term, or PR time, is the time allowed for scanning in both directions by the vehicle operator to determine whether there is a sufficient gap to initiate and complete the crossing maneuver safely and the time to actuate the transmission. According to AASHTO the value for J is equal to 2.0 sec. This value is a constant since there is no guidance as to when it might be appropriate to vary J for changing conditions, such as operator or vehicle types. However the key issue here is not what value of PR time is absolutely correct (e.g., 2.0 or 2.5 sec) but what the impact of different values of PR time on the ISD values would be.

To answer this question sensitivity analyses were performed on the Case IIIA formulation. As mentioned above the measure of effectiveness used in all analyses was elasticity. Again the elasticity values are the ratio of change in ISD over the range of interest to the mean ISD divided by the ratio of change in the selected parameter over the range of interest to the mean of that parameter. From Figure 1, for example, the elasticity value (E_d) for PR time is calculated as

$$E_d = \frac{\dfrac{302.6515 - 235.399}{\dfrac{302.6515 + 235.399}{2}}}{\dfrac{3.5 - 0.50}{\dfrac{3.5 + 0.50}{2}}} = \frac{\dfrac{302.6515 - 235.399}{302.6515 + 235.399}}{\dfrac{3.5 - 0.50}{3.5 + 0.50}} = 0.17 \qquad (2)$$

The result of the sample computation shown above indicates that ISD will change by 0.17 percent for each 1.00 percent change in PR time over the range of interest for PR time. Because the relationship between most parameters and ISD is nonlinear, the sensitivity of ISD to the parameter is not constant over the range of interest. However the elasticity value is the most accepted way of representing the relative magnitude of that sensitivity in a single number. A positive value for E_d indicates that ISD increases with increasing values of the parameter. A negative value of E_d indicates that ISD decreases with increasing values of the parameter.

Sensitivity analyses were performed on the 1990 AASHTO Case IIIA procedure to determine the relative importance of the various factors that are part of the ISD equation. Different ISD values were calculated as a variable of interest was stepped through a range of values and the remaining variables were held constant at some predefined default value. A spreadsheet was used to perform the calculations and tabulate the results. For a single-parameter analysis, for example, a set of ISD values was calculated for a series of design speeds ranging from 32.2 km/hr (20 mph) to 112.7 km/hr (70 mph) in 16.1-km/hr (10-mph) increments while the value of t_a was held constant at 10.0 sec and the value of J was held at 2.0 sec. Figure 1 shows the table and the results of the first set of sensitivity analyses.

When design speed was varied and all other variables were held constant, ISD showed a sensitivity to changes in design speed characteristic of a variable multiplied by a constant. The elasticity of the relation between the two variables is equal to 1.00. This means that for 1.00 percent change in design speed there is a corresponding change of 1.00 percent in ISD.

A second analysis of the current model was performed by varying t_a through a series of values ranging from 4.00 to 16.00 sec in 0.25-sec increments while the value of design speed was held constant at 80.5 km/hr (50 mph) and the value of J was held at 2.0 sec. The elasticity of the relation between ISD and the time t_a is equal to 0.75. This means that for a 1.00 percent change in the time required to accelerate and clear the major highway pavement there is a corresponding change of 0.75 percent in ISD. This means that the ISD model is not quite as sensitive to changes in t_a as it is to changes in design speed.

The current model was analyzed a third time by varying J through a series of values ranging from 0.50 to 3.50 sec in 0.10-sec increments while the value of design speed was held constant at 80.5 km/hr (50 mph) and the value of t_a was held at 10 sec. The elasticity of the relation between ISD and the perception/shift actuation time is equal to 0.17. This means that for a 1.00 percent change in PR time there is a corresponding change of 0.17 percent in ISD (Figure 2). This means that the ISD model is relatively insensitive to changes in J.

Figure 3 shows the revised criteria that would result if PR time were raised from 2.0 to 2.5 or 3.0 sec. Increasing the PR time by 0.5 sec to 2.5 sec would increase the ISD required for Case IIIA by only 4.17 percent. An increase of 1.0 sec in PR time, to 3.0 sec, would increase Case IIIA ISD by 8.3 percent.

Although the single-parameter sensitivity analysis completely tests each individual parameter's influence on ISD, it is possible that varying combinations of the parameters might yield unexpected results. For this reason analysis of a second set of sensitivities, which varied both t_a and J within a given design speed, was undertaken. Speed was varied from 32.2 km/hr (20 mph) to 112.7 km/hr (70 mph) in 16.1-km/hr (10-mph) increments. The J term was varied from 0.5 to 3.5 sec in 0.1-sec increments. The time to accelerate, t_a, was varied from 4.00 to 16.00 sec in 0.25-sec increments. A tabulation (Table 2; see below as well) of the elasticity values was produced and used to construct the surface plot shown in Figure 2. The plot shows the elasticities that result from varying V and t_a across a range of values for J (0.5 to 3.5 sec).

An interesting aspect of this plot is that the elasticities are the same across any design speed. For example the elasticity value obtained with V = 32.2 km/hr (20 mph) and t_a = 8.0 sec while varying J is equal to 0.18. For all other values of V the E_d is also 0.18 when t_a = 8.0 sec. This occurs because the ISD for Case IIIA is directly proportional to speed. Since the denominator (the J terms) of the elasticity equation (Equation 2) remains constant, the relative proportion between the elasticity values is directly proportional to speed. As expressed earlier, because elasticity is a measure of the range over the mean of one parameter, a proportional increase will simply cancel out.

It should be pointed out that over the range of all possible conditions for V, t_a, and J the elasticities vary from 0.33 to 0.11. [Table 2 shows the range of elasticity values for V = 32.2 km/hr (20 mph). Table 2 would be the same for all values of V, as explained above.] This would lead one to believe that PR time can have a greater influence on ISD values than was illustrated. However these endpoint values are for design and operating conditions that are relatively extreme. Therefore the characterization that ISD is relatively insensitive to PR time holds true.

ISD=0.2784*V*(ta+J)

Default V = 80.5 kph
Default ta = 10 sec
Default J = 2 sec

Ed =	1.00	Ed =	0.75	Ed =	0.17
V (kph)	ISD (m)	ta (sec.)	ISD (m)	J (sec.)	ISD (m)
0	0.0	0	44.8	0	224.2
32.2	107.6	4.00	134.5	0.50	235.4
40.3	134.5	4.25	140.1	0.60	237.6
48.3	161.4	4.50	145.7	0.70	239.9
56.4	188.3	4.75	151.3	0.80	242.1
64.4	215.2	5.00	156.9	0.90	244.4
72.5	242.1	5.25	162.5	1.00	246.6
80.5	269.0	5.50	168.1	1.10	248.8
88.6	295.9	5.75	173.7	1.20	251.1
96.6	322.8	6.00	179.3	1.30	253.3
104.7	349.7	6.25	184.9	1.40	255.6
112.7	376.6	6.50	190.5	1.50	257.8
		6.75	196.2	1.60	260.0
		7.00	201.8	1.70	262.3
		7.25	207.4	1.80	264.5
		7.50	213.0	1.90	266.8
		7.75	218.6	2.00	269.0
		8.00	224.2	2.10	271.3
		8.25	229.8	2.20	273.5
		8.50	235.4	2.30	275.7
		8.75	241.0	2.40	278.0
		9.00	246.6	2.50	280.2
		9.25	252.2	2.60	282.5
		9.50	257.8	2.70	284.7
		9.75	263.4	2.80	286.9
		10.00	269.0	2.90	289.2
		10.25	274.6	3.00	291.4
		10.50	280.2	3.10	293.7
		10.75	285.8	3.20	295.9
		11.00	291.4	3.30	298.2
		11.25	297.0	3.40	300.4
		11.50	302.6	3.50	302.6
		11.75	308.2		
		12.00	313.8		
		12.25	319.4		
		12.50	325.1		
		12.75	330.7		
		13.00	336.3		
		13.25	341.9		
		13.50	347.5		
		13.75	353.1		
		14.00	358.7		
		14.25	364.3		
		14.50	369.9		
		14.75	375.5		
		15.00	381.1		
		15.25	386.7		
		15.50	392.3		
		15.75	397.9		
		16.00	403.5		

FIGURE 1 Single-parameter sensitivity analysis of AASHTO Case IIIA.

CASE IIIB—LEFT-TURN MANEUVER

In the AASHTO Case IIIB situation a vehicle is stopped on the minor road. The intention of the driver is to complete a left-turn maneuver by clearing traffic approaching from the left and then entering the traffic stream approaching from the right. The AASHTO ISD model is constructed such that a vehicle accelerating from a stop to turn left into a major highway should have, as a minimum, sufficient sight distance so that a collision will not occur if a vehicle approaching from the right and traveling at the design speed of the major road appears when the turning vehicle begins its maneuver. The turning vehicle should also be able to accelerate to a safe running speed by the time the approaching vehicle closes to within a specified tailgate distance or minimum separation. According to the 1990 Green Book it is assumed that the major-road vehicle reduces speed from the design speed to 85 percent of the design speed of the major road.

The required intersection sight distance in Case IIIB is given by

$$\mathrm{ISD} = Q - h \qquad (3)$$

where

ISD = sight distance along the major highway from the intersection required for a vehicle to depart from a stop, accelerate to a speed V_a, and complete a turn to the left without being overtaken by a vehicle approaching from the right traveling at design speed and decelerating to a speed V_a(m);

Q = distance traveled by major-road vehicle approaching from the right (m); and

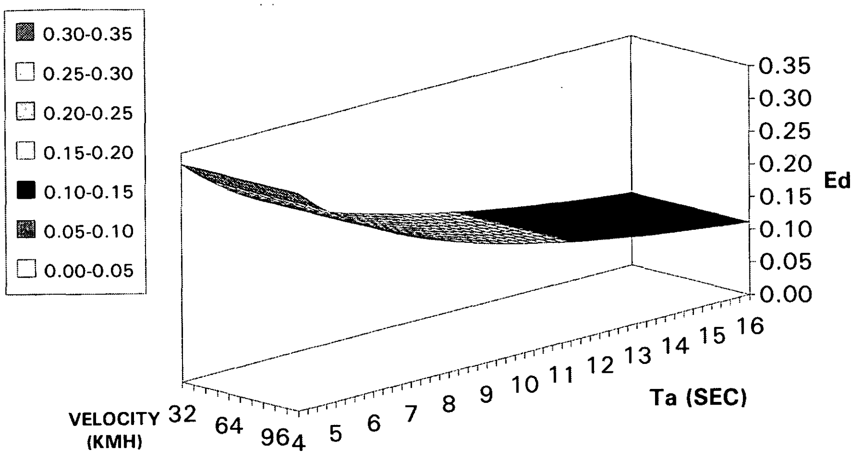

FIGURE 2 Surface plot of multiple-parameter sensitivity analysis for Case IIIA.

h = distance on major roadway traveled by minor-road vehicle from the midpoint of the turning lane on the minor roadway to end of maneuver (m).

In both the 1990 Green Book and previous editions the underlying assumptions used in developing the equations for Q and h were not clearly explained or defined. Information received during the course of research in NCHRP 15(14)-1 identified several of these assumptions and allowed the graphical solutions in the Green Book to be replicated exactly. For the Case IIIB maneuver Q and h can be expressed as

$$Q = 0.2784(J + t_a) \times 0.95V_{ds} \quad (4)$$

where V_{ds} is design speed of the major roadway (km/hr), and

$$h = P - 4.88 - VG - L \quad (5)$$

where P is distance required for minor road vehicle to reach 85 percent of design speed (m) and VG is vehicle gap at conclusion of maneuver (m). AASHTO specifies that VG is equal to the distance traveled in 2.0 sec at 85 percent of the design speed of the major roadway.

$$VG = 0.2784\ (0.85V_{ds}t_{VG}) \quad (6)$$

where t_{VG} is specified vehicle gap (2.0 sec).

In this current formulation two assumptions are made regarding the major-road vehicle. The first is that the driver of the major-road vehicle is traveling at the design speed of the roadway. This is a reasonable assumption because in some situations motorists may drive above the posted speed limit of the facility, operating nearer the design speed. In those cases in which drivers are traveling at less than the design speed, this assumption creates a margin of safety by prescribing more sight distance than is actually required.

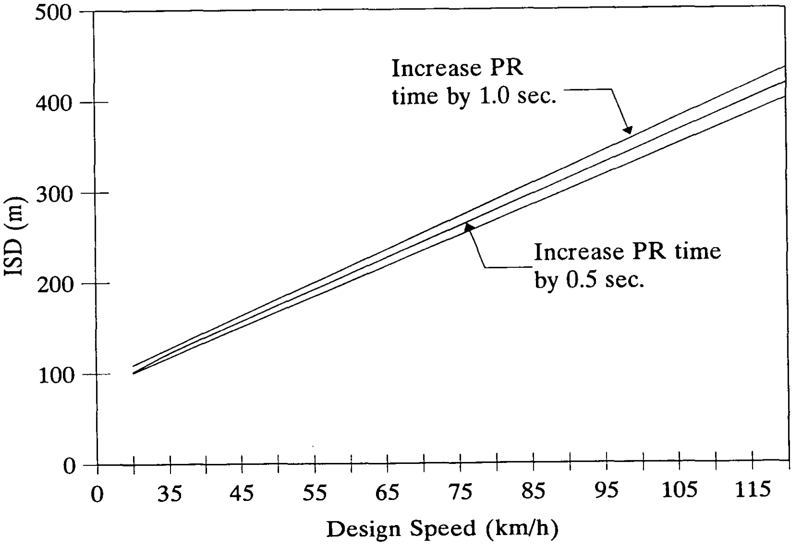

FIGURE 3 Effect of change in PR time on ISD for Case IIIA.

TABLE 2 Elasticity Values for Case IIIA Sensitivity Analysis

Velocity (km/h)	t_a (s)	Elasticity	Velocity (km/h)	t_a (s)	Elasticity
32.2*	4.00	0.3333	32.2	10.25	0.1633
32.2	4.25	0.3200	32.2	10.50	0.1600
32.2	4.50	0.3077	32.2	10.75	0.1569
32.2	4.75	0.2963	32.2	11.00	0.1538
32.2	5.00	0.2857	32.2	11.25	0.1509
32.2	5.25	0.2759	32.2	11.50	0.1481
32.2	5.50	0.2667	32.2	11.75	0.1455
32.2	5.75	0.2581	32.2	12.00	0.1429
32.2	6.00	0.2500	32.2	12.25	0.1404
32.2	6.25	0.2424	32.2	12.50	0.1379
32.2	6.50	0.2353	32.2	12.75	0.1356
32.2	6.75	0.2286	32.2	13.00	0.1333
32.2	7.00	0.2222	32.2	13.25	0.1311
32.2	7.25	0.2162	32.2	13.50	0.1290
32.2	7.50	0.2105	32.2	13.75	0.1270
32.2	7.75	0.2051	32.2	14.00	0.1250
32.2	8.00	0.2000	32.2	14.25	0.1231
32.2	8.25	0.1951	32.2	14.50	0.1212
32.2	8.50	0.1905	32.2	14.75	0.1194
32.2	8.75	0.1860	32.2	15.00	0.1176
32.2	9.00	0.1818	32.2	15.25	0.1159
32.2	9.25	0.1778	32.2	15.50	0.1143
32.2	9.50	0.1739	32.2	15.75	0.1127
32.2	9.75	0.1702	32.2	16.00	0.1111
32.2	10.00	0.1667			

*NOTE: 32.2 km/h = 20 mi/h.

The second assumption concerning the major-road vehicle is that the driver decelerates to 85 percent of the design speed on the major roadway. This may not be a valid assumption for all drivers at all locations because it is not known what the average or expected speed reduction would be across the general population. The use of the 85 percent reduction in design speed results in the use of a multiplier of 0.95 in Equation 4. It is assumed that the driver of the major-road vehicle initiates braking at 100 percent of design speed and concludes the braking at 85 percent of design speed. The factor of 0.95 indicates a slowing of the vehicle over the braking distance. The AASHTO Green Book does not indicate how the 0.95 was developed. It is assumed to be a close approximation of an average speed over the braking distance.

Sensitivity analyses were performed on the 1990 AASHTO Case IIIB procedure. As in the other AASHTO procedures the purpose of the analyses was to determine the relative importance of the various factors that are present in the Case IIIB equation. Different ISD values were calculated as the variable of interest was stepped through a range of values. While one variable was being varied, the other variables were held constant at a predefined default value.

For the AASHTO Case IIIB equation the predefined defaults were set at V = 80.5 km/hr (50 mph), J = 2.00 sec, L = 15.795 m (19 ft), and t_{VG} = 2.00 sec. The V term was stepped in 8.05-km/hr (5-mph) increments from 32.2 km/hr (20 mph) to 112.7 km/hr (70 mph), J was stepped in 0.25-sec increments from 0.50 to 3.50 sec, and t_{VG} was stepped in 0.10-sec increments from 0.30 to 3.00 sec. Because the Case IIIB equation requires the additional parameters of P and t_a, these values were created in a lookup table in the spreadsheet. This table is based on Table IX-7 of the 1990 Green Book (*1*). Because Table IX-7 did not contain all the needed values, several intermediate points were found by interpolation. The lookup table contains values for P and t_a for a range of from 24.15 km/hr (15 mph) to 112.7 km/hr (70 mph). The lookup table is entered with the current value of V, the velocity, and the corresponding values for the parameters P and t_a are found.

Figure 4 shows the results of the sensitivity analysis for the AASHTO formulation of Case IIIB. When design speed was varied and all other variables were held constant, ISD showed a great sensitivity to changes in design speed. The elasticity of the relation between the two variables is equal to 1.36. This means that

$\mathrm{ISD} = Q - h$

$Q = 0.2784*(0.95V)*(ta + J)$

$h = P - 4.88 - VG - L$

$VG = 0.2784\ (0.85)*V*tvg$

Default V = 80.5 kph

(P = 155.55 m, ta = 14.9 sec)

Default J = 2 sec

Default L = 5.795 m

Default tvg = 2 sec

Ed =	1.36	Ed =	0.17	Ed =	0.13
V (kph)	ISD (m)	J (sec.)	ISD (m)	tvg (sec.)	ISD (m)
0		0	210.6	0	215.0
32.2	66.3	0.50	221.2	0.30	220.8
40.3	87.6	0.60	223.3	0.40	222.7
48.3	110.2	0.70	225.5	0.50	224.6
56.4	141.7	0.80	227.6	0.60	226.5
64.4	173.4	0.90	229.7	0.70	228.4
72.5	210.7	1.00	231.9	0.80	230.3
80.5	253.1	1.10	234.0	0.90	232.2
88.6	300.7	1.20	236.1	1.00	234.1
96.6	351.8	1.30	238.2	1.10	236.0
104.7	411.4	1.40	240.4	1.20	237.9
112.7	479.9	1.50	242.5	1.30	239.8
		1.60	244.6	1.40	241.7
		1.70	246.8	1.50	243.6
		1.80	248.9	1.60	245.5
		1.90	251.0	1.70	247.4
		2.00	253.1	1.80	249.3
		2.10	255.3	1.90	251.2
		2.20	257.4	2.00	253.1
		2.30	259.5	2.10	255.1
		2.40	261.7	2.20	257.0
		2.50	263.8	2.30	258.9
		2.60	265.9	2.40	260.8
		2.70	268.1	2.50	262.7
		2.80	270.2	2.60	264.6
		2.90	272.3	2.70	266.5
		3.00	274.4	2.80	268.4
		3.10	276.6	2.90	270.3
		3.20	278.7	3.00	272.2
		3.30	280.8		
		3.40	283.0		
		3.50	285.1		

FIGURE 4 Single-parameter sensitivity analysis of AASHTO Case IIIB.

for every 1.00 percent change in design speed there is a corresponding change of 1.36 percent in the ISD value.

When the equation is examined with respect to *J*, the PR time, the elasticity value is 0.17. This means that the ISD is relatively insensitive to changes in the PR time. A 50.0 percent change in *J*, an increase from 2 to 3 sec, results in an increase in the ISD values of only 8.5 percent. Similarly when the equation is varied with respect to t_{VG}, the elasticity is 0.13, again indicating a relatively inelastic parameter.

As with Case IIIA a second set of sensitivity analyses was performed to rule out the possibility that varying combinations of the input parameters would yield unexpected results. These analyses varied *V*, *J*, and t_{VG}. The *V* term was varied from 40.25 km/hr (25 mph) to 112.7 km/hr (70 mph) in 8.05-km/hr (5-mph) increments. The *J* term was varied from 0.5 to 3.5 sec in 0.1-sec increments. The t_{VG} term was varied from 0.3 to 3.0 sec in 0.1-sec increments. A surface plot of the results is shown in Figure 5. It should be noted that elasticities are not plotted for *V* equal to 32.2 km/hr (20 mph) because of the tendency of the AASHTO equation to yield negative numbers at parameter combinations of low speed, quick reaction time, and short tailgate distances.

The highest elasticity plotted in Figure 5 is approximately 0.56. This particular point results from the evaluation of the AASHTO equation with V = 40.25 km/hr (25 mph), t_{VG} = 0.3 sec, and *J* being varied from 0.5 to 3.5 sec. The lowest elasticity plotted in Figure 5 is 0.14, indicating that for every 1.00 percent increase in PR time there is a 0.14 percent increase in ISD. This means that if the PR time for Case IIIB was increased from 2 to 4 sec, a 100 percent increase, the resulting ISD would increase only 14 percent. This case resulted from an evaluation of the AASHTO equation with V = 112.7 km/hr (70 mph), t_{VG} = 3.0 sec, and *J* being varied from 0.5 to 3.5 sec. It should be noted that the higher elasticity value is for a set of design and operating conditions that is relatively excessive. As with Case IIIA the characterization that ISD is relatively insensitive to PR time holds true.

Following on the previous discussion, an examintion of Figure 5 shows that the majority of the elasticities are in the range of 0.1 to 0.2. The shading for this range of elasticities covers approximately 50 percent of the surface. If elasticities in the range of 0.2 to 0.3 are included, approximately 75 percent of the surface is covered. This again illustrates, for most design and operational conditions, that the Case IIIB AASHTO equation is relatively insensitive to PR time. In particular the typical range of Case IIIB situations, having a design speed of 48.3 km/hr (30 mph) to 80.5 km/hr (50 mph) and a t_{VG} set by AASHTO equal to 2.0 sec, lies well within the first shaded region, with elasticities in the range of 0.1 to 0.2.

Figure 6 shows the ISD values that would result if the PR time for Case IIIB were increased by either 0.5 or 1.0 sec. With an

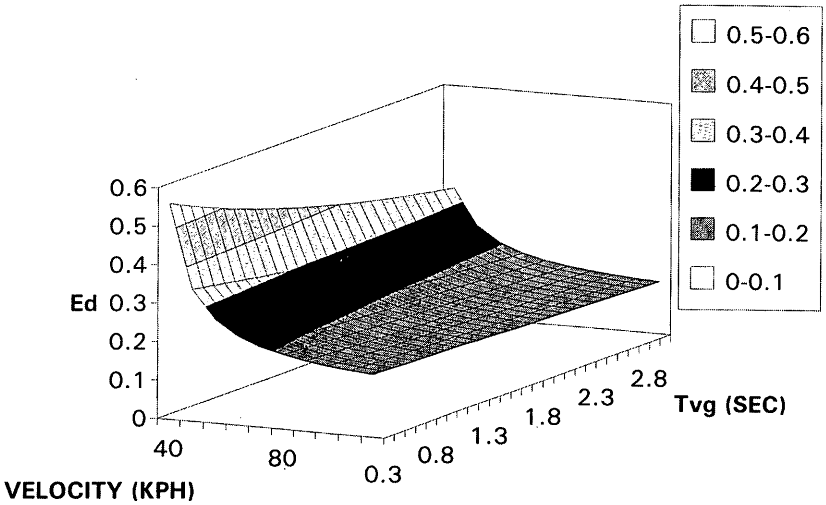

FIGURE 5 **Surface plot of multiple-parameter sensitivity analysis for Case IIIB.**

increase to 2.5 sec the change in ISD ranges from 6 percent at 32.2 km/hr (20 mph) to 3 percent at 112.7 km/hr (70 mph). If PR time was increased to 3.0 sec the ISD would increase by 11 percent at 32.2 km/hr (20 mph) and 6 percent at 112.7 km/hr (70 mph).

CASE IIIC—RIGHT-TURN MANEUVER

According to current AASHTO policy the Case IIIC scenario is the same as the Case IIIB scenario, only the vehicle on the minor road is making a right turn instead of a left turn. As such the minor-road vehicle has to be concerned only with major-road vehicles approaching from one direction. However the equations for calculating the sight distance are nearly identical, resulting in Case IIIC values that differ by approximately two feet from the corresponding values in Case IIIB. The only difference in the calculations is that the constant value of 4.88 m (16 ft) in Equation 5 is replaced by a value of 4.3615 m (14.3 ft), reflecting the shorter distance traveled by the minor-road vehicle when making a right turn.

The sensitivity analyses of Case IIIC yield the same results as those for Case IIIB. Varying a single parameter at a time results in an elasticity of 0.17. Varying two parameters at a time, to check for any unusual occurrences, produces values that, when plotted, create a duplicate of Figure 5 (from the Case IIIB discussion).

CONCLUSIONS AND RECOMMENDATIONS

Several conclusions can be reached on the basis of the results of the review and analyses. These include the following:

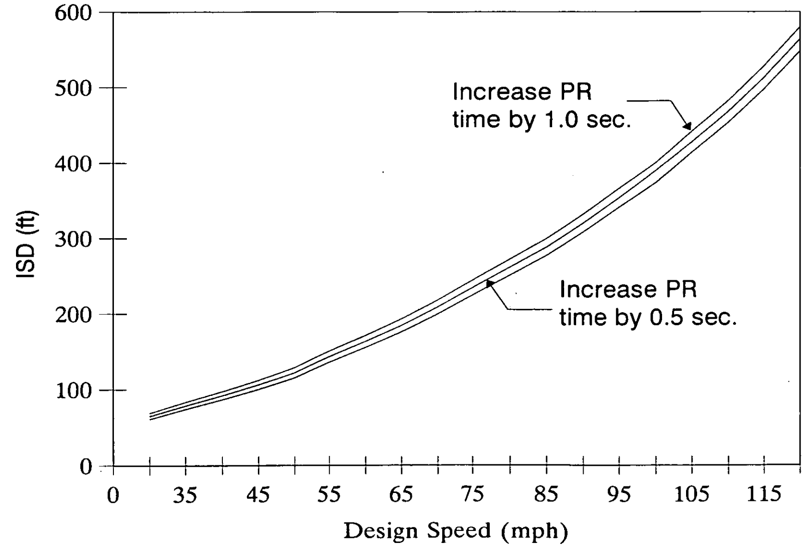

FIGURE 6 **Effect of change in PR time on ISD for Case IIIB.**

- PR time has long been considered an important element in highway design and operations.
- Several empirically based studies have confirmed the use of the currently specified AASHTO values for PR times for ISD applications.
- Although there has been a great deal of research on PR times, especially as this topic relates to highway design, there appears to be some doubt about how well the current values used for highway design purposes represent real-world conditions.
- For applications related to Case III ISD determination, PR time has little influence on the overall ISD requirement.

Following on these conclusions, the following recommendations are made:

- The current values used for PR time for Case III ISD applications should be retained because of their validation from several empirical studies and the insensitivity in changes in ISD values relative to changes in PR times.
- A greater use of sensitivity analyses is encouraged, including the use of elasticities as a measure of effectiveness, to assess the relative importance of various design and operational parameters (e.g., highway capacity).

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REFERENCES

1. *A Policy on the Geometric Design of Highways and Streets.* AASHTO, Washington, D.C., 1990.
2. *A Policy on Intersections at Grade.* AASHO, Washington, D.C., 1940.
3. *A Policy on Sight Distance for Highways.* AASHO, Washington, D.C., 1940.
4. Hooper, K. G., and H. W. McGee. Driver Perception-Reaction Time: Are Revisions to the Current Standards in Order? In *Transportation Research Record 904*, TRB, National Research Council, Washington, D.C., 1983.
5. Wickens, C. D. *Engineering Psychology and Human Performance.* Charles E. Merrill Publishing Company, Columbus, Ohio, 1984.
6. Hostetter, R. S., H. W. McGee, K. W. Crowley, E. L. Sequin, and G. W. Dauber. *Improved Perception-Reaction Time Information for Intersection Sight Distance.* Report FHWA/RD-86/. FHWA, U.S. Department of Transportation, 1986.
7. Albrecht, W. P., Jr. *Microeconomic Principles.* Prentice-Hall, Inc., Englewood Cliffs, N.J., 1983.

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